Assesing the Impacts by Pan-European TIMES Model

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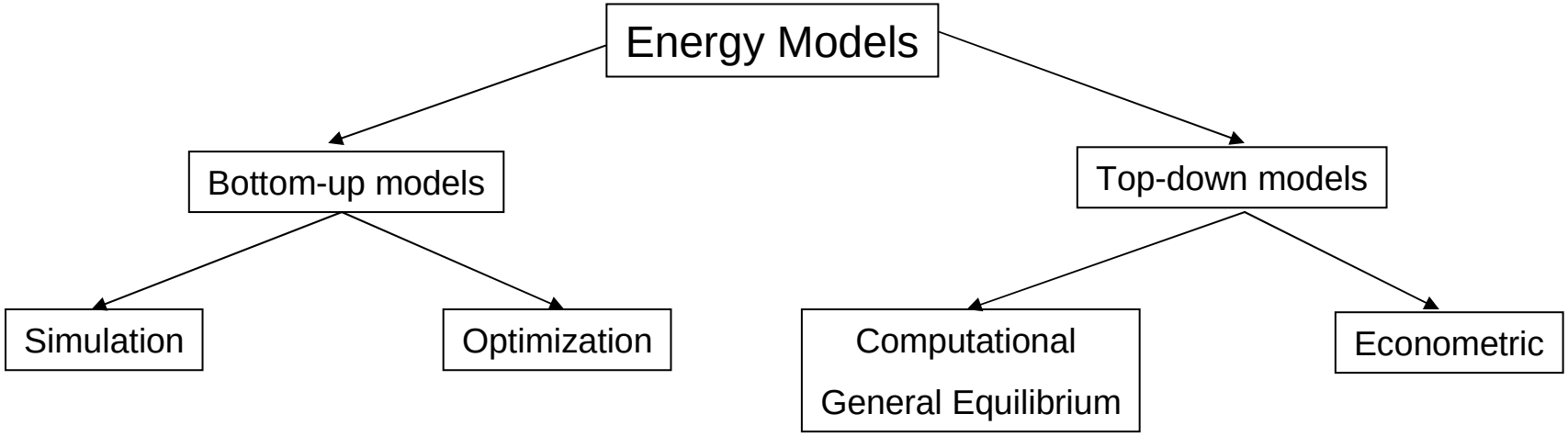
Categories of energy models



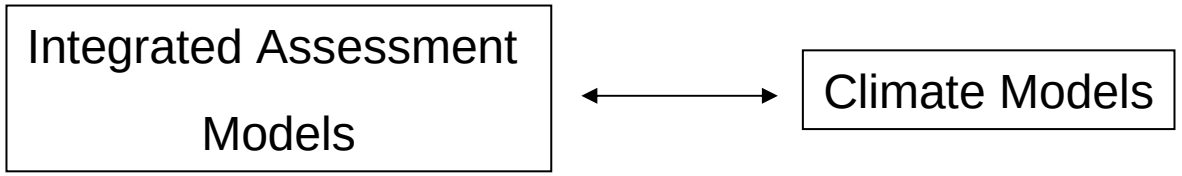
Characteristics:

i. Sectoral coverage or Entire energy system
ii. Single region or Multi regions
iii. Short term or Long-term
iv. Recursive dynamic or Perfect foresight

Characteristics:

i. Single region or Multi regions
ii. Recursive dynamic or Perfect foresight

Attempt to link model types



Goals of the TIMES development

- Restrictions in mo[illegible]g of load curves
- Changes the model h[illegible]difficult
+ Modelling flexible proces[illegible]

- Load c[illegible]s only for electricity and district he[illegible]
- [illegible]nging the model horizon difficult
- Rigid Processes

