PRIMES ENERGY SYSTEM MODEL

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E³M - Lab

OVERVIEW OF PRIMES MODELLING APPROACH

PRIMES Model Features

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

PRIMES Model Coverage

Geographical coverage

•Each EU-27 member-state taken individually

•Also, candidate MS and neighbors, such as Norway, Switzerland, Turkey, South East Europe

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

Core of the model: market linked sub-models for demand sectors (industry, services households, etc), power/steam generation, fuel supply

Satellite models: Biomass supply, refineries, detailed transport sector model, gas supply (Eurasian), H2 supply

Model Running:

•Country-by-country

•Multiple countries with endogenous electricity trade

Model ling methodology

Exogenous

- Economic Activity
- World energy prices
- Technology parameters
- Policies and measures

Sequence of model interactions

Agents (representative household, industry per sector, services, power generation, etc.) act individually optimizing their profit or welfare, influenced by habits, comfort, risk, technology etc. using individual (private) discount rates

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

Commodity Pricing reflects costs and apply a Ramsey-Boiteux methodology (adaptable to both regulated monopoly and competitive markets) plus mark-up reflecting market power

Market equilibrium evolves over time with investment being endogenous

Overall or sectoral restrictions may apply, for example on carbon dioxide emissions

Mathematically, the model solves as a concatenation of mixed-complementarity problems with overall constraints (e.g. carbon constraint with associated shadow carbon value)

Model ling methodology

Foresight is built in the agents' decision making representations, depending on lifetime of equipment

Deterministic modelling (no stochastic elements)

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

PRIMES Modelling Scheme

Demand = function of Price

Through fairly complex energy demand projection models

Supply = Demand

Through complex energy supply models

Price = function of Supply

Through a finance and pricing model which reflects market competition regime and regulation

Iteration on Price until reaching equilibrium

Iterations may follow a Gauss-Seidel algorithm

Level of Detail

- 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 (e.g. water heating, cooking) and 12 types of electrical durable goods (e.g. refrigerator, washing machine, television)
- 4 transport modes, 10 transport means (e.g. cars, buses, motorcycles, trucks, airplanes) and 10 vehicle technologies (e.g. internal combustion engine, hybrid cars)
- 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 240 grid interconnections
- Other sub-systems: refineries, gas supply, biomass supply, hydrogen supply, primary energy production
- 7 types of emissions from energy processing (e.g. SO_2, NO_x, PM)
- CO_2 emissions from industrial processes
- GHG emissions and abatement (using IIASA's marginal abatement cost curves for non CO_2 GHGs)

Policy Instruments

- Technology promoting policies 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, …) at sectoral, country and/or EU level
- Emission Trading Schemes and non ETS targets
- Renewable targets
- Energy efficiency targets
- Green, White Certificates or other obligations and support schemes (e.g. RES)
- Security of Supply constraints
- Price and competition regulation

OVERVIEW OF PRIMES MODELLING APPROACH

Inputs to the model

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

Outputs from the model

- 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 and industrial processes; GHG emissions
- Policy Assessment Indicators (e.g. import dependence ratio, RES ratios, CHP ratios, efficiency indices, etc.)

DATA INPUT SOURCES

NEW CRONOS - EUROSTAT
- •Energy Balance sheets
- •Energy prices (complemented by other sources)
- •Macroeconomic and sectoral activity data
- •Population data and projection

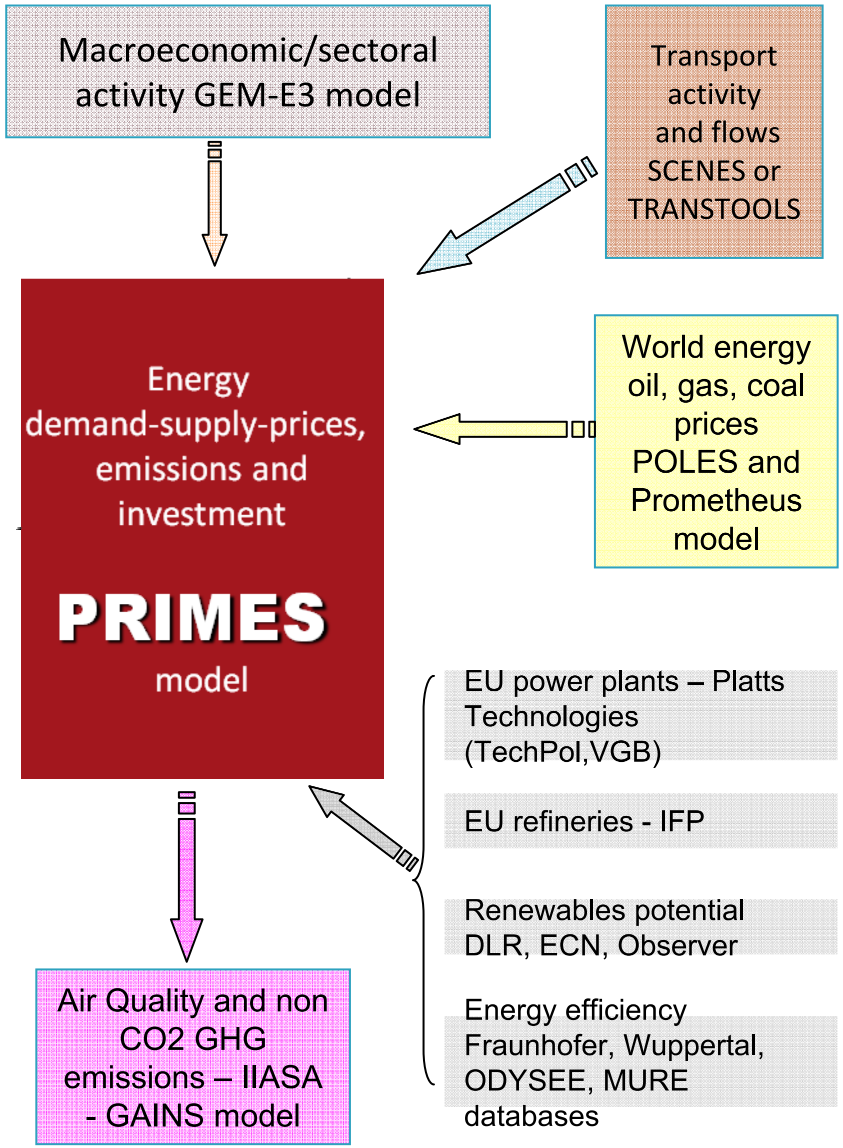
Technology databases mostly developed under EC programs
- •MURE, ICARUS, ODYSEE – demand sectors
- •VGB, SAPIENTIA, TECHPOL – supply sector technologies
- •NEMS model database, US DOE

Activity data from Industry associations

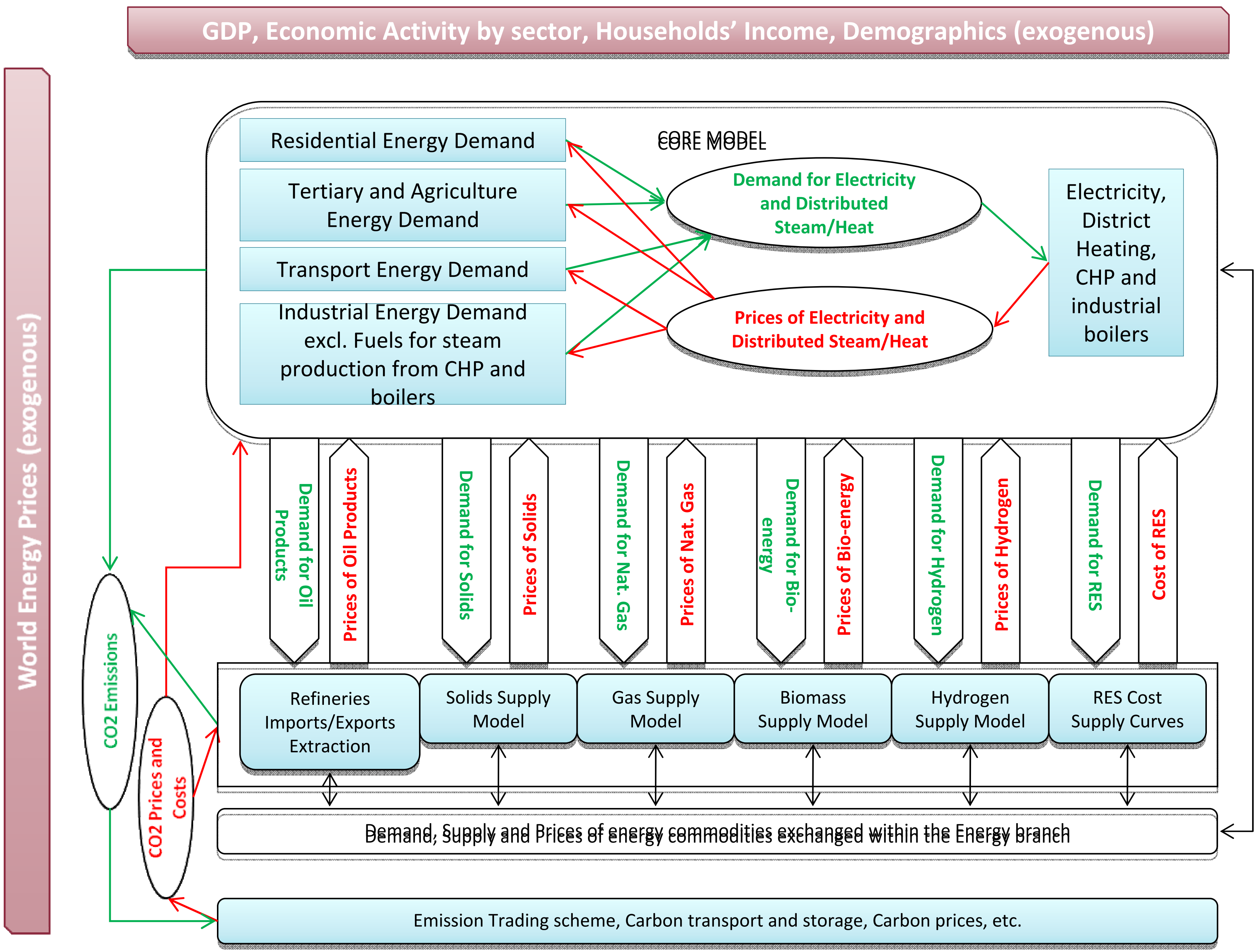
Various surveys (e.g. CHP) and Platts databse on power plants

Specifically commissioned studies
- •DLR, ECN and Observer's databases on RES potential
- •TNO study on CO2 storage potential
- •Vuppertal and Fraunhofer databases on energy efficiency
- •Specific database on biomass resources and possibilities

Links with other models



MODULAR STRUCTURE OF THE PRIMES MODEL



CLASSIFICATION OF ENERGY COMMODITIES AND SECTORS

Energy Commodities

Solids: Coal, Lignite, Coke, Briquettes, Other solid fuels

Oil: Crude-oil, Refinery Gas, Gasoline, Biogasoline blend, Diesel Oil, Biodiesel blend, Kerosene, Biokerosene blend, LPG, Residual Fuel Oil, Bioheavy blend, Naphtha, Other oil products

Gaseous: Natural gas, Coke oven gas, blast furnace gas, gas works

Nuclear energy

RES: Thermal Solar (active), Geothermal low and high enthalpy, Wind offshore, Wind onshore, Solar PV, CSP, Hydro Lakes, Hydro run-of-river, Tidal and Wave

Biomass and **Waste**: biodiesel, bioethanol, biokerosene, biohydrogen, bioheavy, small scale solid biomass, large scale solid biomass, biogas, waste solid, waste gas

Steam/Heat (industrial steam and distributed heat)

Electricity

Hydrogen

Demand Sectors

Households subdivided in 5 dwelling types

Services subdivided in market services sector, non market services, trade sector

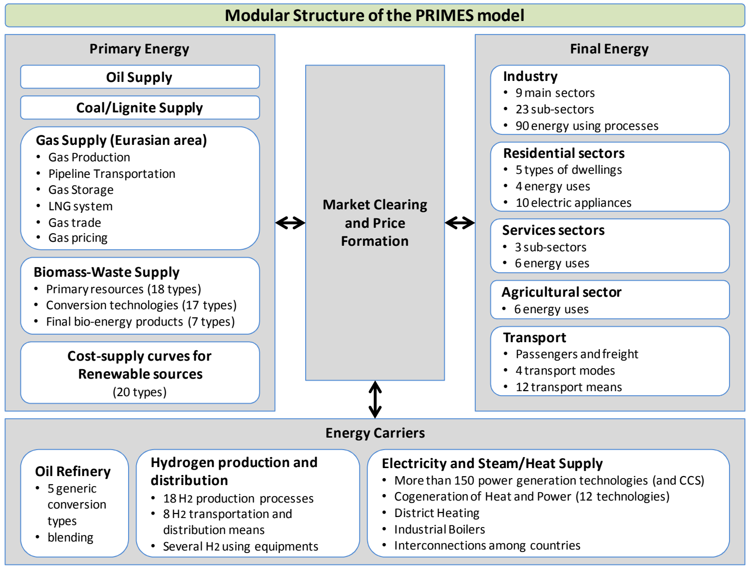
Agriculture

Industry subdivided in

- iron and steel (integrated steelworks, electric arc),
- non ferrous metals (primary aluminium, secondary aluminium, copper, zinc, lead, other non ferrous),
- Chemicals (fertilizers, petrochemical, inorganic chemicals, low energy chemicals)
- Paper and pulp (pulp, paper)
- Food, drink and tobacco
- Engineering goods
- Textiles
- Other industrial sectors

Energy branch (extraction, refineries, nuclear fuel and waste, electricity self use, gas supply, hydrogen, bio-energy production)

Modular structure



Renewables in Power Generation

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.

General Methodology of PRIMES Demand sub-models

- 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
  - Firstly Useful energy demand is determined
  - 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 (e.g. water heating, motor drives)
- Useful energy needs (e.g. air conditioning, lighting, motive power) are met through consuming final energy, which is determined by optimizing processing costs, involving
  - Endogenous choice of equipment (vintages, technologies and learning)
  - Endogenous investment in energy efficiency (savings)
  - Endogenous purchase of associated energy carriers and fuels (demander is price taker)
- Decisions at each nesting level are based on an equivalent perceived cost reflecting actual costs, utility (e.g. comfort) and risk premium
- Capital decisions use weighted average cost of capital (WACC) and subjective discount rates
- 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

Methodology for Industrial Energy Demand

- Mechanisms represented
  - Integration in macroeconomic decisions (production function)
  - Sectoral value added derived with GEM-E3, translation in physical output indicators for certain heavy industries
  - 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 (e.g. black liquor, blast furnace gas)
  - engineering-oriented representation of energy saving possibilities (e.g. shift to more efficient process technologies)
  - Influence from standards, emission constraints, pollution permits and
  - Technology vintages and dynamics
  - Interaction with Power and Steam sub-model for industrial CHP and boilers
- Substitutions are possible between processes, energy forms, technologies and energy savings

Methodology for Energy Demand in Buildings

- Mechanisms represented
  - Useful energy demand, final energy demand, equipment choice, energy efficiency investment and fuel mix derived 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 agriculture and services breakdown by sub-sector (e.g. market services, trade)
  - 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

SECTOR	SUB-SECTORS	ENERGY USES
Iron and Steel	Electric arc Iron and Steel integrated	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

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

SECTOR	SUB-SECTORS	ENERGY USES
Chemicals production	Fertilizers Petrochemical Inorganic chemicals Low enthalpy chemicals	Air compressors Low enthalpy heat Lighting 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 Ceramics and bricks Glass basic production Glass recycled production Other building materials production	Electric kilns Cement kilns Air compressors Lighting Motor drives Glass annealing electric Glass tanks electric Low enthalpy heat Glass annealing thermal Glass tanks thermal Material 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
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
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
Other	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
	Other industrial sectors goods	Air compressors Lighting Motor drives Drying and separation electric Machinery Steam and high enthalpy heat Low enthalpy heat Space heating

Tertiary Sectors

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

SECTOR	ENERGY USES	ENERGY TECHNOLOGIES
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

Transport sector (aggregate model variant)

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

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

Households

SECTOR	HOUSEHOLD TYPES	ENERGY USES
Dwellings	• Central boiler households (all fuel types) • 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

Methodology Overview of the Power-Steam sub-model

The PRIMES model simulates power generation and investment as a result of
- Non linear optimization of the sector (least total cost) under
- operational and grid constraints
- Reliability and reserve constraints
- Demand (load curve with 11 typical segments)
- Policy restrictions.

The optimisation is inter-temporal (perfect foresight) or optionally myopic

The model solves simultaneously
- a unit commitment-dispatching problem
- a capacity expansion problem
- a DC-linearised optimum power flow problem (over interconnectors)

The optimisation is simultaneous for
- Power (HV, MV, LV and auto-producers)
- CHP
- distributed steam
- distributed heat
- district heating and
- industrial boilers

It satisfies synchronised chronological load curves of power, steam and heat, which are endogenous resulting from the sectoral demand sub-models

The model data distinguish between
- Utilities
- Industrial size production
- Highly decentralised production

Price determination

Capital costs based on WACC for discounting over time

Long run marginal cost principles for capacity expansion

Short run marginal costing for dispatching

Ramsey-Boiteux model for commodity pricing
- total revenue requirement incl. fixed and stranded costs
- plus market power mark-up
- prices per sector depending on demand elasticities

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

Power model features

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)

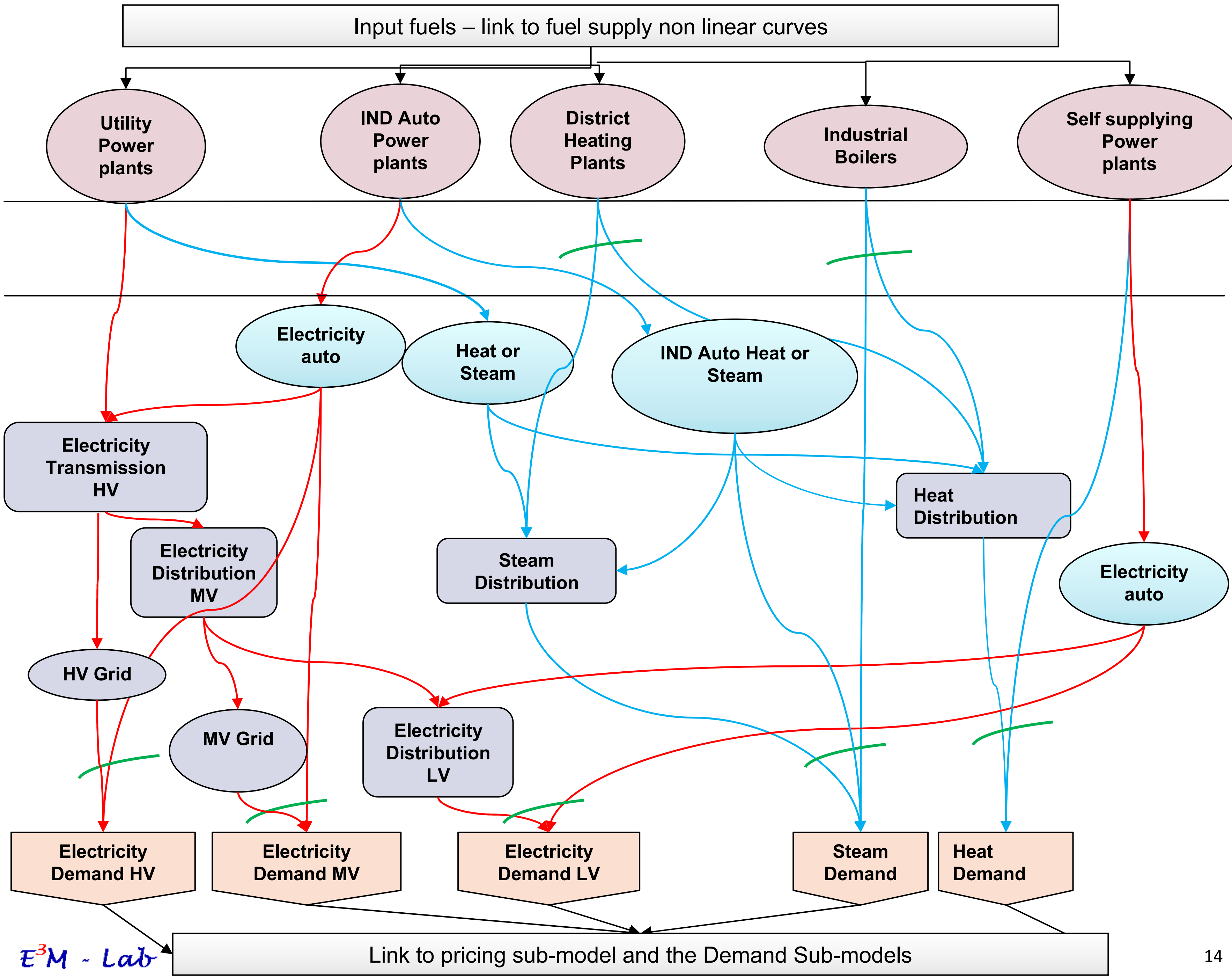
Hydro lakes and Pumping represented endogenously

Intermittent RES as deterministic equivalent

Reliability constraints per country

Interconnection DC power flows constraints

FLOWS WITHIN THE POWER-STEAM MODEL



Non linear cost supply curves

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.

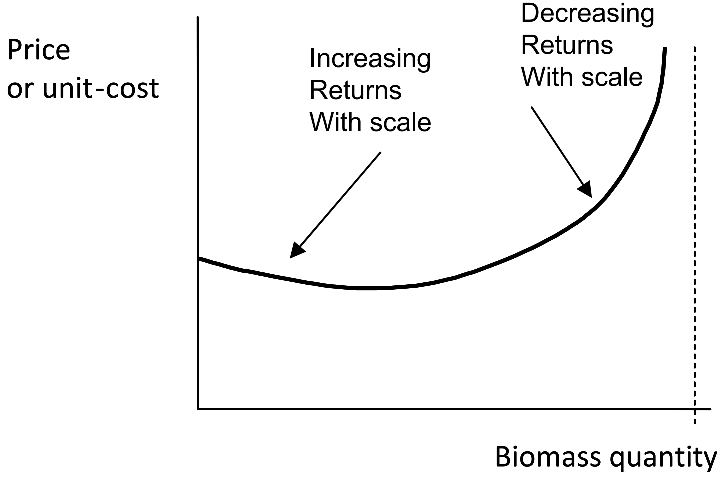
Supply curves are used in many places in PRIMES:

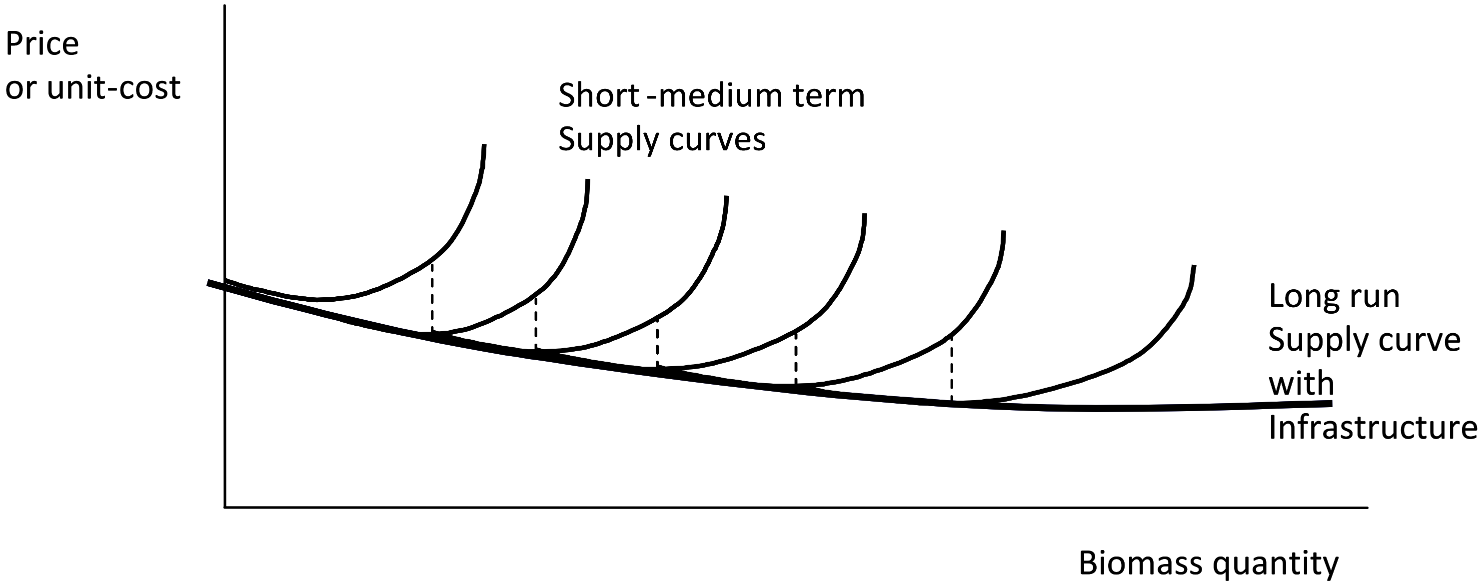
Renewable sources

Sites for Wind

Nat. Gas supply

Biomass and Waste etc.





POWER SECTOR SUB-MODEL

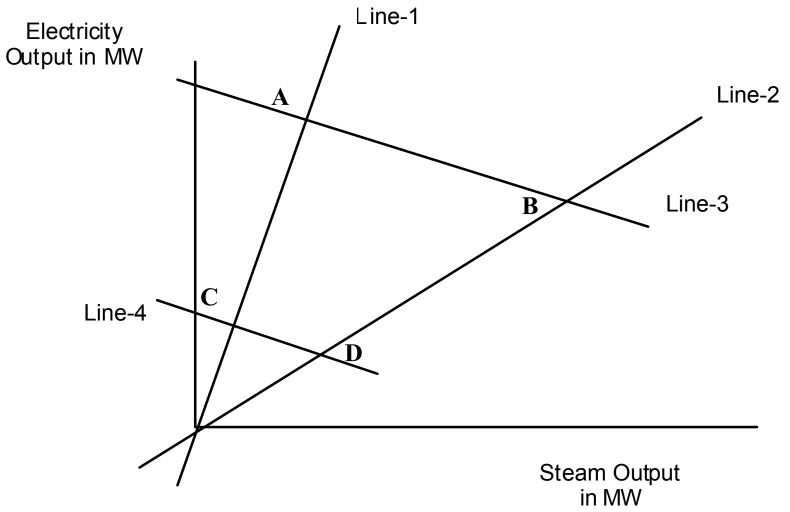
CHP Technologies

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

Technical-Economic Parameters of Plants

1. Capital cost (Euro'05/kW) and financial charges during construction
   - Retrofitting costs and possibilities, incl. DESOx, DENOx, aux. CCS
   - 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

CHP Possibilities domain



RES and reserve power

Stochastic RES are considered as deterministic equivalent production

Capacity credits from stochastic RES are derived per type and country as function of volume and dispersion parameters

The model considers reserve power constraints which take into account capacity credits from stochastic RES

Hydro Lakes are dispatchable but are energy constrained

Pumping and use of storage is endogenous

The model formulates impact of stochastic RES on power grid investment and costs, distinguishing between offshore wind, onshore wind, solar PV and the level of decentralisation

Solid fuel power technologies

1.Steam Turbine Coal Industrial
2.Steam Turbine Coal Conventional
3.Steam Turbine Coal Supercritical
4.Fluidized Bed Combustion Coal
5.Integrated Gasification Combined Cycle Coal
6.Pulverized Coal Supercritical CCS post combustion
7.Pulverized Coal Supercritical CCS oxyfuel
8.Integrated Gasification Coal CCS post combustion
9.Integrated Gasification Coal CCS pre combustion
10.Integrated Gasification Coal CCS oxyfuel
11.Steam Turbine Coal Industrial
12.Steam Turbine Lignite Conventional
13.Steam Turbine Lignite Supercritical
14.Fluidized Bed Combustion Lignite
15.Integrated Gasification Combined Cycle Lignite
16.Pulverized Lignite Supercritical CCS post combustion
17.Pulverized Lignite Supercritical CCS oxyfuel
18.Integrated Gasification Lignite CCS post combustion
19.Integrated Gasification Lignite CCS pre combustion
20.Integrated Gasification Lignite CCS oxyfuel

Oil firing power technologies

1.Steam Turbine Refinery Fuels
2.Gas Turbine Diesel Industrial
3.Steam Turbine Fuel Oil Conventional
4.Peak Device Diesel Conventional
5.Steam Turbine Fuel Oil Supercritical
6.Fuel Oil Supercritical CCS post combustion
7.Integrated Gasification Fuel Oil CCS pre combustion
8.Internal Combustion Engine Diesel
9.Peak Device Diesel Advanced
10.Small Device Light Oil

Gas firing power technologies

1.Steam Turbine Gas Industrial
2.Gas Turbine Gas Industrial
3.Gas Combined Cycle Industrial
4.Steam Turbine Gas Conventional
5.Gas Turbine Combined Cycle Gas Conventional
6.Peak Device Gas Conventional
7.Gas Turbine Combined Cycle Gas Advanced
8.Gas combined cycle CCS post combustion
9.Gas combined cycle CCS pre combustion
10.Gas combined cycle CCS oxyfuel
11.Internal Combustion Engine Gas
12.Peak Device Gas Advanced
13.Small Device Gas

Biomass firing power technologies

1.Steam Turbine Biomass Industrial
2.IG Biomass CC Industrial
3.Steam Turbine Biomass Solid Conventional
4.Peak Device Biogas Conventional
5.High Temperature Solid Biomass Power Plant
6.Peak Device Biogas Advanced
7.Small Device Biomass Gas
8.MSW incinerator CHP
9.Internal Combustion Engine Biogas

Nuclear technologies

1.Nuclear fission second generation
2.Nuclear fission third generation
3.Nuclear fission fourth generation
4.Nuclear Fusion

RES technologies

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. Wind small scale
10. Solar PV Low Resource
11. Solar PV Medium Resource
12. Solar PV High Resource
13. Solar Thermal
14. Solar PV Very High
15. Solar PV small scale
16. Tidal and waves
17. Lakes
18. Run of River
19. Geothermal High

Representation of Interconnectors

PRIMES simulates power flows among countries taking into account present and future interconnection capacities

•System comprises 35 nodes (one per country) and 240 links between nodes

•Generation and Load are associated with nodes

•Known data for links include MW capacity, resistance and reactance (ENTSOE data) – future capacities are exogenous reflecting project survey information, TSO announcements and TEN

Power flows across the links result from optimal (least cost) power flow over a DC linearized network

Optionally, the model can run on a country-by-country basis with fixed net imports per country

Regional power market simulation

PRIMES can solve the power system model simultaneously by region, with endogenous links between regions, which are the following:

1. **Iberian**: Portugal, Spain
2. **British islands**: UK, Ireland
3. **Central Europe**: France, Germany, Belgium, Netherlands, Luxembourg, Switzerland, Austria, Italy
4. **Central-Eastern Europe**: Poland, Czech Republic, Slovakia, Hungary, Slovenia
5. **Nordic**: Norway, Sweden, Finland, Denmark
6. **Baltic**: Lithuania, Estonia, Latvia, Kaliningrad
7. **South East Europe**: Romania, Bulgaria, Greece, Albania, Croatia, Bosnia & Herzegovina, FYROM, Serbia-Kosovo-Montenegro, Turkey

External links (with exogenous net imports): Russia, Ukraine, Moldova, Belarus, Morocco, Middle East

Alternative regional configurations are possible (user-defined)

Summary of interconnection capacities

		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
UK	Ireland	1.85	1.85	4.05	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80
Luxembourg	Belgium	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Netherlands	UK				1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Netherlands	Belgium	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
Germany	Belgium						1.32	1.32	1.32	1.32	1.32	1.32
Germany	Luxembourg	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Germany	Netherlands	7.70	8.05	8.80	8.80	8.80	8.80	8.80	8.80	8.80	8.80	8.80
France	UK	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
France	Belgium	3.12	3.47	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22
France	Luxembourg							1.75	1.75	1.75	1.75	1.75
France	Germany	4.40	4.40	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50
Spain	France	4.35	4.35	6.55	6.55	6.55	6.55	6.55	6.55	6.55	6.55	6.55
Portugal	Spain	3.25	3.25	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05
Denmark	Germany	2.45	2.45	3.20	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50
Sweden	Germany	1.10	1.10	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Sweden	Denmark	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
Norway	UK						1.35	1.35	1.35	1.35	1.35	1.35
Norway	Netherlands			0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Norway	Germany				0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Norway	Denmark	1.10	1.10	1.10	1.25	1.25	1.40	1.75	1.75	1.75	1.75	1.75
Norway	Sweden	5.15	5.15	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Finland	Sweden	2.25	2.60	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Finland	Norway	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Austria	Germany	7.95	7.95	9.45	10.95	13.20	13.20	13.20	13.20	13.20	13.20	13.20
Italy	France	4.00	4.00	4.38	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10
Italy	Austria	0.35	0.86	1.80	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
Switzerland	Germany	13.85	13.85	17.60	17.60	17.60	17.60	17.60	17.60	17.60	17.60	17.60
Switzerland	France	8.53	8.53	8.53	8.53	8.53	8.53	8.53	8.53	8.53	8.53	8.53
Switzerland	Austria	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
Switzerland	Italy	6.46	7.61	8.91	8.91	10.60	10.60	10.60	10.60	10.60	10.60	10.60
Slovenia	Austria	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
Slovenia	Italy	1.85	2.20	4.25	4.25	4.25	4.25	4.25	4.25	4.25	4.25	4.25
Czech	Germany	4.40	4.40	4.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
Czech	Austria	1.80	1.80	2.55	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
Slovakia	Austria			0.35	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
Slovakia	Czech	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Poland	Germany	3.01	3.01	4.11	5.21	5.21	5.21	5.21	5.21	5.21	5.21	5.21
Poland	Sweden		0.55	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Poland	Czech	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
Poland	Slovakia	2.20	2.20	3.30	4.25	4.25	4.25	4.25	4.25	4.25	4.25	4.25
Hungary	Austria	2.90	2.90	3.25	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Hungary	Slovenia			1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Hungary	Slovakia	2.20	2.20	3.30	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
Estonia	Finland			0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Estonia	Latvia	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Lithuania	Sweden				1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Lithuania	Poland			1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Lithuania	Latvia	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Hungary	Italy						1.10	1.10	1.10	1.10	1.10	1.10
Hungary	Slovenia	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97
Hungary	Hungary	1.30	1.30	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
Serbia	Hungary	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Serbia	Hungary	0.55	0.82	0.82	0.82	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Romania	Hungary	0.92	0.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92
Romania	Serbia	0.91	0.91	0.91	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01
Albania	Italy					0.50	0.50	0.50	0.50	0.50	0.50	0.50
Albania	Serbia	0.25	0.25	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
FYROM	Serbia	1.01	1.01	1.01	1.01	1.01	1.01	2.02	2.02	2.02	2.02	2.02
FYROM	Albania				0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Bosnia	Hungary	1.54	3.63	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80
Bosnia	Serbia	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05
Bulgaria	Serbia	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Bulgaria	Romania	4.84	4.84	4.84	4.84	4.84	4.84	4.84	4.84	4.84	4.84	4.84
Bulgaria	FYROM			1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Greece	Italy		0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greece	Albania	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
Greece	FYROM	0.98	0.98	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96
Greece	Bulgaria	0.98	0.98	2.64	2.64	2.64	2.64	2.64	2.64	2.64	2.64	2.64
Turkey	Bulgaria	0.80	2.31	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51
Turkey	Greece			0.35	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Middle East	Turkey	2.20	2.20	2.20	2.20	3.30	3.30	3.30	3.30	3.30	3.30	3.30
Africa	Spain	0.45	0.45	0.50	0.55	0.60	0.65	0.70	0.70	0.70	0.70	0.70
Africa	Italy					1.10	1.10	1.10	1.10	1.10	1.10	1.10
Africa	Middle East					1.10	2.20	2.20	2.20	2.20	2.20	2.20
CIS	Finland	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
CIS	Slovakia	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
CIS	Poland	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
CIS	Hungary	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
CIS	Latvia	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
CIS	Estonia	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
CIS	Lithuania	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
CIS	Romania	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
CIS	Turkey	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Malta	Italy					0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total		170.84	178.82	217.63	235.65	244.63	249.70	252.86	252.86	252.86	252.86	252.86

Biomass Supply Model Features

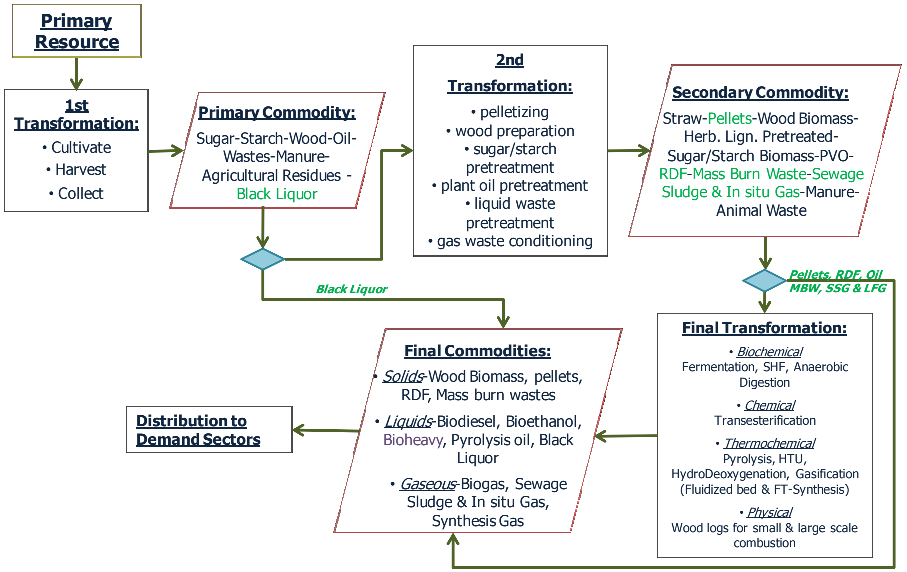
- Projects optimal use of biomass/waste resources and investment in secondary and final transformation, so as to meet a given demand of final biomass/waste energy products, projected to the future by the rest of the PRIMES model.
- Projects land, agricultural, forest and waste resources used in production 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.

Bio-energy feedstock and final commodities

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

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*	

Transformation diagram



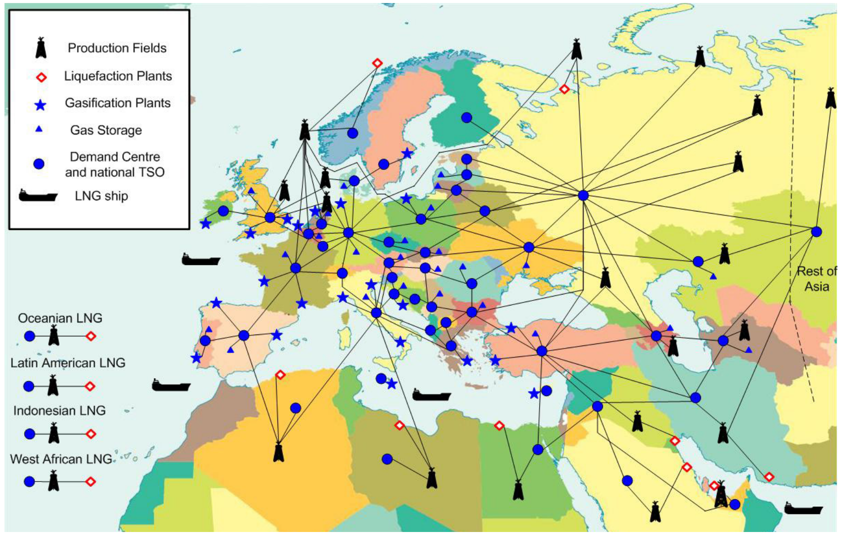
Bio-energy Processes

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

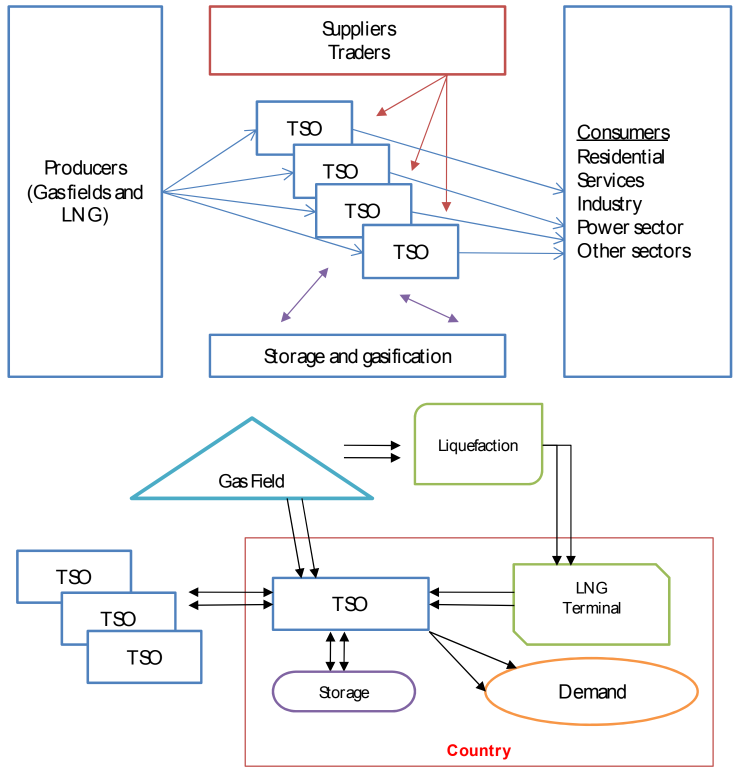
Natural Gas Supply Model features

- 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

Geographical coverage (includes global LNG market)



Scheme of Commercial and Physical Flows



Gas model methodology

- 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)
- Gas demand and prices can be linked with core PRIMES model

CONTEXT OF PRIMES MODELLING

What PRIMES can do

- The distinctive feature of PRIMES is the combination of micro-economic foundations with engineering at a fairly high level of detail
- Detailed energy system projection up to 2050 include:
  - Detailed energy balances
  - Structure of demand by sector
  - Structure of power system and other fuel supplies
  - Investment and technology uptake
  - Costs per sector, overall costs, consumer prices and certificate prices (incl. ETS) if applicable
- Impact assessment of specific energy and environment policies
  - Price signals, such as taxation, subsidies, ETS
  - Technology promoting policies, such as standards, labelling campaigns, both for demand and supply technologies
  - RES supporting policies, such as feed-in tariffs, RES obligations, green certificates, facilitation of accessing resources, biofuels, ...
  - Efficiency promoting policies, such as eco-design measures, standards for buildings, regulation for cars, regulation for industrial processes, white certificates, ESCO (indirect simulation), cogeneration, district heating
  - Security of supply policies (e.g. subsidy on domestic production, upper limits on imports, interconnecting infrastructure)
  - Internal market and competition policies (acting on trade among countries and price mark-ups)
  - Environmental policies, such as large combustion plant directive, emission ceilings, ETS and non-ETS, auctioning vs. grandfathering of allowances
  - Specific sectoral energy supply policies, such as for domestic coal/lignite, for nuclear, etc.
  - Policies may differentiate per MS or apply EU-wide
- The linked model system PRIMES, GEM-E3 and GAINS can perform energy-economy-environment policy analysis in a closed-loop

What PRIMES cannot do

- Cannot deliver short-term forecasts as it is not an econometric model (so projections are not statistically based on past observations, which in PRIMES are only used for parameter calibration)
- Cannot perform closed-loop energy-economy equilibrium analysis, unless linked with a macroeconomic model such as GEM-E3
- Cannot perform detailed short-term engineering analysis of electricity system or gas system operation, as specialised models do (e.g. for an hourly operation in a year)
- Although rich in sectoral disaggregation, PRIMES is limited by the concept of representative consumer per sector, not capturing differences due to heterogeneity of consumer types and sizes
- PRIMES lacks spatial information and representation (at a level below that of countries) and so lacks details about distribution and transport infrastructure and flows that depend on detailed spatial information (expect electricity and gas flows over a country-to-country based grid infrastructure, which is represented in PRIMES)
- *Other issues where policy analysis might benefit from quantitative information consistent with overall scenarios – participants' ideas?*

Comparison of PRIMES with other 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 Approach for World energy prices

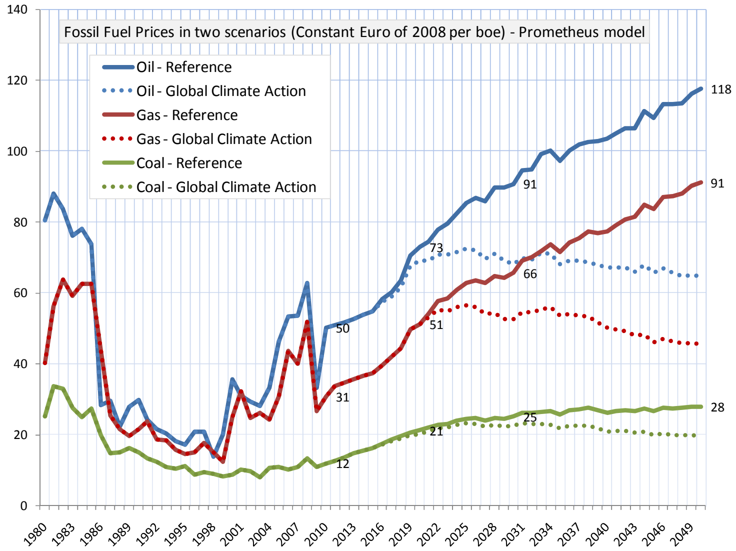
PRIMES takes as input projection of prices of imported fossil fuels

Consistency is endured by projecting world energy prices using a world energy model which projects global energy demand and supply under similar policy context, technology evolution and market conditions than the PRIMES scenario for the EU. The world energy model simulates interaction between demand, supply, exploration and reserves under specific policy and technology evolution context.

World energy prices apply uniformly on all EU MS, but border prices are differentiated by country in order to compute factory-input prices per country (e.g. taking into account transport costs)

Fossil fuel import prices would change if a different global context is assumed along similar assumptions on almost all other variables (e.g. unilateral EU climate action versus global action)

Example of World energy price projection as input to PRIMES



Prometheus World Energy Model

PROMETHEUS is a full scale simulation model of energy supply, energy demand and energy prices at world level (10 regions), including

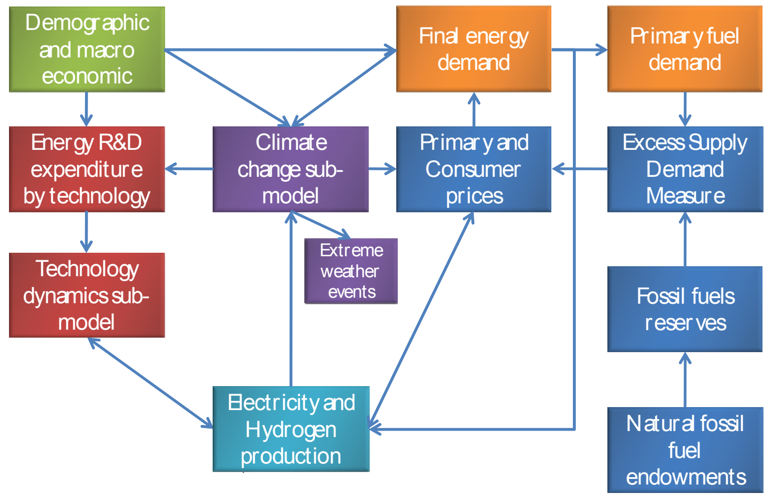
- Projection of demographic and economic activity growth
- Energy system balances
- Energy demand sectors, including transport sector
- Power generation
- Hydrogen production and use technologies
- Production and market equilibrium of primary resources (oil, gas, coal) with data on reserves and endogenous exploration
- Technologies and their dynamic learning-by-doing
- CO2 Emissions

All exogenous parameters are stochastic (known as probability distributions) and so PROMETHEUS generates stochastic information (probability distributions) for all energy, environment and technology results, yearly up to 2050

PROMETHEUS can be also be run in a deterministic mode; the stochastic mode captures the uncertainties related to ultimate fossil fuel resources, economic development, etc

Results Include energy consumption by fuel, fuel resources and prices, CO2 emissions, greenhouse gases concentration, temperature change, technology uptake and dynamic technology improvement as well as demographic and economic activity indicators

Sub-models in PROMETHEUS



PRIMES Approach for Macro-economic and sectoral development

Macro-economic and sectoral development is input to PRIMES

Inputs need to be specified by sector (see extract)

Care is taken to use a macro-economic and sectoral projection that relies on similar scenario concepts than those prevailing the PRIMES scenario

The macro projection usually relies on published projections about GDP and demographics, such as for example the DG ECFIN/EPC Ageing Report of 2009

To project activity by sector, a macro-economic model such as GEM-E3 is used, which is calibrated to fit the high level GDP, factor productivity and population projection

If required, closed-loop simulations can be performed, using PRIMES and GEM-E3, as for example to evaluate the macro and sectoral impacts of RES and energy efficiency policies

GEM-E3 Model Overview

Detailed computable general equilibrium model with integration of energy and environment for all EU MS and for World regions

Model operated by E3MLab and JRC/IPTS

Model data for the EU based entirely on EUROSTAT

Multiple sectors and endogenous trade

Long experience of policy analysis with GEM-E3:

- Analysis for the EU Single Market Act
- Climate change policies, incl. ETS and pledges
- Recycling of energy or environment taxation
- Energy policies
- Taxation, Social Security, Double Dividend
- Research and Development Policies

Extract of Macro-economic scenario input to PRIMES

Demographic indicators	**1990**	**2005**	**2020**	**2050**
Population (000)	38038	38174	37960	33275
Active population			16823	14747
Economic indicators	**1990**	**2005**	**2020**	**2050**
Millions of euro (2005 prices)				
GDP (market prices)	144709	244420	406095	590381
Consumption Expenditure of Households	76258	154949	249394	365328
Gross Value Added (basic prices)	130887	215344	359409	522509
GDP per capita	3804	6403	10698	17743

Value Added (in 2005 prices) used as a proxy to sectoral activity

Sectoral Activity Indicators	**1990**	**2005**	**2020**	**2050**
Agriculture	7705	9760	13584	16572
Construction	10391	12987	22578	32758
Services	83767	139562	239950	372862
Market services	23206	57260	99187	166809
Non market services	41884	41469	68809	100690
Trade	18677	40834	71954	105363
Industry & energy	29024	53035	83298	100318
Energy Sector	8292	12649	14014	13372
Industry	20732	40386	69284	86945
Iron and steel	1482	1637	1527	1330
Non ferrous metals	168	450	422	317
Chemicals	1909	3065	5040	8723
Fertilisers/inorganic chemicals	769	823	1033	970
Petrochemicals	147	355	542	726
Other chemicals	477	500	849	1527
Pharmaceuticals/cosmetics	515	1386	2616	5500
Non metallic minerals	1149	2539	3865	5053
Cement and derived products	405	1087	1699	2239
Ceramics, bricks, etc.	213	484	691	856
Glass production	263	640	990	1322
Other non metallic minerals	268	328	485	637
Pulp, paper and printing	861	3008	4801	6044
Paper and pulp production	451	1306	1880	2039
Printing and publishing	410	1702	2921	4005
Food, drink and tobacco	3824	7409	13071	16434
Textiles	1736	1914	1974	1180
Engineering	7882	12444	24387	30249
Other industries	1721	7922	14197	17615

Representation of technologies in PRIMES

Technologies are represented explicitly in each demand or supply sub-model

Generally, technical-economic characteristics of technologies include energy efficiency, investment cost, O&M cost, variable non fuel cost.

In demand sectors a technology is associated with the specific energy use, e.g. motor drives, primary aluminium electrolysis, cement kiln, water heating in households, lighting, air conditioning, passenger car, aviation, etc.

In demand sectors technology vintages are modelled as cycles of dynamic change involving four generic vintages: ordinary, improved, advanced, future.

In power sector all investment and generation depend on date of commissioning of plants, hence full accounting of technology vintages.

Technology progress

Technical-economic characteristics of technologies are assumed to change over time (as a result of R&D and eventually economies of scale in mass production)

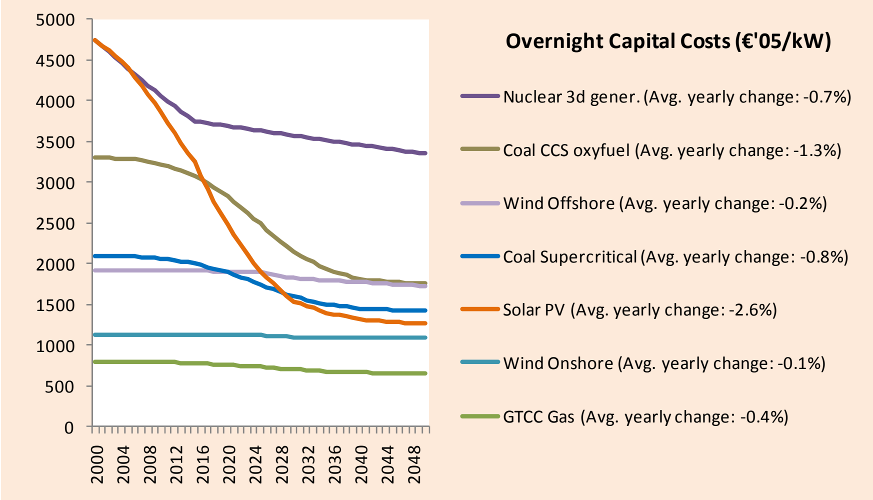
The rate of change of technical-economic characteristics over time is an assumption of the modelling which may be altered depending on the scenario

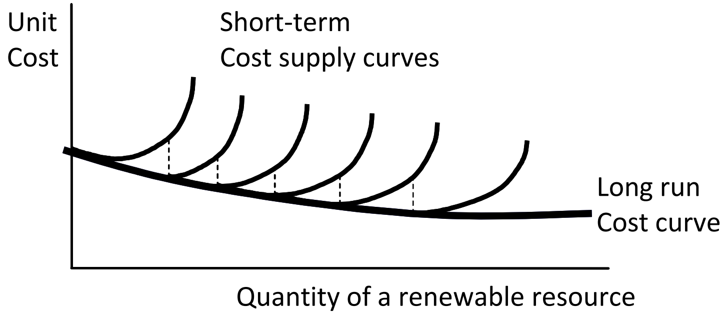
Depending on the scenario, learning-by-doing and economies of scale effects are introduced in the quantification of technical-economic parameters for both demand and supply-side technologies.

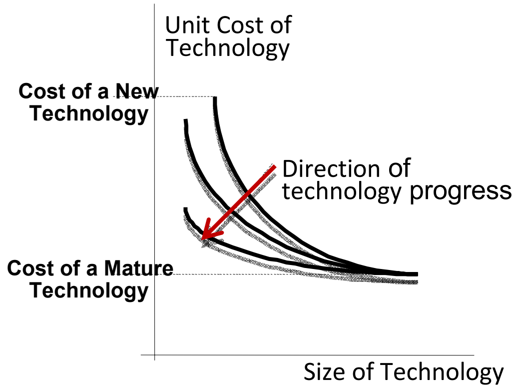
However, the PRIMES model does not include in a fully endogenous way the learning-by-doing mechanism (non convexity issue) but handles learning in the building of scenarios

Technology progress is also assumed regarding the cost gap between technologies of different sizes, for example small scale wind vs. large scale wind parks. As the power model distinguishes between stylised scales (utility, industrial, decentralised), scenarios with high degree of decentralised generation can be simulated.

Examples of technology developments







Discount rates

PRIMES simulates decentralised decision-making by agents (representative energy consumers and suppliers)

Capital budgeting decisions involve discount rates, which are considered from a private (not social) perspective

For business agents (industrial consumers, power utilities, etc.) the model uses a Weighted Average Cost of Capital and for private agents (households, private cars) the model uses a "subjective" discount rate

- WACC is composed of a lending rate, a return to equity capital rate and a risk premium
- Subjective discount rates include risk premium which reflects cash flow issues and general risk aversion

When aggregating model projections over time (e.g. for cost-benefit analysis) one should use a social discount rate

Examples of discount rates used

Large power utilities: 8% (real)

Heavy Industry: 10-12%

Small industry: 14%

Services sectors: 11-14%

Households: 17%

Private cars: 18%

Public or business transport: 11%

Grid infrastructure: 7%

Infrastructure

Infrastructure explicitly represented in the model:

- High voltage interconnectors (topology with 35 nodes and 240 possible links)
- High pressure gas pipelines, LNG terminals, storage facilities (in the gas supply model)

Infrastructure implicitly (cost approach, not physical) represented in the model:

- Grid extensions for connecting RES power plants
- Grid enhancement and ancillary services equipment to facilitate high penetration of variable RES
- Distribution network for electricity
- Gas distribution (density influences gas penetration in heat uses)
- Heat/Steam distribution network
- Smart metering (related to peak load pricing)
- Smart grids to integrate decentralised generation (cost impacts associated with parameters facilitating decentralisation)
- Refuelling infrastructure (density of this – associated with costs – influence penetration of alternative fuels in transportation; only in detailed transport model)

For all types of infrastructure the model computes cost as capital annuity payments and operation costs. The model computes separate tariff component which are added to consumer prices in order to recover cost of infrastructure. Cost allocation to consumers is on a pro rata basis.

For implicitly represented infrastructure, costs are computed through simple relationships linking to the service provided by the infrastructure.

MARKETS

Unit Commitment and Capacity Expansion

- PRIMES takes a least cost optimisation approach for unit commitment and capacity expansion in power generation It is assumed that the Internal Electricity market gradually moves towards a well-functioning market and thus a least cost approach is appropriate, being consistent with a competitive market
- Least cost unit commitment and capacity expansion is representative of a variety of market designs, as for example pools, bilateral contracts with spot market, etc., provided that the market is sufficiently competitive
- Fuels, renewable resources, nuclear sites etc. are represented as cost-supply curves bound by potential; thus the least cost optimisation is essentially non linear.
- PRIMES solves simultaneously for electricity, district heating, CHP and auto-production, performing multi-commodity market clearing
- The model performs closed-loop simulation between demand and supply with prices clearing the market:
    - Demand for electricity is firstly projected by sector and by segment of the load curve (also for steam and heat)
    - Generation is projected together with capacity expansion so as to meet aggregate demand (load curve)
    - Prices per sector are then computed taking into account marginal costs, fixed costs, capital costs and grid costs (Ramsey-Boiteux method) and exogenous mark-ups reflecting degree of market competition
    - Price determination for grid, PSOs and RES subsidy recovery reflect regulatory practices
    - Demand is projected again with new prices until demand and supply match
- Prices lie above marginal costs as needed to recover fixed costs and eventual stranded costs (from premature scrapping and old capacities)
- Mark-ups (positive or negative) are calibrated per country and are assumed to gradually tend, over time, to normal rates

Electricity trade

- PRIMES has two options for computer running: a) separate optimisation per country with fixed net imports, which are obtained after a regional model running, b) full optimisation at the level of regions. Optimisation for the entire EU is not possible because of limitations in computer capability
- The regional model optimisation takes into account interconnection capacities (and Net Transfer Capacities) through DC linearized optimal power flows. This means that an injection to a bus (in the model a country node) is propagated to all interconnecting links. When interconnection use is at capacity limit, marginal costs differ by node (country).
- This regional modelling approach can be seen as corresponding to common balancing with coordinated management of interconnectors.

Regional disaggregation for power sector

PRIMES can solve the power system model simultaneously by region, with endogenous links between regions, which are the following:

1. **Iberian**: Portugal, Spain
2. **British islands**: UK, Ireland
3. **Central Europe**: France, Germany, Belgium, Netherlands, Luxembourg, Switzerland, Austria, Italy
4. **Central-Eastern Europe**: Poland, Czech Republic, Slovakia, Hungary, Slovenia
5. **Nordic**: Norway, Sweden, Finland, Denmark
6. **Baltic**: Lithuania, Estonia, Latvia, Kaliningrad
7. **South East Europe**: Romania, Bulgaria, Greece, Albania, Croatia, Bosnia & Herzegovina, FYROM, Serbia-Kosovo-Montenegro, Turkey

External links (with exogenous net imports): Russia, Ukraine, Moldova, Belarus, Morocco, Middle East

Alternative regional configurations are possible (user-defined)

Gas Supply Model

- The Gas Supply model simulates an oligopoly market over multiple countries, involving many actors (consumers, TSOs, traders and upstream producers)
  - Consumers are price takers with demand being elastic with prices
  - TSOs manage gas hubs and minimize cost of gas supply
  - Traders maximise profits, perform arbitraging operations and are price takers from upstream producers
  - Upstream producers compete along a Nash-Cournot game (with conjectural variations)
  - The number of competitors acting on each node change over time to reflect growing competition (long term trend towards a well functioning market)
- Operations and flows are constrained by a physical system involving pipelines, LNG terminals, gas storage facilities, liquefaction plants and gas producing wells
- The model simulates two layers of flows: physical gas flows and commercial transactions
- A consumer on one node can be commercially supplied with gas produced at a node without direct link with the consumption node (e.g. if gas swaps implement the commercial transaction)
- Since the gas network constraints are binding, gas supply prices differ by node (country)
- Price determination reflects marginal costs, an endogenous mark-up and fixed costs that recover cost of infrastructure
- Upstream producers tariff gas according to a gas cost function inclusive of gas field exhaustion rents (Hotelling's rule)
- The model simulates gas balancing on a daily basis, considering load characteristics of gas demand sectors and the possibilities of storing gas and using LNG
- The market clearing for pipeline gas is on a Eurasian scale, while for LNG the coverage is global
- Investment in gas infrastructure is exogenous
- Characteristics of gas companies are also exogenous

Use of the gas supply model

- Investment in gas infrastructure is exogenous
- Characteristics of gas companies are also exogenous
- The gas supply model has been used for specific gas sector analyses:
  - Congestion and profitability of new gas transport routes
  - Alternative scenarios about development of new gas suppliers
  - Impact of gas shortages for certain upstream suppliers
  - Changes in the global market for LNG
  - Impact of reduced gas demand in the EU owing to energy efficiency and RES
  - Impact of growth of domestic gas demand within major gas suppliers of Europe

Gas Supply model coverage

- 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 and Prometheus demand projections

Approach for carbon market modelling

- The model can analyse various emission constraints: per sector, per country or EU-wide
- The sectors are grouped in ETS and non ETS, with different representations of mechanisms
- For ETS
  - A EU-wide emission constraint is applied reflecting total volume of allowances (per year) and assumptions about permissible international credits (e.g. CDM)
  - Grandfathering (free allowances) can be represented through exogenous quotas per sector and per country; carbon prices are, entirely or partially (reflecting degree of market competition), treated as opportunity costs and price signals, but actual payments only correspond to excess emissions by sector
  - Auctioning of allowances is represented by modelling carbon prices inducing true payments by sector
  - Carbon prices are determined iteratively (until ETS volume of allowances is exactly met) and apply on all ETS sectors and countries in a uniform way
  - Inter-temporal aspects, such as arbitraging over time within the ETS, are considered in the modelling by introducing cumulative allowances as a constraint and excluding borrowing from the future (the model running is however iterative, as inter-temporal optimisation was not technically possible because of computer limitations)
- For non ETS
  - The model can handle non ETS emission reduction targets either on a country level or EU-wide assuming possible exchanges between MS
  - Carbon values (i.e. shadow prices associated with the volume constraint) serve to convey price signals to non-ETS sectors without entailing direct payments (only indirect costs)
- Carbon prices and carbon values act on top of any other policy measure (of specific character, for example standards, specific taxes, subsidies, RES policies and obligations, etc.), thus ETS carbon prices determined endogenously depend on the extend of other policies and measures assumed for a scenario

Summary of modelling emissions and costs

- CO_2 emissions are endogenous in PRIMES and depend on combustion of fossil fuels.
- CO_2 from industrial processes are included.
- Non CO_2 GHGs are projected through the GAINS model.
- Emissions change as a result of alterations in level of energy demand, fuel mix, technology mix.
- Changes in CO_2 emissions is a result of analytical model calculations
- Changes in rest of GHGs are represented through reduced-form marginal abatement cost curves, quantified by IIASA and integrated in the PRIMES modelling framework.
- Auctioning payments do have a budget constraint and a price effect on behaviour of energy actors (in a way similar to a carbon tax)
- Grandfathering have a price effect but not necessarily a budget effect, depending on the degree of passing opportunity costs through to consumer prices

International carbon credits

PRIMES do not model the international market for carbon credits (e.g. CDM)

Usually the scenarios assume that the EU is a price-taker of the marginal CDM price and also that there is an upper bound on the volume of carbon credits to be taken from CDM

Thus, if the assumed CDM price is lower than the estimated EU ETS carbon price, carbon credits from CDM are taken up to the upper bound

Using PRIMES in linked form with Prometheus model or other global model (e.g. GEM-E3, POLES), it is possible to simulate global ETS and carbon markets with different groupings (bubbles). Such a study was carried out recently for the Copenhagen pledges.

GENERIC ISSUES ON TECHNOLOGY PENETRATION

Technologies in demand-side models of PRIMES

All demand-side models of PRIMES are structured as a tree: a sector is subdivided in sub-sectors or processes which are further subdivided in several energy uses

As the decomposition into energy uses is sufficiently detailed, the model associates one technology type to an energy uses. For example a cement kiln is a technology type corresponding to the energy use cement kilns. Similarly central space heating boiler is a technology type associated with the energy use of space heating in central heating dwelling type; technology types can use different fuels. Only in the transport sector multiple technology types compete in serving the same energy use (e.g. for private cars: internal combustion engine (diesel, petrol), hybrid, electric car).

For each technology type, four technology vintages (technology generations) compete with each other in the modelling of consumer choice.

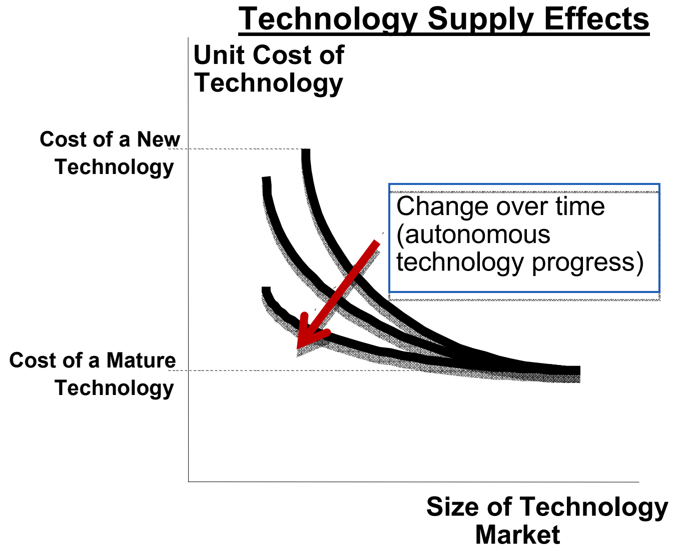
The technology vintage names are: ordinary, improved, advanced and future, differing in their characteristics (purchase cost, energy efficiency, etc.)

- Depending on economic context and policy drivers the representative consumer by sector is modelled to make a choice between technology vintages.
- In the next time period, the characteristics (cost and efficiency) of the ordinary technology change to reflect the average characteristics of the technology stock, depending on the vintage choices in the previous time period and the rate of decay of the stock
- Premature replacement of equipment is possible depending on economics
- In the next time period, a new consumer choice is modelled regarding the mix of the updated ordinary technology and the other technology vintages

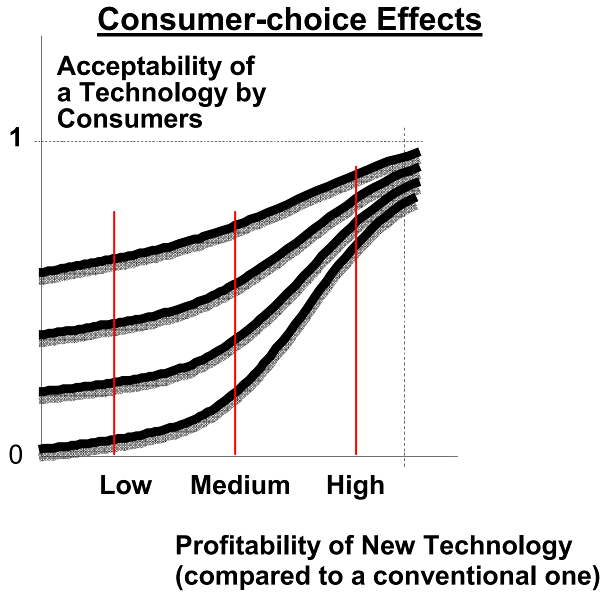
The possible technology progress is built in the assumptions about the technical-economic characteristics of the technology vintages (per energy use)

These assumptions differ by scenario in order to reflect policies that influence future technology progress (R&D, standards, carbon or efficiency policies) which may include a context leading equipment producers to deliver lower costs for higher performance as a result of mass production

Economies' of scale and learning effects



Relation between acceptability and profitability



Technologies in Power Generation and other supply sectors

Technologies are represented explicitly and have different technical-economic characteristics: energy efficiency, investment cost, O&M cost, variable non fuel cost, self-consumption, etc.

In power sector, cost and performance features of plants depend on date of commissioning of plants

The model keeps track of technology vintages (both for old plants and new investments) over the entire projection period

As retrofitting is endogenous, an old plant may get higher performance through investment

Adding Carbon capture, FGD or DENOx to an existing plant lowers net energy efficiency

Technology progress

Technical-economic characteristics of technologies are assumed to change over time (as a result of R&D and eventually economies of scale in mass production)

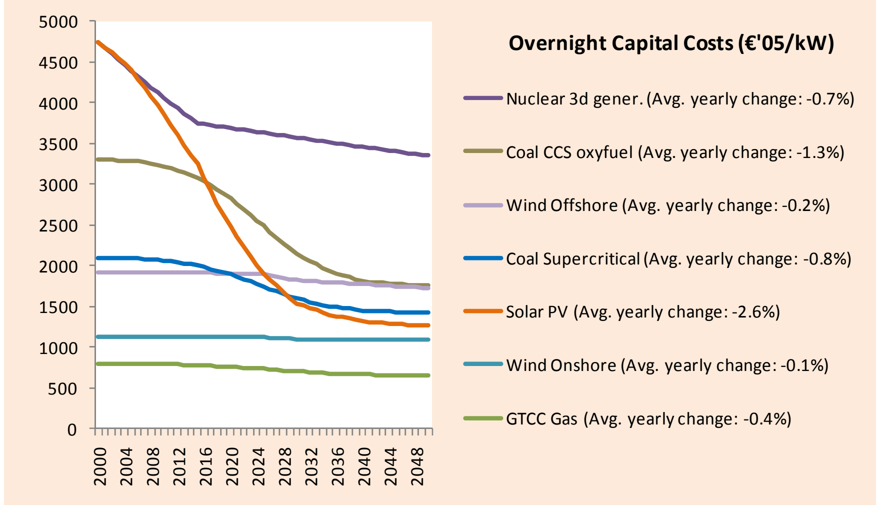
The rate of change of technical-economic characteristics over time is an assumption of the modelling which may be altered within each scenario

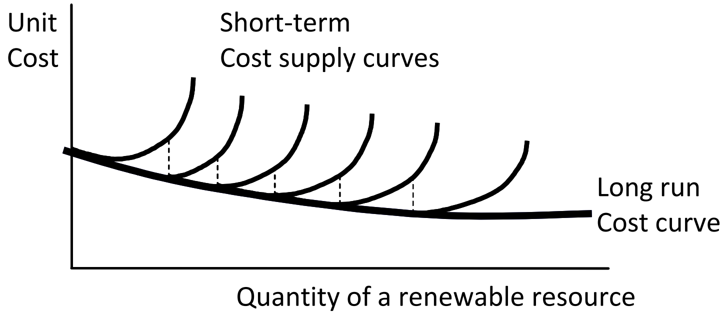
Depending on the scenario, learning-by-doing and economies of scale effects are introduced in the quantification of technical-economic parameters for both demand and supply-side technologies.

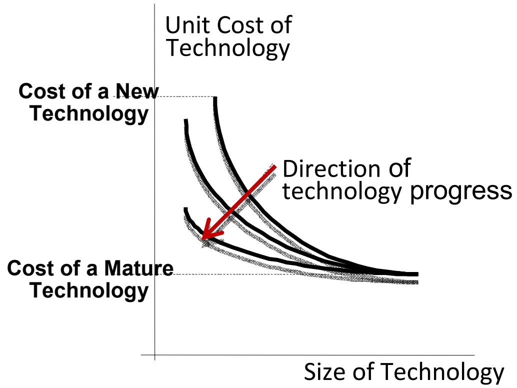
However, the PRIMES model does not include in a fully endogenous way the learning-by-doing mechanism (non convexity issue) but handles learning in the building of scenarios, which may be related to enabling policies

Technology progress is also assumed regarding the cost gap between technologies of different sizes, for example small scale wind vs. large scale wind parks. As the power model distinguishes between stylised scales (utility, industrial, decentralised), scenarios with high degree of decentralised generation can be simulated.

Examples of technology developments







Example of technical-economic data for power plants

TECHNICO-ECONOMIC DATA

	Overnight Capital Costs (€'05/kW)				
	2000	2005	2020	2030	2050
Steam Turbine Gas Industrial	994	994	991	972	964
Gas Turbine Gas Industrial	402	402	400	393	389
Gas Combined Cycle Industrial	688	704	703	698	697
Steam Turbine Gas Conventional	920	920	918	900	892
Gas Turbine Combined Cycle Gas Conventional	625	640	639	635	634
Peak Device Gas Conventional	365	365	364	357	354
Gas Turbine Combined Cycle Gas Advanced	800	799	762	706	660
Delayed Deployment					
Gas combined cycle CCS post combustion	1385	1383	1370	1422	1107
Gas combined cycle CCS pre combustion	1550	1547	1451	1347	949
Gas combined cycle CCS oxyfuel	1670	1666	1543	1394	937
Reference Deployment					
Gas combined cycle CCS post combustion	1385	1383	1273	1104	1010
Gas combined cycle CCS pre combustion	1550	1547	1343	1033	860
Gas combined cycle CCS oxyfuel	1670	1666	1421	1048	840
Internal Combustion Engine Gas	951	915	912	895	887
Peak Device Gas Advanced	456	456	455	446	443
Small Device Gas	684	684	683	669	664

	Thermal Efficiency for Net Electricity Generation				
	2000	2005	2020	2030	2050
Steam Turbine Gas Industrial	46.6%	46.6%	47.3%	48.5%	49.5%
Gas Turbine Gas Industrial	38.6%	38.6%	39.1%	39.9%	40.6%
Gas Combined Cycle Industrial	50.2%	50.2%	51.8%	54.3%	56.6%
Steam Turbine Gas Conventional	41.7%	41.7%	42.0%	42.4%	42.7%
Gas Turbine Combined Cycle Gas Conventional	52.7%	52.7%	54.1%	56.5%	58.5%
Peak Device Gas Conventional	38.6%	38.6%	39.1%	39.9%	40.6%
Gas Turbine Combined Cycle Gas Advanced	53.9%	53.9%	56.0%	59.2%	62.2%
Delayed Deployment					
Gas combined cycle CCS post combustion	41.8%	41.8%	42.4%	42.0%	50.9%
Gas combined cycle CCS pre combustion	39.6%	39.7%	40.3%	39.8%	50.7%
Gas combined cycle CCS oxyfuel	37.4%	37.5%	38.5%	38.6%	51.0%
Reference Deployment					
Gas combined cycle CCS post combustion	41.8%	41.8%	44.4%	48.9%	53.3%
Gas combined cycle CCS pre combustion	39.6%	39.7%	42.7%	48.3%	54.0%
Gas combined cycle CCS oxyfuel	37.4%	37.5%	40.9%	47.5%	54.6%
Internal Combustion Engine Gas	46.2%	46.8%	48.6%	49.1%	50.0%
Peak Device Gas Advanced	38.6%	38.6%	39.1%	39.9%	40.6%
Small Device Gas	35.8%	36.2%	37.6%	40.1%	45.8%

	Fixed Operation and Maintenance Costs (€'05/kW)				
	2000	2005	2020	2030	2050
Steam Turbine Gas Industrial	16.6	16.6	16.5	16.2	16.1
Gas Turbine Gas Industrial	11.9	11.9	11.8	11.6	11.5
Gas Combined Cycle Industrial	17.6	18.0	18.0	17.9	17.8
Steam Turbine Gas Conventional	16.6	16.6	16.5	16.2	16.1
Gas Turbine Combined Cycle Gas Conventional	15.6	16.0	16.0	15.9	15.8
Peak Device Gas Conventional	11.0	11.0	10.9	10.7	10.6
Gas Turbine Combined Cycle Gas Advanced	20.0	20.0	19.6	19.0	18.5
Delayed Deployment					
Gas combined cycle CCS post combustion	27.8	25.9	29.0	31.6	23.3
Gas combined cycle CCS pre combustion	24.6	23.0	25.9	29.6	21.6
Gas combined cycle CCS oxyfuel	25.0	23.3	26.9	31.2	22.2
Reference Deployment					
Gas combined cycle CCS post combustion	27.8	25.9	27.0	24.6	21.2
Gas combined cycle CCS pre combustion	24.6	23.0	24.0	22.7	19.6
Gas combined cycle CCS oxyfuel	25.0	23.3	24.8	23.4	19.9
Internal Combustion Engine Gas	13.3	12.8	12.8	12.5	12.4
Peak Device Gas Advanced	11.7	11.5	11.4	11.2	11.1
Small Device Gas	24.3	23.9	22.5	19.2	16.9

	Variable Operation non Fuel Costs (€'05/MWh)				
	2000	2005	2020	2030	2050
Steam Turbine Gas Industrial	4.6	4.6	4.6	4.6	4.6
Gas Turbine Gas Industrial	1.8	2.1	3.4	3.4	3.4
Gas Combined Cycle Industrial	2.1	2.1	2.1	2.1	2.1
Steam Turbine Gas Conventional	2.1	2.1	2.1	2.1	2.1
Gas Turbine Combined Cycle Gas Conventional	2.1	2.1	2.1	2.1	2.1
Peak Device Gas Conventional	1.8	2.1	3.4	3.4	3.4
Gas Turbine Combined Cycle Gas Advanced	2.1	2.0	1.9	1.8	1.7
Delayed Deployment					
Gas combined cycle CCS post combustion	3.2	3.1	3.0	3.0	2.9
Gas combined cycle CCS pre combustion	2.5	2.5	2.4	2.4	2.3
Gas combined cycle CCS oxyfuel	3.5	3.4	3.4	3.4	3.1
Reference Deployment					
Gas combined cycle CCS post combustion	3.2	3.1	3.0	2.9	2.7
Gas combined cycle CCS pre combustion	2.5	2.5	2.4	2.3	2.1
Gas combined cycle CCS oxyfuel	3.5	3.4	3.3	3.2	3.0
Internal Combustion Engine Gas	2.0	2.0	2.0	2.0	2.0
Peak Device Gas Advanced	2.0	2.0	2.0	2.0	2.0
Small Device Gas	0.7	0.7	0.7	0.7	0.7

	Self consumption Rate				
	2000	2005	2020	2030	2050
Steam Turbine Gas Industrial	3.0%	3.0%	3.0%	3.0%	3.0%
Gas Turbine Gas Industrial	1.0%	1.0%	1.0%	1.0%	1.0%
Gas Combined Cycle Industrial	2.5%	2.5%	2.5%	2.5%	2.5%
Steam Turbine Gas Conventional	3.0%	3.0%	3.0%	3.0%	3.0%
Gas Turbine Combined Cycle Gas Conventional	2.5%	2.5%	2.5%	2.5%	2.5%
Peak Device Gas Conventional	1.0%	1.0%	1.0%	1.0%	1.0%
Gas Turbine Combined Cycle Gas Advanced	2.0%	2.0%	2.0%	1.9%	2.0%
Delayed Deployment					
Gas combined cycle CCS post combustion	24.0%	24.0%	22.4%	20.2%	16.6%
Gas combined cycle CCS pre combustion	28.0%	27.9%	25.5%	22.2%	16.0%
Gas combined cycle CCS oxyfuel	32.0%	31.9%	28.4%	23.2%	15.1%
Reference Deployment					
Gas combined cycle CCS post combustion	24.0%	24.0%	21.6%	18.0%	16.0%
Gas combined cycle CCS pre combustion	28.0%	27.9%	24.1%	18.3%	15.0%
Gas combined cycle CCS oxyfuel	32.0%	31.9%	26.6%	18.5%	14.0%
Internal Combustion Engine Gas	1.5%	1.5%	1.5%	1.5%	1.5%
Peak Device Gas Advanced	1.0%	1.0%	1.0%	1.0%	1.0%
Small Device Gas	0.7%	0.7%	0.7%	0.7%	0.7%

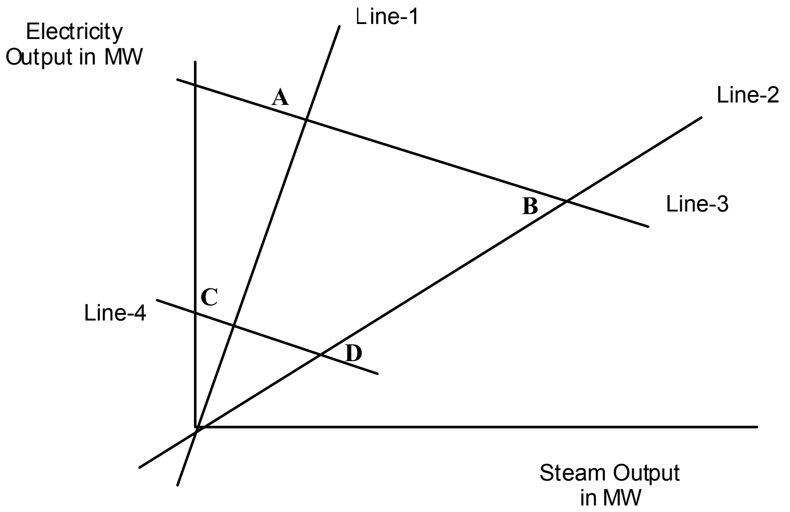
	Risk Premium which increases the wieghted average cost of capita				
	2000	2005	2020	2030	2050
Steam Turbine Gas Industrial	0.00%	0.00%	0.00%	0.00%	0.00%
Gas Turbine Gas Industrial	0.00%	0.00%	0.00%	0.00%	0.00%
Gas Combined Cycle Industrial	0.00%	0.00%	0.00%	0.00%	0.00%
Steam Turbine Gas Conventional	0.00%	0.00%	0.00%	0.00%	0.00%
Gas Turbine Combined Cycle Gas Conventional	0.00%	0.00%	0.00%	0.00%	0.00%
Peak Device Gas Conventional	0.00%	0.00%	0.00%	0.00%	0.00%
Gas Turbine Combined Cycle Gas Advanced	10.00%	5.00%	0.00%	0.00%	0.00%
Delayed Deployment					
Gas combined cycle CCS post combustion	1000.00%	1000.00%	2.25%	1.27%	0.00%
Gas combined cycle CCS pre combustion	1000.00%	1000.00%	4.50%	2.53%	0.00%
Gas combined cycle CCS oxyfuel	1000.00%	1000.00%	6.00%	3.38%	0.00%
Reference Deployment					
Gas combined cycle CCS post combustion	1000.00%	1000.00%	1.75%	0.24%	0.00%
Gas combined cycle CCS pre combustion	1000.00%	1000.00%	2.50%	0.34%	0.00%
Gas combined cycle CCS oxyfuel	1000.00%	1000.00%	2.50%	0.50%	0.00%
Internal Combustion Engine Gas	0.00%	0.00%	0.00%	0.00%	0.00%
Peak Device Gas Advanced	100.00%	7.50%	0.00%	0.00%	0.00%
Small Device Gas	100.00%	7.50%	0.00%	0.00%	0.00%

E3M - Lab

CHP Technologies

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

CHP Possibilities domain



Technical-Economic Parameters of Plants

1. Capital cost (Euro'05/kW) and financial charges during construction
   - Retrofitting costs and possibilities, incl. DESOx, DENOx, aux. CCS
   - 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

RES and reserve power

Stochastic RES are considered as deterministic equivalent production

Capacity credits from stochastic RES are derived per type and country as function of volume and dispersion parameters

The model considers reserve power constraints which take into account capacity credits from stochastic RES

Hydro Lakes are dispatchable but are energy constrained

Pumping and use of storage is endogenous

The model formulates impact of stochastic RES on power grid investment and costs, distinguishing between offshore wind, onshore wind, solar PV and the level of decentralisation

POWER SECTOR SUB-MODEL

DEMAND-SIDE MODELLING ISSUES

Energy Efficiency

The PRIMES model explicitly represents the formation of useful energy demand, the choice of technologies by type of energy use and the fuel mix which form final energy demand

Energy efficiency progress, as modelled, is due to:

- ➢Lowering useful energy demand because higher energy costs induce substitutions towards non energy goods and services and behavioural changes (less heating, less mobility, switch off appliances)
- ➢Changing mix of energy uses, where possible (more efficient industrial processes, more recycling of scrap)
- ➢Shifting technology choice towards more efficient technologies
- ➢Changing fuel mix with fuels having different specific energy consumption rates (e.g. from conventional to electric car, use of heat pumps)
- ➢Undertaking investment in direct energy savings (insulation, better control systems)

Methodological approach

Mechanisms are used in the model to ensure that from the perspective of decision making energy efficiency gains entail higher costs (with a subjective component) compared to less efficient choices (reflecting actual market penetration of efficient technology):

- ➢Cost of advanced technologies is perceived by the consumer as being higher than true costs, reflecting uncertainty about technology performance, maintenance, repairing services, etc.
- ➢In capital budgeting decisions a subjective discount rate, or a WACC, is used which include a risk premium, so pay back periods of energy saving investment are longer than suggested by engineering studies
- ➢Disutility costs are considered when **useful** energy demand reduces from a reference level (e.g. switching off lights imply less luminosity). Disutility is monetised on the basis of the income compensating variation concept

Barriers to energy efficiency

- Engineering-based economic evaluations show that some of the energy efficiency improving measures imply negative total net costs for the energy consumer (short pay back period).
- However, energy consumption statistics do not show the massive uptake of efficient technology having lower lifetime engineering costs
- Several factors explain this paradox, such as market and non market barriers (lack of information, uncertainty surrounding performance of new technologies and non zero transactions costs, split incentives) and the conditions influencing economic decision-making by individuals (limited availability of cash flow, risk aversion, hence high subjective discount rates).
- In addition, rebound effects tend to partly offset the demand-reducing effects of energy efficiency measures, as energy cost reduction allows for higher energy use.
- Perceived cost of technologies: In the PRIMES model consumers perceive higher costs for advanced technologies than engineering-based estimations, because of uncertainty, barriers and imperfections mentioned above
- Rebound effects are also modelled: for example energy savings by households may result in lower spending for energy, hence relaxing disposable income constraint inducing additional spending in non-energy and energy goods and services
- Public policy promoting energy efficiency acts through the price drivers but also through the removal of uncertainty and barriers for new technologies
- Standards imposed by legislation on new technologies also influence the menu of technology choice
- Those interventions are modelled in PRIMES by sector and type of energy use and are assumed to intensify in the context of emission abating scenarios or energy efficiency scenarios

The energy efficiency value

Energy saving investment especially in buildings can be influenced either indirectly from the above mentioned instruments or directly through a so-called "efficiency value"

Specified by sector or at an overall level it is conceived as a shadow price of efficiency targets; for example movement towards near zero energy buildings can be induced by rising the level of the energy efficiency value

When the energy efficiency value is considered at a country level, it may be used to simulate White Certificates; through iterations the model determines the level of the efficiency value which induces the desired energy efficiency target; thus the energy efficiency value can be interpreted as the market price of the white certificates

Specific sector policies

CHP promoting policies are modelled in the power sector model through:

- CHP obligations (percentage of power produced from CHP plants)
- Lowering risk premium associated with CHP plant components which reflect facilitation of selling CHP electricity to power pools and exchanges
- Bounds on industrial electricity supply which reflect bilateral contracts based on CHP power and steam
- Technology parameters which reflect reduction of cost differences between large scale and smaller scale plants

The detailed PRIMES-TREMOVE transport model allows for simulating the effects of various specific policies, such as modal shifts, infrastructure, congestion pricing, etc. in addition to standard instruments such as taxes, standards and technology promotions.

Policy instruments affecting energy efficiency

Taxes on fuels, such as energy tax, carbon tax, ETS carbon prices or simply change in excise taxes

- Change relative cost of fuels inducing fuel switching
- Change unit cost of technologies altering selection of technology vintages
- Change unit cost of energy uses and processes implying changes in the mix of uses-processes
- Change unit cost of energy services inducing changes in useful energy demand and eventually enabling energy saving expenses

Carbon values influence choices like carbon taxes, but do not entail payments by consumer (unless energy carrier prices are affected by carbon values), but do imply higher indirect costs

Standards on technologies (eco-design, CO_2 regulation for cars, etc.) are modelled by penalising technology vintages which do not comply with standards and by reducing the perceived cost barriers that are associated with advanced technologies (which comply with the standards); consequently the model simulates a different technology uptake than in a reference scenario and energy efficiency indicators change

Labels, campaigns and other similar technology promotion policies are represented by lowering the perceived cost components of technology vintages and by reducing risk premium

Policies promoting uptake of near zero energy buildings are simulated through efficiency values (see box in the left) which induce more energy savings and an acceleration of renovation rates

Policies based on institutional measures, e.g. ESCO, are simulated by assuming lower perceived costs, lower risk premia for the uptake of advanced technologies and a reduction of the discount rates

Effects of smart metering are represented by altering the parameters of the load curves associated with energy uses

Electric Appliances

Appliance	Source	Base Case	improved	BAT	BNAT
Washing machine	EuP and IEA	0.998kWh/cycle 443EUR		-10% (+25% cost)	Technical performance limit might soon be
	PRIMES	1.57kWh/cycle 582EUR	40% improvement, 0.95kWh/cycle	-50% (+32% cost)	further -5%, at 25% cost increase
Dryer	EuP	3.48kWh/cycle 463EUR		-88% and -44% (+92% and +60% cost)	Change of technology (e.g. heat pumps) could
	PRIMES	2.38kWh/cycle 427EUR	34% improvement 1.83kWh/cycle	-50% at 100% cost	further -5%, at 30% cost increase
Dishwasher	EuP and IEA	0.828kWh/cycle 520EUR		-7% (+45% cost)	Improvement of 3.1% (2005-2010); -0.5% p.a.
	PRIMES	0.74kWh/cycle 415EUR	34% improvement 0.56kWh/cycle	-50% at 100% cost	further -5%, at 30% cost increase
Lighting	EuP			Residential: -70% Services: -70% Street: -30%	LEDs and OLEDs
	PRIMES		-26% at 30% cost	-80% at 250% cost	further -2% at 35% cost
Entertainment/office equipment	EuP			TVs: -20% Computers: -65 to -75%	TVs:-30 to -50% compared to current Computers: software and consumer
	PRIMES	815EUR	-10% at 32% cost	further -10% at 32% cost	further -5%, at 25% cost increase

Buildings

PRIMES uses a range with different costs per sub-category; possible to go down to 25 kWh/m2 (floor of near zero energy building) for new buildings

McKinsey Germany 2007:

- Renovations to 70kWh/m² (space heating) have negative abatement costs for all types of housing (at 20€/tCO_2)
- Passive Houses have a positive abatement cost

BAT

- Passive House:
- Heating and cooling: 15kWh/m² (McKinsey renovation: 20kWh/m²)
- Primary energy (incl. appliances and lighting): 120kWh/m²

BNAT

- Ultra-passive house: 7kWh/m² (ETP 2008)

Illustration (scenario result for the entire building stock)

Reference scenario	2000	2005	2010	2015	2020	2025	2030
Final energy kWh/m²	180	176	159	146	132	117	107

Illustrative assumptions about cars

Technology	Source		Base case	Improved	Advanced	Future
ICE gasoline	McKinsey	efficiency [l/100km]			6.1	
	2009	cost [EUR]			22252	
	IEA	efficiency [l/100km]	7.0	5.6	4.3	
	2009	cost [USD]		21752	22752	
	PRIMES	efficiency [l/100km]	*10.0*	8.0	6.3	5.7
		cost [EUR]	*19252*	22461	26739	30750
	DOE	efficiency [l/100km]	*8.99*		5.6	
	2010	cost [USD]				
	EPA	efficiency [l/100km]		7.2	5.3	
	2005	cost [USD]		19964	20570	
ICE diesel	McKinsey	efficiency [l/100km]			4.5	
	2009	cost [EUR]			23795	
	IEA	efficiency [l/100km]	7.0			3.9
	2009	cost [USD]			24795	26795
	PRIMES	efficiency [l/100km]	9.7	7.5	5.9	5.4
		cost [EUR]	21795	27927	32714	37239
	EPA 2005	efficiency [l/100km]			5.8	
	FEV/EPA	cost [USD]			23786	
		efficiency [l/100km]			6.5	
	ORNL	cost [USD]			24344	
	WBSCD 20(	efficiency [l/100km]		8.0		
HEV gasoline	McKinsey	efficiency	7.0	3.92		
	2009	cost [EUR]		23252		
	IEA	efficiency	6.7	5.5	5.0	3.2
	2009	cost [USD]	21752	22252	23752	37950
	PRIMES	efficiency	6.3	5.0	3.9	3.6
		cost [EUR]	27167	30563	35037	38742
	EPA 2005	efficiency		4.9		
	EPRI	cost [USD]		21752		
		efficiency		6.0		
	ORNL	cost [USD]		21935		
	WBCSD 20(	efficiency		7.5	6.3	

Technology	Source		Base case	Improved	Advanced	Future
HEV diesel	McKinsey	efficiency [l/100km]	7.0	5.6		
	2009	cost [EUR]		23252		
	IEA	efficiency [l/100km]	6.0	5.5	4.7	2.7
	2009	cost [USD]	22252	24252	25252	26752
	PRIMES	efficiency [l/100km]	6.3	5.0	3.9	3.6
		cost [EUR]	26953	30322	34761	38438
	EPA	efficiency [l/100km]			2.9	
	2005	cost [USD]			23375	
	WBCSD 2004	efficiency [l/100km]	7.6	6.4		
EV	McKinsey	efficiency [l/100km]			3.0	1.5
	2009	cost [EUR]			55252	25052
	IEA	efficiency [l/100km]			2.8	2.8
	2009	cost [USD]			31752	36752
	PRIMES	efficiency [l/100km]	3.7	3.5	3.2	2.9
		cost [EUR]	32292	36329	41647	46052
	WBCSD 2004	efficiency				2.0

Note: for EV 1l/100km is approximately 8.5 kWh/100km

COSTS

Determination of Costs and Prices

A great deal of of costs are endogenous in the model, including:

- investment costs, equipment purchasing costs, energy savings investment
- operating and variable costs
- fuel purchase costs
- payments for taxes and ETS
- payments for recovering RES supporting policies
- tariffs for recovering cost of infrastructure

Subjective cost elements, carbon values, efficiency and RES values, and non linear resource or plant site cost elements do not entail payments and so are not included in cost reporting, however they influence decisions and may imply indirect costs , e.g. through different investment choices (which are included in the cost reports)

Prices are determined from costs (marginal and/or average) and reach levels needed to recover fixed costs including cost from premature replacement or lower use of old equipment, as well as cost of infrastructure. Depending on assumed market competition regime, prices may include a cost mark-up reflecting super-normal profit from market power. For some fuels, prices determination may reflect opportunity cost pricing (e.g. related to the main substitutable fuel, or in case of grandfathering auction permits)

The sequence is as follows:

- ➢Prices of imported fuels are exogenous
- ➢Prices at factory entrance take into account transport costs and possible specificities by country
- ➢Bio-energy commodity costs depend on biomass supply costs
- ➢Prices of domestically produced commodities without international trade depend on costs
- ➢Prices for electricity, steam and gas are determined through a complex model, as explained above, and use Ramsey Boiteux technique for allocation by sector. They reflect all cost elements, recover fixed costs plus mark-up.
- ➢Pre-tax prices are increased by taxes to form consumer prices by sector
- ➢Costs incurring by energy consumers for their equipment and energy savings are computed at the level of the demand sub-models

Cost reporting from a macro-economic perspective

PRIMES reports on costs and prices by sector in detail

For policy evaluation, PRIMES reports on costs from the perspective of final energy consumers, namely industry, households, services and transportation

Such costs per sector are decomposed in:

- ➢Annuity payments for capital based on the sector's discount rate (alternatively annualised cash payments for investment)
- ➢Annuity payments for energy saving investments (or annualised cash payments for investment)
- ➢Variable costs for operation and maintenance
- ➢Fuel purchase costs (which reflect all costs incurring by energy suppliers, including taxes, ETS, etc.)
- ➢Direct tax payments

Adding these costs for all demand sectors the model computes the ***Total Energy System Cost***, which can be seen as payment by the rest of the economy in order to get the required energy services (reported as % of GDP it indicates the cost of energy for the economy)

Taxes and auction revenues may be excluded from this total cost when assuming that the recycling of public revenues in the economy is performed without transaction costs

Tax revenues from energy are reported separately

Cash payment for investment is also reported (by sector and by type)

Disutility Costs

Disutility costs are meant to occur when a consumer decreases useful energy demand (luminosity, mobility, temperature, etc.) as a result of perceiving high relative cost of energy or after voluntary actions

PRIMES monetizes disutility costs according to the income compensating variation principle: what extra revenue should the consumer get in order to re-establish the level of utility (useful energy) at the same level as before the additional energy cost

The inclusion of disutility costs ensures that there is no free-lunch type of results in any policy scenario relative to reference

Extract from a PRIMES model report on costs (from a decarbonisation scenario)

System costs in M€'08 (including auction payments)	2005	2020	2030	2050
Total costs	1226369	2156145	2754296	3791943
Energy related costs[1]	1226369	2155761	2752558	3767502
Industry	216228	312867	338941	418796
Residential	388122	708819	836088	1273878
Tertiary	192763	285593	317777	393957
Transport	429256	848482	1259751	1680872
[1] supply side costs allocated in the demand side equivalent to	*328519*	*509657*	*596455*	*630012*
Costs of reducing industrial processes CO2 emissions	0	0	0	13436
Capital costs	0	0	0	2797
Variable costs	0	0	0	10639
Costs reducing non-CO2 GHGs emissions	0	384	1738	11006
ETS sectors	450120	687465	802862	993368
non-ETS sectors	776249	1468679	1951434	2798575

Auction payments in M€'08	2020	2030	2050
Total	34190	61868	19340
Energy related CO2 emissions	29459	46195	14705
Demand side	3184	8910	5879
Industry	1355	4429	5059
Residential	0	0	0
Tertiary	0	0	0
Transport	1828	4481	819
Supply side	26276	37285	8827
Power generation	23892	30317	3118
District heating	499	1810	1523
Energy branch	1884	5157	4186
Non-energy related CO2 emissions	4477	15427	3815
Non-CO2 GHGs emissions	254	246	819

System costs in M€'08 (revised for auction revenues)	2005	2020	2030	2050
System costs (including auction payments)	1226369	2156145	2754296	3791943
Auction revenues		34190	61868	19340
distributed on the basis of verified EU-ETS emissions in 2005 (88%)		30087	54444	17019
distributed to the least wealthy Member States (10%)		3419	6187	1934
distributed as "Kyoto bonus" (2%)		684	1237	387
System costs (excluding deductible auction revenues)	1226369	2129069	2715069	3782946

System costs as % of GDP	2005	2020	2030	2050
Including auction payments	10.5	14.4	15.5	15.9
Excluding deductible auction revenues	10.5	14.2	15.3	15.9

Investment expenditure (energy related) in M€'08	00-05	15-20	25-30	45-50
Demand side				
Industry	47492	104240	86531	163495
Residential	64581	220233	191177	1191712
Tertiary	28164	129754	128603	417681
Transport (investment expenditure for vehicles, vessels, etc.)	3111747	3468054	4317725	5887997
Supply side				
Power grid investment	105058	186365	272117	211328
Power plants	125767	270376	309301	509156
electricity only	106934	235297	295560	479124
CHP units	18833	35079	13741	30032
Steam boilers	15200	5043	7212	5662

Decomposition of system costs in M€'08	2005	2020	2030	2050
Industry	216228	312867	338941	418796
Capital Cost	54097	65326	77837	84933
Energy Purchases	162131	242415	251556	315874
Electricity	84735	127150	129127	116264
Steam	14860	23808	27612	21694
Fuels	62537	91456	94816	177916
RES Subsidy	0	0	0	0
Direct Efficiency Investment Costs	0	3770	5118	12930
Disutility Costs	0	0	0	0
Auction Payments	0	1355	4429	5059
Households	388122	708819	836088	1273878
Capital Cost	129389	257210	321777	383816
Energy Purchases	258733	379319	388351	352940
Electricity	111960	188918	215369	209794
Steam	4986	8170	8063	5836
Fuels	141787	182231	164919	137310
RES Subsidy	0	10101	13123	16799
Direct Efficiency Investment Costs	0	170	4307	311640
Disutility Costs	0	62018	108530	208683
Auction Payments	0	0	0	0
Tertiary	192763	285593	317777	393957
Capital Cost	34378	47764	52586	80559
Energy Purchases	158385	204011	203181	147629
Electricity	98465	138134	146013	103382
Steam	4475	3716	3542	2285
Fuels	55446	62160	53626	41961
RES Subsidy	0	2217	2639	5045
Direct Efficiency Investment Costs	0	2422	8514	77066
Disutility Costs	0	29179	50858	83658
Auction Payments	0	0	0	0
Transport	429256	848482	1259751	1680872
Additional Capital Cost	0	282807	698848	1123943
Energy Purchases	429256	539080	511475	457136
Electricity	9039	19759	66728	170756
Steam	0	0	0	0
Fuels	420217	519322	444747	286381
RES Subsidy	0	0	0	0
Direct Efficiency Investment Costs	0	0	0	0
Disutility Costs	0	24767	44947	98973
Auction Payments	0	1828	4481	819
Energy System Cost including Auction Payments	1226369	2155761	2752558	3767502
Additional Costs for process CO2 emissions abatement	0	0	0	13436
Additional Costs for non CO2 GHG abatement	0	384	1738	11006
Total System Cost including Auction Payments	1226369	2156145	2754296	3791943
Auction Payments	0	34190	61868	19340
Total System Cost excluding Auction Payments	1226369	2121954	2692428	3772603
as % of GDP	*10.5*	*14.2*	*15.1*	*15.8*

Cumulative system costs (from 2005) in M€'08	2005	2020	2030	2050
Industry	216228	3953300	7286127	14326127
Households	388122	8034003	15856810	35890387
Tertiary	192763	3555635	6607918	13414795
Transport	429256	9082938	19862867	50230766
Additional Costs for process CO2 emissions abatement	0	0	0	140577
Additional Costs for non CO2 GHG abatement	0	2497	11144	94075
Total System Cost including Auction Payments	1226369	24628373	49624866	114096728
Auction Payments	0.0	175784.1	641994.4	1386798.0
Total System Cost excluding Auction Payments	1226369	24452589	48982871	112709930

	2005	2020	2030	2050
Disutility Costs related to change of load factor in transport	0	0	0	442515
Revised Total System Cost excluding Auction Payments	1226369	2121954	2692428	4215118
as % of GDP	*10.5*	*14.2*	*15.1*	*17.7*
Revised Cummulative System Cost excluding Auction Payments	1226369	24452589	48982871	117342948

Extract from PRIMES report on energy prices (from a decarbonisation scenario)

	PRE TAX PRICE (in €/toe)				EXCISE TAX (in €/toe)					VAT (%)				END USER PRICE (in €/toe)			
	2005	2020	2030	2050	2005	2020	2025	2030	2050	2005	2020	2030	2050	2005	2020	2030	2050
Diesel oil																	
Power generation	516.7	753.9	799.8	748.7	124.3	107.7	109.4	83.0	70.4	0.0	0.0	0.0	0.0	641.0	861.6	882.8	819.1
Industry	446.5	632.7	657.4	575.3	131.4	146.1	149.8	150.4	133.0	0.0	0.0	0.0	0.0	577.9	778.9	807.8	708.3
Households	473.2	669.3	698.4	647.0	115.8	125.3	127.8	127.7	272.4	17.8	18.6	18.5	19.1	693.5	942.5	978.8	1095.5
Services	470.4	656.3	680.6	595.9	98.0	100.6	99.9	99.1	98.4	0.0	0.0	0.0	0.0	568.3	756.9	779.7	694.3
Agriculture	489.5	668.6	692.7	601.8	158.1	155.9	155.2	153.6	220.1	0.0	0.0	0.0	0.0	647.6	824.5	846.4	821.8
Transport private	529.4	779.4	795.8	1216.3	485.1	457.2	447.6	453.5	454.7	18.6	19.0	19.0	18.9	1203.1	1471.5	1486.3	1987.5
Transport public	531.5	778.4	795.7	1213.1	458.4	426.5	424.6	423.0	423.6	0.0	0.0	0.0	0.0	989.9	1204.9	1218.7	1636.6
rail	525.2	769.1	785.5	1049.7	474.0	449.7	427.4	321.5	256.7	0.0	0.0	0.0	0.0	999.2	1218.8	1107.0	1306.4
navigation	539.6	800.6	808.4	1217.4	474.5	456.2	453.2	451.2	447.8	0.0	0.0	0.0	0.0	1014.1	1256.8	1259.6	1665.3
Gasoline																	
Transport private	514.4	754.3	772.1	1126.3	701.9	716.0	700.2	702.7	698.1	18.6	19.3	19.3	19.3	1442.4	1753.7	1759.4	2176.2
Transport public	540.9	749.1	766.3	1118.6	410.6	392.0	390.4	388.3	388.9	0.0	0.0	0.0	0.0	951.5	1141.0	1154.6	1507.5
navigation	507.3	704.9	734.2	1161.9	460.1	447.0	447.7	448.4	449.0	0.0	0.0	0.0	0.0	967.4	1151.9	1182.5	1610.9
Fuel oil																	
Power generation	278.2	419.9	423.2	419.8	42.4	14.7	11.5	10.8	11.2	0.0	0.0	0.0	0.0	320.6	434.7	434.0	431.0
Industry	265.2	384.3	402.4	351.7	41.1	58.2	60.9	63.2	62.4	0.0	0.0	0.0	0.0	306.3	442.6	465.5	414.0
LPG																	
Industry	617.3	760.5	787.5	678.4	96.8	102.0	99.7	96.9	98.1	0.0	0.0	0.0	0.0	714.2	862.4	884.4	776.5
Households	631.2	833.2	864.6	738.5	124.1	99.4	100.6	100.5	84.9	18.7	18.8	18.8	18.5	896.8	1107.9	1146.6	975.7
Services	653.5	858.6	880.6	701.5	96.1	95.7	96.0	96.2	93.8	0.0	0.0	0.0	0.0	749.5	954.4	976.8	795.3
Agriculture	655.1	849.6	878.1	755.2	104.8	100.3	102.5	104.0	33.9	0.0	0.0	0.0	0.0	759.9	949.9	982.2	789.1
Transport private	516.8	665.8	684.9	616.4	170.8	157.5	158.4	158.9	156.2	20.4	20.7	20.7	20.3	827.8	993.3	1018.5	929.3
Transport public	555.8	722.6	746.5	630.1	114.7	101.1	101.1	101.1	101.3	0.0	0.0	0.0	0.0	670.4	823.7	847.7	731.4
Byproducts																	
Power generation	31.5	39.5	41.2	39.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.5	39.5	41.2	39.5
Naptha																	
Industry	316.6	464.0	483.0	418.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	316.6	464.0	483.0	418.3
Other liquid fuels																	
Industry	276.4	397.2	412.0	352.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	276.4	397.2	412.0	352.9
Kerosene																	
Transport public	568.7	784.0	852.5	1841.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	568.7	784.0	852.5	1841.1
Natural gas																	
Power generation	215.2	387.3	395.8	339.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	215.2	387.3	395.8	339.5
Industry	230.1	409.3	419.1	1451.2	21.0	21.0	20.8	20.7	20.7	0.0	0.0	0.0	0.0	251.1	430.3	439.8	1471.9
Households	387.5	578.6	592.4	1525.8	62.7	71.6	72.3	72.4	76.6	13.4	14.5	14.3	13.8	510.4	744.3	759.7	1823.9
Services	384.6	570.3	583.4	1527.2	62.5	61.5	60.0	58.3	52.6	0.0	0.0	0.0	0.0	447.0	631.8	641.7	1579.7
Agriculture	403.5	583.5	600.3	1530.0	91.2	126.3	125.9	123.9	121.0	0.0	0.0	0.0	0.0	494.7	709.8	724.2	1651.0
Transport private	410.9	577.8	591.4	1526.0	148.9	129.4	128.8	129.0	132.6	11.4	11.2	11.1	11.0	623.7	786.1	800.0	1841.6
Transport public	409.7	605.1	699.8	1590.9	57.9	57.6	51.3	43.9	36.0	0.0	0.0	0.0	0.0	467.6	662.7	743.7	1626.9
Solids																	
Hard coal - PG	93.2	159.4	162.9	147.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	93.2	159.4	162.9	147.6
lignite - PG	83.2	92.9	89.3	115.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	83.2	92.9	89.3	115.9
Iron and steel	151.6	220.1	237.4	223.1	1.2	4.7	4.8	5.0	6.6	0.0	0.0	0.0	0.0	152.8	224.7	242.3	229.7
Other industries	100.2	162.8	179.7	154.0	6.8	8.0	8.5	10.3	16.5	0.0	0.0	0.0	0.0	107.0	170.8	190.0	170.5
Households	254.4	317.4	344.3	372.2	2.3	12.2	12.0	11.8	12.0	18.5	19.2	19.0	19.0	304.0	393.0	423.6	457.2
Tertiary	200.3	280.1	313.9	302.8	7.0	17.5	16.4	16.7	14.2	0.0	0.0	0.0	0.0	207.2	297.5	330.6	317.0
Biomass																	
Power generation	274.7	406.4	466.1	494.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	274.7	406.4	466.1	494.6
Households	731.2	1052.7	1207.2	1349.7	0.0	0.0	0.0	0.0	0.0	18.7	19.4	19.4	19.5	868.0	1257.2	1441.8	1612.7
Tertiary	637.2	879.2	1051.2	1123.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	637.2	879.2	1051.2	1123.6
Waste																	
Power generation	119.6	113.0	120.3	147.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	119.6	113.0	120.3	147.3
Ethanol																	
Transport private	2127.6	1788.6	1560.2	1115.6	0.0	0.0	0.0	0.0	0.0	16.3	17.3	17.4	17.3	2474.7	2097.7	1832.2	1308.3
Transport public	2127.6	1788.6	1560.2	1115.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2127.6	1788.6	1560.2	1115.6
H2F																	
Transport private	4862.4	4356.1	3979.3	3193.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4862.4	4356.1	3979.3	3193.3
Transport public	4862.4	4356.1	3979.3	3193.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4862.4	4356.1	3979.3	3193.3
Electricity																	
Average price	1056.3	1422.6	1472.2	1421.4	98.1	144.0	144.2	144.0	147.8	5.0	6.0	7.0	8.8	1212.2	1661.3	1729.2	1708.0
Industry	751.0	1023.4	978.9	925.9	71.2	118.2	118.5	118.7	126.3	0.0	0.0	0.0	0.0	822.1	1141.6	1097.6	1052.2
Households	1233.3	1738.0	1823.0	1711.3	116.1	161.8	161.0	160.8	157.0	14.9	15.7	15.8	15.6	1550.0	2198.9	2296.4	2159.4
Services	1321.1	1658.8	1719.4	1566.8	125.2	171.6	170.2	169.3	170.9	0.0	0.0	0.0	0.0	1446.2	1830.4	1888.8	1737.7
Agriculture	978.9	1433.8	1532.4	1404.2	186.1	230.3	231.2	230.9	209.8	0.0	0.0	0.0	0.0	1165.0	1664.0	1763.3	1614.0
Transport private	1413.9	1790.7	1874.6	1734.7	69.3	176.4	171.7	166.9	163.8	14.7	15.5	14.9	14.8	1701.2	2271.2	2345.9	2179.8
Transport public	1355.6	1314.4	1241.4	1075.7	125.6	198.2	191.7	178.7	165.5	0.0	0.0	0.0	0.0	1481.2	1512.6	1420.1	1241.3
Steam																	
Average price	202.8	278.5	300.2	270.0	0.0	0.0	0.0	0.0	0.0	3.5	4.0	3.6	3.4	210.0	289.7	311.0	279.1
Industry	177.6	255.8	280.0	244.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	177.6	255.8	280.0	244.2
Households	190.5	336.9	358.7	393.2	0.0	0.0	0.0	0.0	0.0	20.0	20.3	20.3	20.0	228.7	405.2	431.6	471.8
Services	432.9	372.0	401.2	405.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	432.9	372.0	401.2	405.9
Agriculture	423.2	367.8	409.5	414.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	423.2	367.8	409.5	414.2

Extract from PRIMES report on tax revenues

TAX REVENUES (in M€'05)	2005	2020	2030	2050
Fuel excise tax				
Residential	22169.8	26214.3	25420.0	18031.4
Tertiary	17073.1	19710.8	18557.8	11658.0
Industry	12080.0	18193.2	18974.5	16698.8
Transport	167027.2	147799.4	114872.0	41034.4
Power generation	1458.0	162.1	39.0	2.2
Energy Branch	2299.0	2948.8	3094.4	5479.3
Total	222107.2	215028.5	180957.7	92904.0
Fuel VAT tax				
Residential	32765.8	50244.0	51202.2	45784.1
Tertiary	0.0	0.0	0.0	0.0
Industry	0.0	0.0	0.0	0.0
Transport	39195.1	40497.4	32012.5	21416.2
Power generation	0.0	0.0	0.0	0.0
Energy Branch	0.0	0.0	0.0	0.0
Total	71960.9	90741.5	83214.8	67200.3
Investment VAT tax				
Residential	11481.9	21585.6	28958.9	103274.0
Tertiary	0.0	0.0	0.0	0.0
Industry	0.0	0.0	0.0	0.0
Transport	59037.5	67308.4	90771.7	132111.7
Power generation	0.0	0.0	0.0	0.0
Energy Branch	0.0	0.0	0.0	0.0
Total	70519.4	88894.1	119730.7	235385.6
Auction payments				
Residential	0.0	0.0	0.0	0.0
Tertiary	0.0	0.0	0.0	0.0
Industry	0.0	1283.0	4192.7	4789.1
Transport	0.0	1730.5	4241.3	775.6
Power generation	0.0	23089.1	30411.9	4393.0
Energy Branch	0.0	1783.5	4881.9	3962.1
Total	0.0	27886.1	43727.7	13919.8
Total tax revenues				
Residential	66417.5	98044.0	105581.2	167089.4
Tertiary	17073.1	19710.8	18557.8	11658.0
Industry	12080.0	19476.2	23167.2	21487.8
Transport	265259.8	257335.8	241897.5	195337.8
Power generation	1458.0	23251.1	30450.9	4395.2
Energy Branch	2299.0	4732.2	7976.3	9441.5
Total	364587.4	422550.1	427630.8	409409.7

NUCLEAR

Methodology for modelling nuclear power

Investment in nuclear power is treated as an economic decision in the PRIMES model. Nuclear deployment depends on electricity demand, load profiles, economic features of competing technologies and carbon prices

Nuclear decisions, taken together with all other power plant decisions, fit within least cost capacity expansion to a long-term horizon (under perfect foresight) and within least cost unit commitment and is influenced by policy drivers for example by carbon prices

Investment decision on nuclear distinguish between:

- Extension of lifetime of an existing plant (involves investment cost lower than for a new plant)
- Building a new nuclear plant on an existing site, if such possibility exist (investment cost is lower than for a new site)
- Building a new nuclear plant on a new site (Greenfield development)

The unit cost of nuclear plant investment differs by country depending on economies of scale experienced in nuclear industry: it ranges from first-of-the-kind investment costs for countries that may invest in nuclear for the first time to investment cost levels corresponding to high economies of scale.

The unit cost of investment depends on the nuclear technology: second, third and fourth generation technologies are represented in the model database

Technology progress over time is represented by nuclear technology

The unit cost of investment take into account costs for future decommissioning (15% provision)

Variable and fuel costs of nuclear power take into account waste recycling and disposal costs

The lifetime of old nuclear plants is set as specified in their license and is extendable upon investment. New nuclear plants are supposed to have lifetime of 40 years, extendable after investment.

Representation of Policy Constraints

The model can represent the following possible policy constraints on nuclear investment:

- No nuclear in the future
- Phase-out of nuclear
- Fixed decommissioning dates for specific plants
- Permission of extension of lifetime (as economic decision or as a decided policy)
- Permission of investment only on existing sites
- Upper bounds on nuclear expansion
- No constraints on nuclear expansion

Cost-potential curve for Nuclear

To reflect growing cost of developing new nuclear sites, the model includes site specific cost elements, which differ by country and evolve over time (or set as a scenario specific assumption)

These costs are based on cost-potential curves, which apply only for Greenfield investment and are non linear with increasing slope

Policies aiming at higher nuclear are represented by shifting the nuclear cost-potential curve to the right (lower cost for equal potential)

Model database for Nuclear

The PRIMES model database includes a detailed inventory of nuclear power plants that are in operation in Europe and their characteristics

The database also keeps track of new nuclear projects underway on which exogenous nuclear investment data are based

Regarding new nuclear plants, In PRIMES, nuclear second refers to generation II reactors until 2015 and will include after 2015 the commercially most advanced reactors (e.g. EPR, AP, VVER 1200) currently summarized under generation III and III+; nuclear third refers to the remaining set of generation III+ reactors and nuclear fourth refers to generation IV reactors.

Technical-economic assumptions

Overnight Capital Costs (€'05/kW)	2010	2020	2030	2050
Nuclear second	3056	3056	3056	3056
Nuclear third	4057	3690	3573	3350
Nuclear Fourth	5135	4592	4292	3750
Steam Turbine Coal Conventional	1280	1279	1274	1270
Steam Turbine Coal Supercritical	2066	1898	1596	1428
Pulverised Coal Suprcritical CCS post combustion	3012	2721	2199	1908

Thermal Efficiency for Net Electricity Generation	2010	2020	2030	2050
Nuclear second	34%	34%	36%	37%
Nuclear third	34%	34%	36%	41%
Nuclear Fourth	34%	34%	36%	46%
Steam Turbine Coal Conventional	37%	38%	39%	41%
Steam Turbine Coal Supercritical	40%	42%	46%	49%
Pulverised Coal Suprcritical CCS post combustion	30%	32%	36%	39%

Fixed Operation and Maintenance Costs (€'05/kW)	2010	2020	2030	2050
Nuclear second	62.1	61.3	60.4	58.8
Nuclear third	38.8	37.9	37.1	35.6
Nuclear Fourth	33.6	32.7	31.9	30.4
Steam Turbine Coal Conventional	25.6	25.5	25.5	25.4
Steam Turbine Coal Supercritical	40.5	37.5	32.3	28.0
Pulverised Coal Suprcritical CCS post combustion	42.9	40.4	37.7	32.2

Variable Operation non Fuel Costs (€'05/MWh)	2010	2020	2030	2050
Nuclear second	6.1	7.3	8.7	12.6
Nuclear third	3.5	3.7	3.9	4.5
Nuclear Fourth	2.8	2.8	2.8	2.8
Steam Turbine Coal Conventional	1.2	1.2	1.1	1.0
Steam Turbine Coal Supercritical	2.5	2.4	2.3	2.0
Pulverised Coal Suprcritical CCS post combustion	3.0	2.9	2.8	2.5

Self consumption Rate	2010	2020	2030	2050
Nuclear second	5.3%	5.3%	5.3%	5.3%
Nuclear third	5.3%	5.3%	5.3%	5.3%
Nuclear Fourth	5.3%	5.3%	5.3%	5.3%
Steam Turbine Coal Conventional	8.7%	8.7%	8.7%	8.7%
Steam Turbine Coal Supercritical	7.3%	7.3%	7.3%	7.3%
Pulverised Coal Suprcritical CCS post combustion	31.8%	30.3%	27.5%	25.9%

30 years period assumed for calculating generation costs
WACC 9% (real) and 7500 operating hours per year

Illustrative calculations of generation costs

Capital and Fixed Operation and Maintenance Costs (€'05/MWh)

	2010	2020	2030	2050
Nuclear second	48.3	48.2	49.8	54.2
Nuclear third	62.9	57.5	49.7	46.7
Nuclear Fourth	110.9	99.5	75.0	50.7
Steam Turbine Coal Conventional	22.2	22.2	22.1	22.1
Steam Turbine Coal Supercritical	37.1	31.7	26.8	23.8
Pulverised Coal Suprcritical CCS post combustion	63.4	51.9	38.9	33.2

Variable Operation and Fuel Costs incl CCS costs if applicable (€'05/MWh)

	2010	2020	2030	2050
Nuclear second	14.7	15.7	16.8	20.4
Nuclear third	12.1	12.1	12.0	11.5
Nuclear Fourth	11.4	11.2	10.9	9.1
Steam Turbine Coal Conventional	29.5	38.7	42.6	44.8
Steam Turbine Coal Supercritical	28.3	35.9	37.8	39.0
Pulverised Coal Suprcritical CCS post combustion	48.2	57.1	56.6	56.4

Total Cost except CO2 allowances cost (€'05/MWh)

	2010	2020	2030	2050
Nuclear second	62.9	63.9	66.7	74.5
Nuclear third	75.0	69.6	61.7	58.1
Nuclear Fourth	122.2	110.7	85.8	59.8
Steam Turbine Coal Conventional	51.8	60.9	64.7	66.9
Steam Turbine Coal Supercritical	65.3	67.6	64.5	62.8
Pulverised Coal Suprcritical CCS post combustion	111.6	109.0	95.5	89.6

Total Cost plus 25€/t CO2 allowances cost (€'05/MWh)

	2010	2020	2030	2050
Nuclear second	62.9	63.9	66.7	74.5
Nuclear third	75.0	69.6	61.7	58.1
Nuclear Fourth	122.2	110.7	85.8	59.8
Steam Turbine Coal Conventional	74.8	83.4	86.2	87.5
Steam Turbine Coal Supercritical	86.4	87.7	82.9	80.2
Pulverised Coal Suprcritical CCS post combustion	115.1	112.4	98.4	92.3

Total Cost plus 50€/t CO2 allowances cost (€'05/MWh)

	2010	2020	2030	2050
Nuclear second	62.9	63.9	66.7	74.5
Nuclear third	75.0	69.6	61.7	58.1
Nuclear Fourth	122.2	110.7	85.8	59.8
Steam Turbine Coal Conventional	97.9	105.9	107.7	108.1
Steam Turbine Coal Supercritical	107.5	107.9	101.3	97.7
Pulverised Coal Suprcritical CCS post combustion	118.7	115.7	101.4	95.0

Total Cost plus 100€/t CO2 allowances cost (€'05/MWh)

	2010	2020	2030	2050
Nuclear second	62.9	63.9	66.7	74.5
Nuclear third	75.0	69.6	61.7	58.1
Nuclear Fourth	122.2	110.7	85.8	59.8
Steam Turbine Coal Conventional	144.1	150.9	150.6	149.4
Steam Turbine Coal Supercritical	149.6	148.1	138.1	132.5
Pulverised Coal Suprcritical CCS post combustion	125.7	122.3	107.2	100.3

RES

MODEL COVERAGE FOR RES

RES in power generation

1. Wind Power Low Resource (avail. 10-15%)
2. Wind Power Medium Resource (avail. 16-20%)
3. Wind Power High Resource (avail. 21-28%)
4. Wind Power Very High Resource (avail. 29-37%)
5. Wind Offshore Power Low Resource (avail. 18-22%)
6. Wind Offshore Power Medium Resource (avail. 23-35%)
7. Wind Offshore Power High Resource (avail. 36-40%)
8. Wind Offshore Power Very High Resource (avail. 41-45%)
9. Solar PV Low Resource (avail. 9-12%)
10. Solar PV Medium Resource (avail. 13-16%)
11. Solar PV High Resource (avail. 17-20%)
12. Solar PV Very High Resource (avail. 21-25%)
13. Solar Thermal (avail. depending on country)
14. Solar PV very small scale (avail. depending on country)
15. Wind very small scale(avail. depending on country)
16. Tidal and waves (avail. Depending on country)
17. Lakes (energy constraint – water, no constraint on nominal power)
18. Run of River (avail. Depending on country)
19. Geothermal Medium (diff. Potential and costs)
20. Geothermal High (diff. Potential and costs)
21. Geothermal Small (diff. Potential and costs)
22. Waste Solid
23. Landfill Gas
24. Biogas
25. Biomass solid
26. Bio-liquid
27. Hydro-pumping (endogenous depending on potential)

Note: Distinction by level of resource intensity is based on yearly resource availability at full nominal power, thus availability of say 25% means that 1 MW produces 8760*25%= 2190 MWh and power available is 1*25%=0.25MW on a yearly basis (deterministic equivalent)

RES in direct final demand energy uses

1. Solar thermal (collectors for water heating)
2. Passive solar (not accounted for but implicitly included in energy saving potential)
3. Low enthalpy geothermal energy for heat uses
4. Heat pumps (distinguishing hydro, air and geo resources, RES accounting according to Eurostat rules)
5. Direct biomass combustion
   - Small scale solid (wood, wood waste, pellets)
   - Large scale solid (industrial uses)
   - Waste (industrial waste)
   - Biogas
6. Biogas blended in distributed gas
7. Biofuels in transportation
   - Aggregate model: bio-diesel blend, bio-gasoline blend, ethanol, bio-kerosene blend, bio-heavy blend)
   - Additional biofuels in detailed model: B100, DME, biogas

Data for RES

Technical – economic characteristics (investment cost, O&M cost, variable cost, availability rates) which vary over time and country

Non linear cost-potential curves for renewable resources (unit cost depend on quantity and time) reflecting difficulty of getting access to resource, availability of sites, acceptance, grid connection difficulties, performance and for biomass land and waste energy resource availability

Data on Potentials from: ECN (Admire-Rebus database), DLR (database), Green-X, RES-2020, Observer, national sources, various studies and a special data collection for biomass resources

How PRIMES projects investment in RES

Investment in RES is projected on economic grounds as for any other technology. The relative competitiveness of RES depend on technology progress (change of technical-economic characteristics over time), policies supporting RES directly or indirectly.

The unit cost of RES energy production is composed of the annuity payment for capital (depending on WACC and risk premium), the fixed O&M cost and the variable cost, where capital and fixed cost are divided by the number of yearly hours of full capacity production, which depends on the resource availability rate

The capital part of the cost of RES investment as perceived for decision making (not for actual payment) is increased by a rate reflecting the non linearly increasing cost-potential curve, which may change by scenario according to assumptions about RES facilitation policies

For the biomass resources and commodities the model determines prices which span the whole chain of activities and processes for producing and transforming feedstock, reflect the possibly increasing cost of land use (for crops) and of collecting wastes and price-setting components which reflect competition (for example pricing relative to substitute fuels)

On costs and prices excise taxes and VAT are added as appropriate

Direct RES subsidies reduce unit cost of capital or commodity prices (for biomass) – see box to the right

Decision making may be influenced by a ***RES-value*** (e.g. EUR/MWh from RES) which is a shadow marginal benefit reflecting RES policies such RES targets, obligations, green certificates, etc. – see box to the right

In power generation RES investment decisions are treated simultaneously with system operation and reserve constraints, which indirectly influence RES competitiveness

Investing on RES on an existing site (after RES plant decommissioning) is considered to be much cheaper than investing on a new site

Direct RES Subsidies

Direct RES subsidies are explicitly accounted for in end-user costs and prices and may vary by scenario.

The model considers subsidies as discounts on capital costs. For this purpose the various forms of RES subsidies are transformed into equivalent capital cost discounts.

Feed-in tariffs are transformed into equivalent capital cost discount by considering the difference between the level of the feed-in tariff and the wholesale electricity price (as determined by the model). In case the difference is negative, then still a small discount on capital cost is retained as a subsidy because a feed-in tariff is anywhere a guarantee for multi-year earnings.

The model determines endogenous recovery of RES subsidies through consumer prices

Indirect RES supporting policies, as modelled

RES Obligation: in power generation a certain percentage of electricity generated must come from RES (modelled as a constraint)

RES blending obligation: fixed blending rate of biofuels for transportation liquid fuels or for distributed gas

Green certificates, Guarantees of Origin or generally RES objectives: a RES shadow value is introduced (in power generation and/or in other sectors) providing a price signal to decision makers for getting benefits from RES; the level of the RES value changes iteratively until the desired volume of green certificate or of the RES target are obtained; when iterating by keeping the same level of RES value across sectors in a country or across countries, the model user simulates policy cases allowing for RES certificate trading or for cost-effective RES exchanges between countries

Higher RES values mirror more enabling policies for RES penetration

RES facilitation policies: meant to include actions, scenario-specific, which increase RES potential and make cheaper the access to potential (reflected onto the parameters of the cost-potential curves)

Note: RES as % of gross final energy is handled by PRIMES as a target, either by sector, or country or EU-wide

RES and power system economics

The stochastic or variable RES (wind, solar, small hydro, tidal-wave) are represented as a **deterministic** equivalent power capacity: nominal capacity is reduced according to the yearly resource availability rate and is assumed to operate uniformly in all yearly load segments

The hydro resources are considered to be **dispatchable** but constrained by yearly available water flows: the model shows that they are used at peak hours until water constraint is met

The stochastic or variable RES get a "**capacity credit**" which is much lower than nominal capacity. It varies by country and scenario depending on total deployment of variable RES: capacity credit decreases with RES quantity deployed and differs by country depending on assumptions about dispersion of RES sites

Capacity credits enter the **reliability or reserve power** constraints: in case of large development of variable RES, the model determines investment in low capital intensive thermal power plants (back-up) in order to meet reliability and reserve power constraints. Thus costs increase and the competitiveness of variable RES decrease.

Large-scale storage is endogenous in the model (hydro-based **pumped storage**): through pumping peak load is reduced and base load increases, with additional cost. Pump storage helps variable RES penetration as it relaxes reserve constraints.

The model represents possibility for producing **hydrogen** from electrolysis and blending hydrogen with natural gas (up to a maximum share of 30-40%). In case of high RES development, hydrogen production, assumed to take place at off peak hours, helps smoothing out the load curve, relaxing reserve power constraints and hence allowing for more variable RES capacities

Regional power market operation under interconnection constraints also help development of RES capacities and is simulated by the model (common balancing)

Solar PV, small wind and small scale CHP at consumer premises

The model represents possible development of direct electricity generation by consumers (households, buildings, industry) through solar PV, very small scale wind, fuel cells and thermal CHP (with multiple fuels)

Capital costs depend on scale, thus individual applications are more costly; however technical progress which reduces the gap between plants of different sizes (scenario-specific assumption) facilitates decentralisation of generation

Individual generation delivering excess generation to the grid is modelled by taking account of avoided medium voltage or low voltage distribution losses; hence distribution costs become lower with decentralisation

Grid parity is meant to occur when the unit cost of individual generation becomes equal to the price of delivered electricity which includes costs of centralised generation and costs of distribution.

So if data assumptions suggest that grid parity is achieved, the model can simulate wide spread use of decentralised generation, which nevertheless depend on WACC and risk premium that is generally higher than in centralised generation

RES and Grid costs

Cost of direct (shallow) connection of RES plants (wind, solar) with the grid are included in the unit investment cost of RES technologies; this is also the case for offshore wind (assumed to develop at reasonable distances from the coast)

Large-scale development of RES (wind, solar) generally imply higher investment requirements in the grid for extension to areas with large potential or for increasing operational reliability

These additional investment are approximated in the model through a non linear equation which increases grid investment as function of the share of variable RES in power generation

Transportation of large RES sources from areas outside the EU (and from long distance offshore) is not included in the standard version of the model (see slide on model extension)

Extract from PRIMES data assumption for recent scenarios

	Overnight Capital Costs (€'08/kW)				Generation Costs (€'08/MWh)				Change
	2005	2020	2030	2050	2005	2020	2030	2050	from 2005
Wind Power Medium	1087	1084	1065	1054	118	118	116	114	-3%
Wind Power High	1193	1190	1169	1157	86	86	85	84	-3%
Wind Offshore Power High	2035	2023	1933	1832	95	95	91	86	-10%
Wind Offshore Power Very High	2618	2602	2487	2356	112	112	107	101	-10%
Wind small scale	2035	2030	1745	1357	367	260	224	174	-53%
Solar PV Low	5068	2850	1770	1454	705	397	246	202	-71%
Solar PV Medium	4675	2629	1632	1341	511	287	178	147	-71%
Solar PV High	4379	2463	1529	1256	383	215	134	110	-71%
Solar Thermal	5671	4367	2904	1707	438	337	224	132	-70%
Solar PV small scale	5322	2993	1858	1527	941	366	228	187	-80%
Tidal and waves	3207	3145	2726	2405	297	182	158	140	-53%

	Overnight Capital Costs (€'05/kW)				Generation Costs (€'08/MWh)				Change
	2005	2020	2030	2050	2005	2020	2030	2050	from 2005
Steam Turbine Biomass Industrial	2296	2126	1868	1724	139	168	168	167	20%
IG Biomass CC Industrial	2336	2060	1639	1405	141	161	148	136	-4%
Steam Turbine Biomass Solid Conventional	2187	2025	1779	1642	130	159	161	160	23%
Peak Device Biogas Conventional	569	568	557	552	69	73	71	73	5%
High Temperature Solid Biomass Power Plant	2336	2060	1639	1405	165	158	148	137	-17%
Peak Device Biogas Advanced	712	710	696	690	112	99	95	97	-14%
Small Device Biomass Gas	1067	1065	1044	1035	127	109	104	100	-21%
MBW incinerator CHP	2915	2060	1639	1405	157	93	80	70	-56%
Internal Combustion Engine Biogas	1440	1436	1408	1397	84	86	85	86	2%

The Biomass Supply model projects costs and prices using demand for bio-energy commodities from power sector, final demand and transportation models

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*

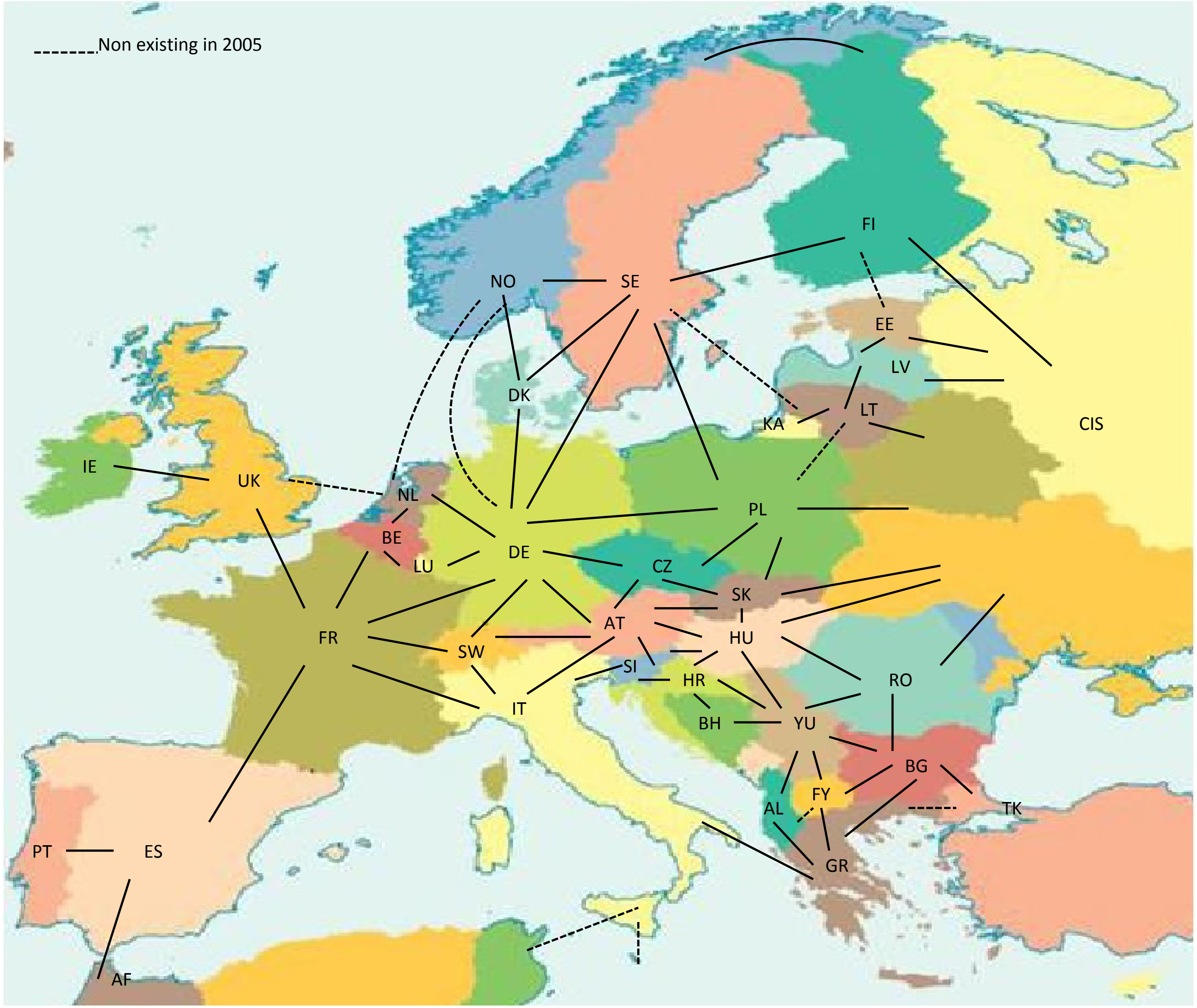
Gaseous
- *Bio-gas*
- *Synthetic Gas*
- *Bio-hydrogen*

Technical Potential of RES Power (PRIMES database)

	2020	2030	2040	2050
Wind Power Low	49	70	76	81
Wind Power Medium	58	73	77	78
Wind Power High	61	82	88	92
Wind Power Very High	74	105	112	117
Wind small scale	4	17	86	96
Wind onshore (GW)	247	348	439	464
Wind Offshore Power Low	5	10	12	13
Wind Offshore Power Medium	16	26	28	31
Wind Offshore Power High	80	124	129	136
Wind Offshore Power Very High	6	9	10	11
Wind offshore (GW)	108	169	180	193
Hydro with reservoir	12	14	16	18
Run of River	11	16	22	26
Hydro (GW)	23	29	37	44
Solar PV Low	50	99	130	161
Solar PV Medium	14	40	57	72
Solar PV High	11	38	52	65
Solar PV Very High	6	21	46	47
Solar PV small scale	51	144	234	235
Solar PV (GW)	131	342	519	581
Solar Thermal	10	25	31	38
Geothermal High	2	5	7	9
Tidal and waves	6	12	23	34
WasteSolid [TWh]	194	220	231	237
WasteGas [TWh]	62	74	79	81
Biogas [TWh]	79	118	137	147
Biomasssld [TWh]	618	838	935	987
Bioliquid [TWh]	27	45	52	56
	979	1294	1433	1508
Bio-Power (GW)	65	86	96	101
Total RES Potential	592	1018	1333	1463
Total Net Capacity (GW-Ref)	1012	1144	1295	1428
	59%	89%	103%	102%

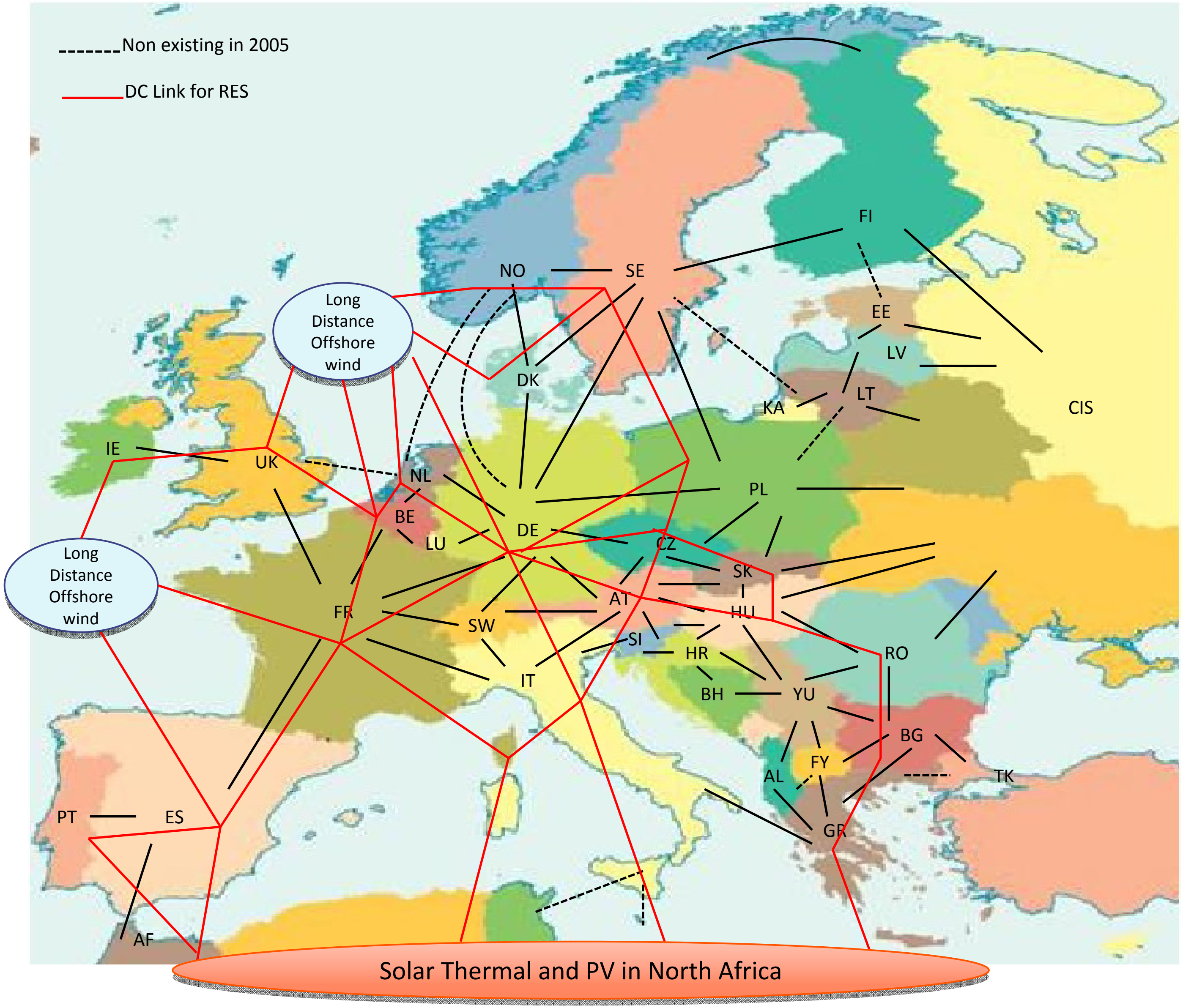
MODELLING OF HIGH RES POWER SCENARIO

Current modelling of AC (and some DC) interconnectors (reinforcements and new links in existing routes, not shown)



E³M - Lab

Construction of a DC highway network is assumed, with converters linked with current AC network



Solar from North Africa:

Capacity: 100 GW

Avail. Rate: 80%

Production: 700 TWh

Inv. Cost: 350 bill. EUR

Long distance offshore wind:

Capacity: 80 GW

Avail. Rate: 45%

Production: 320 TWh

Inv. Cost: 180 bill. EUR

DC links North Africa-Europe:

Cost: 45 bill. EUR

DC links for Offshore wind:

Cost: 15 bill. EUR

Additional DC links and converters within Europe:

Length: 40,000 km

Cost: 80 bill. EUR

Total grid cost:

140 bill. EUR

Total project cost:

670 bill. EUR

Avg. Supply Cost:

75-80 EUR/MWh not including back-up costs

FOSSIL FUELS, CCS AND ROLE OF GAS

Economic approach for CCS

The CCS is one of the possible means for reducing CO2 emissions from the combustion of fossil fuels. When an emission reduction target is set, the CCS (if considered available at a certain time period within scenario assumptions) competes with other means, such as carbon free power generation (renewable energies, nuclear), the fuel switching and the reduction of energy consumption.

The power plants with carbon capture will be more expensive in terms of capital investment and operation costs than similar plants without carbon capture. Moreover, their net thermal efficiency will be lower, since carbon capture needs energy to operate.

The costs of transporting and storing CO2 are modelled through non linear cost curves by country, bounded by storage potential (set exogenously for each scenario per time period). Costs increases with quantity stored.

As CCS technology is assumed to evolve over time (as technology becomes commercially mature), as carbon prices also change over time and as storage costs depend on cumulative quantities stored, investment in CCS involves arbitraging over time: perfect foresight in the model allows for simulating such decisions.

The CCS investment decisions are integrated within the PRIMES sub-model on power and stem generation. The CCS technology for power plants is represented in two ways:

- as typical new power plants enabled with CCS considered as candidate for investment
- as auxiliary technologies candidate for retrofitting existing power plants or plants built (endogenously by the model) without initially having the CCS.

This flexible representation allows assessment of various policy options, as for example the “capture-ready” options or optionally mandatory CCS measures.

Example of technical-economic assumptions for CCS power plants

	Difference from non CCS plant								Net CO2 avoided
	Capital Cost (€/kW)		Net Thermal Efficiency (rate)		Fixed Cost (€/kW)		Non fuel Variable Cost (€/MWh)		
Constant Euros of 2005	2020	2030	2020	2030	2020	2030	2020	2030	
Pulverised Coal Supercritical CCS post combustion	894	833	-0.12	-0.12	7.0	6.9	0.5	0.5	83.5%
Pulverised Lignite Supercritical CCS post combustion	882	819	-0.11	-0.11	7.0	6.8	0.5	0.5	83.5%
Fuel Oil Supercritical CCS post combustion	894	833	-0.13	-0.13	7.0	6.9	0.5	0.5	83.3%
Integratedl Gasification Fuel Oil CCS pre combustion	559	558	-0.07	-0.07	14.9	14.4	2.0	1.9	89.4%
Pulverised Coal Supercritical CCS oxyfuel	685	655	-0.09	-0.09	7.6	7.5	2.0	1.9	99.4%
Pulverised Lignite Supercritical CCS oxyfuel	666	635	-0.08	-0.08	7.7	7.5	2.0	2.0	99.4%
Integrated Gasification Coal CCS post combustion	797	776	-0.07	-0.07	14.9	14.4	2.0	1.9	85.7%
Integrated Gasification Coal CCS pre combustion	467	431	-0.08	-0.08	9.7	9.4	0.5	0.5	86.5%
Integrated Gasification Coal CCS oxyfuel	434	425	-0.06	-0.06	9.3	9.0	1.4	1.4	99.4%
Integrated Gasification Lignite CCS post combustion	520	505	-0.05	-0.05	7.1	6.8	1.1	1.0	86.3%
Integrated Gasification Lignite CCS pre combustion	457	417	-0.07	-0.07	9.6	9.2	0.5	0.5	86.5%
Integrated Gasification Lignite CCS oxyfuel	434	425	-0.06	-0.06	9.3	9.0	1.4	1.4	99.5%
Gas combined cycle CCS post combustion	520	505	-0.07	-0.07	7.1	6.8	1.1	1.0	86.0%
Gas combined cycle CCS pre combustion	401	388	-0.09	-0.08	4.2	4.0	0.5	0.5	86.7%
Gas combined cycle CCS oxyfuel	434	425	-0.09	-0.09	9.3	9.0	1.4	1.4	99.4%

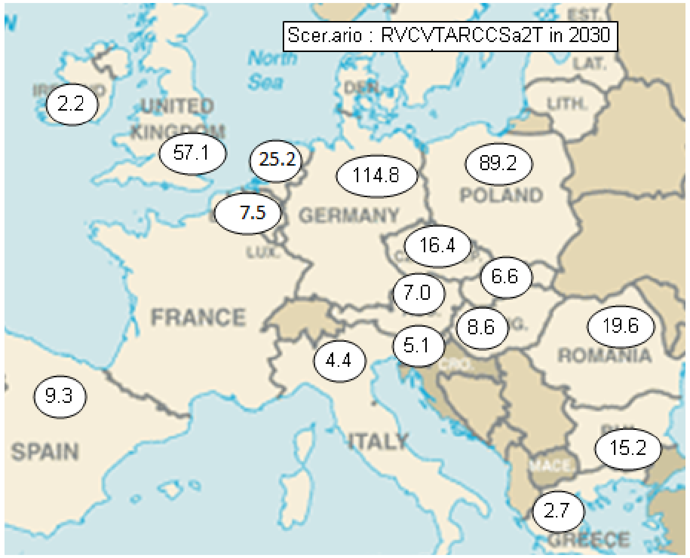
Source: PRIMES database

Data sources for CCS

- VGB, TechPol (database for DG Research) and other sources for technical-economic data
- TNO and JRC for storage potential and cost curves
- Recent study by JRC on storage costs shows similar figures as PRIMES input data

MODELLING CCS IN PRIMES

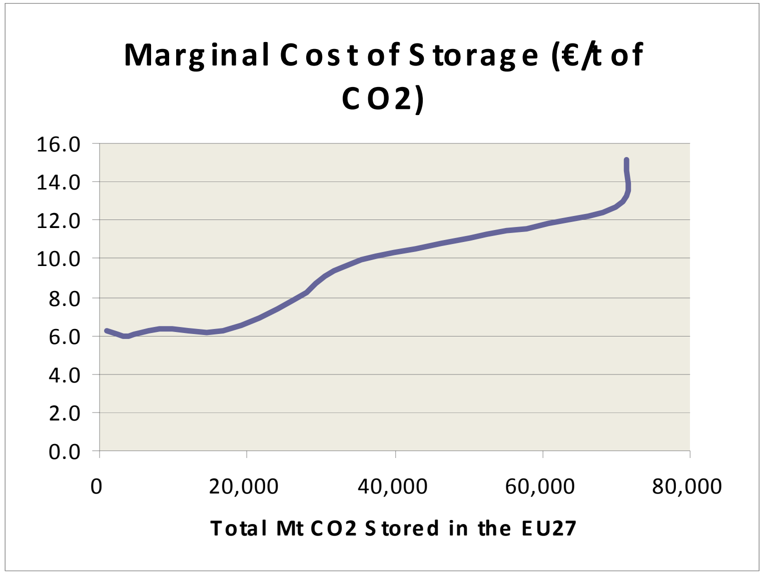
Illustration of PRIMES scenario results developed in 2008 for the impact assessment of a draft CCS directive



Example of alternative policy scenarios on CCS that can be studied with PRIMES

a. The limited mandatory CCS policy: all new coal, lignite and residual fuel oil power plants commissioned after 2020 incorporate the CCS capability.
b. The complete mandatory CCS policy: mandatory implementation of CCS applies also for new gas-firing plants.
c. The capture ready policy: enforces the obligatory capture-ready design of all fossil-fuelled power plants to be built between 2015 and 2020 and the mandatory retrofitting of these plants to incorporate CCS after 2020.

Summary of cost-supply curve for CO2 storage in the EU



Methodology for pricing CO2 storage

It is assumed that CO2 transportation and storage are offered by regulated monopolies operating by country (CO2 exchanges between countries are mot modelled in the current model version)

Both activities operate under strong economies of scale, bear very high fixed costs (and small variable costs) and face high uncertainty about future use of infrastructure

Prices for transportation and storage services are determined on the basis of levelizing total development costs and investments over time on an anticipated cumulative demand for the service

Public acceptance issues and other uncertainties are expressed through parameters shifting the cost-supply curve to the left and up (making more expensive the service and lowering potential)

Scenarios involving delays in CCS development may be simulated by introducing particularly high storage and transport costs for a limited period of time

The pilot CCS plants envisaged for 2020 are assumed to have reserved specific sited for CO2 storage at rather short distances with small marginal costs for storage

Fossil fuels in PRIMES

Liquid fuels: Crude Oil, Feedstock, Refinery Gas, Gasoline (pure or blended with biogasoline), Diesel (pure or blended with biodiesel), Naphtha, LPG, Kerosene (pure or blended with biodiesel), Fuel Oil, other liquids

Solid fuels: Coal, Lignite, Briquettes, Coke, Other solids

Gaseous fuels: Natural Gas, Blast Furnace Gas, Coke Oven Gas, Gas Works

Processing Systems in the Energy Branch (losses, self consumption, final energy consumption)

- Extraction
- Briquetting
- Production of coke and coke oven gas
- Production of Blast furnace gas
- Refineries (with auto-production of electricity and steam)

Refinery sub-model

The refinery sub-model follows a simple aggregate representation of processes and blending:

Atmospheric distillation, vacuum distillation, hydro-cracking, catalytic cracking, reforming, visbreaking, coking, heavy gasification and blending

The refinery model performs cost minimisation solving linear programming, with endogenous capacity expansion, imports-exports within the EU and with rest of the world and demand and auto-production of electricity and steam, as well as emissions

The pricing of refinery output products is based on average costs, inclusive of fixed and capital costs, with allocation of fixed costs to products following simple rules calibrated to past practices

In the core model of PRIMES, the refinery sub-model is replaced by simple equations which mainly aim at determining endogenously auto-production of electricity and steam from CHP, turbines and boilers, which are integrated in the power/steam model.

Use of domestic fuels and take or pay obligations

The power model can handle preference or obligations about using domestically produced fossil fuels (e.g. lignite) by assigning low cost values for some of the first steps of the cost-supply curves for such fuels

In the same way, the model can handle take-or-pay obligations, for example for imported natural gas

The low cost values would reflect a virtual “subsidy” on fuel purchase costs, which however is not accounted for in transactions but only influence economics of fuel mix

Costs used for price determination and costs reported by the model account for actual payments (fuel purchase costs, or fuel production costs)

Low prices are attributed to by-products, such as blast furnace gas, coke-oven gas, refinery gas, reflecting only variable costs

Industrial fuels and CHP

Blast furnace gas and coke oven gas availability is related to activity of integrated steelworks, which are part of the iron and steel sub-model. Future changes in the mix of processes for iron and steel (e.g. shift to electric arc) influence availability of blast furnace and coke oven gas. The use of these gasses is generally in CHP and boilers.

Industrial CHP is integrated in the power/steam model and production is associated with dedicated CHP plants with smaller size and different technical-economic characteristics than utilities; plants. Constraints about delivering steam which can be supplied by industrial CHP plants and industrial boilers depend on results of the demand-side models and induce preferential development of such industrial plants, despite their higher unit costs for power generation reflecting industrial decisions on secure supply

Thus the benefits from auto-production (grid cost savings) and CHP (providing steam) drives development of industrial power generation despite the negative scale effects

Large Combustion Plant Directive and air pollution

The PRIMES model computes emissions of air pollutants, such as: SO2, NOx, PM, VOC, from power generation and other types of combustion

End-of-pipe abatement is represented in the power model: auxiliary FGD, DENOx, electrostatic filters, etc. are options for investment associated to existing or new plants.

Usually in the scenarios it is assumed that according to the Large Combustion Plant directives, all new power plants shall be equipped with such end-of-pipe abatement devices, and so they are included in new power plant investment

Other provisions for old plants, such as transitory measures specifying maximum operating hours for old plants, are represented in the model as constraints on specific plants. Possibilities for retrofitting are endogenous

The model allows for imposing ceilings on atmospheric emissions and associating a shadow price (e.g. price of a SO2 permit)

Atmospheric emissions are computed in the transport sector model, in detail. There is possibility to internalise external costs through taxation on fuels or on vehicles.

The provisions of the IPPC Directive on Best Available Technologies are reflected upon the technical (hence economic) characteristics of new technologies in all sectors. Similarly other regulations are handled, e.g. lighting.

CO2 emissions from industrial processes (non energy related) are handled in relation to industrial production of materials (e.g. cement). The model includes a marginal cost abatement curve for reducing emissions and also CCS investment for more drastic emission cuts. Costs for CCS for processes are determined by accounting for capital and variable costs. Electricity consumption for capturing is determined and adds to total electricity demand.

Fluctuating demand issues and reserve power

The model represents demand variability for electricity and steam/heat for two typical days (one for winter and one for summer). In total 11 load segments are included, with fixed time durations.

Data for annual load curves, from the national TSOs and other sources, are aggregated to obtain equivalent load curves in 11 segments.

The model associates a demand fluctuating profile to every use of electricity and steam or heat included in the demand sector models and also for energy demand in the energy branch. By adding up the sectoral load profiles, the model determines a load profile by country.

Load profiles change over time and in scenarios, depending on the relative shares of various energy uses, the prices (which are higher for sectors with poor load factors), the degree of energy savings (and the use of more efficient equipment) and special measures as the smart meters which in the transport sector are supposed to motivate charging at off peak hours.

When load profiles become smoother, capital intensive power technologies are favoured and reserve power requirements are lower, implying lower overall costs.

The various power plants contribute to reserve power through differentiated estimates of their capacity credits. Variable RES power plants have low capacity credits. In order to meet reserve power constraints, the power model may require additional thermal power (evidently from low capital intensive technologies, such as gas turbines), or may invest in pumped storage (depending on maximum possibilities and costs), or may use import-exports more intensively. Costs are affected and prices recover total cost.

The model solution with endogenous interconnection flows mimics common balancing and operates explicitly per load segment, which are supposed to be synchronised across the countries.

Load segment synchronisation also applies for electricity and steam/heat; this feature is important for capturing the operation of CHP plants

SUPPORT INFRASTRUCTURE NEEDED

Grid, storage and other infrastructure

Investment in new interconnectors is exogenous

Similarly, investment in gas pipelines, LNG terminals and gas storage is exogenous

Investment in distribution grids and for connecting RES is implicitly treated in the model as costs for grid investment, expansion and maintenance

Smart grids and meters are implicitly considered in scenarios as facilitating development of highly decentralised generation. Grid costs and requirements are endogenously determined in such scenarios.

Social acceptance issues are represented in the model either by increasing risk premium factors or by increasing the cost-supply curve locus, where appropriate

Storage in power generation is treated endogenously for hydro pumping and for hydrogen; air compression storage is not represented.

The detailed PRIMES-TREMOVE transport model represents various forms of refuelling or recharging infrastructures which influence selection of vehicle types or the fuel mix

The costs for the above infrastructures are accounted for in total energy system costs and are reported separately.

Reliability and security of supply

Short term reliability in power generation is represented through simple constraints, for example on reserve power.

Long term **generation adequacy** regulations or targets are represented as constraints involving domestic power plant capacities and imported power with differentiated weights depending on regulation definition

Such constraints may induce higher domestic investment in power plants than least cost operation would suggest

More detailed **reliability** issues for power generation, such as ancillary services (voltage control for example), are not represented in the current version. There exist an experimental version of the power sector of PRIMES which includes ramp-up and ramp-down constraints, minimum technical limits on power plant operation, reactive power constraints, etc. This version requires mixed integer programming and is very slow in computer time.

Security of supply policies may be reflected in scenario design through various means:

- Selective taxation on domestic and imported fuels
- Take or pay obligations on domestically produced fuels
- Limitations on imports in electricity balance
- Strict regulations on reserve power from domestic power plants
- Construction of grid infrastructure for electricity and/or gas which may increase diversification in supply
- Policies that support development of domestic resources such as RES, or promote nuclear

Security of supply indicators are reported in model results