TIMES

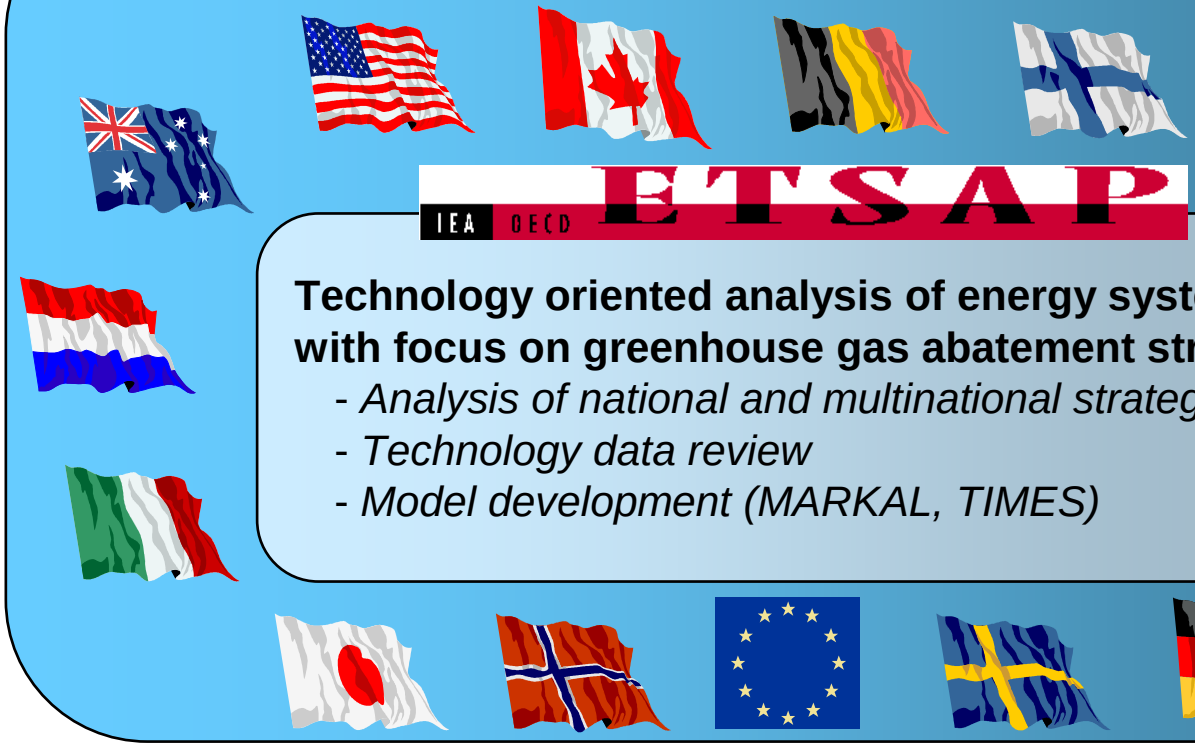
+ All processes and technologies depictable on subannual level
+ Any desired time resolution possible
+ Changes in the model horizon possible (distinction between input and model data)
+ Flexible process description
+ Easy extension of model features

ETSAP

IEA (International Energy Agency)

Implementing Agreements

Energy Technology Systems Analysis Programme (ETSAP)



IEA OECD ETSAP

Operating Agent

www.etsap.org

ETSAP news

Outreach

Technology oriented analysis of energy system models with focus on greenhouse gas abatement strategies

- *Analysis of national and multinational strategies*
- *Technology data review*
- *Model development (MARKAL, TIMES)*

Development

- By ETSAP
- Implementation in GAMS

Applications of the model

- IER:
  - Ostfildern (local)
  - Baden-Württemberg
  - Bavaria
  - Saxonia
  - Hessen
  - Germany (TIMES-D)
  - European electricity and gas sector model (TIMES-EG)
  - European energy system model (TIMES PanEU)
  - Global model (ETSAP-TIAM)
- Other places:
  - Finland (VTT, Helsinki)
  - Belgium (KUL, Leuven)
  - Italy (Turin)
  - South Africa model, Village model (ERC, Cape Town)
  - EU-NEEDS project
  - Global models (EFDA, ETSAP-TIAM)

Methodology

- Bottom-up Model
- Perfect competition
- Perfect foresight
- Optimization (LP/MIP/NLP)

Min/Max Objective function
s.t.
Equations, Constraints
Decision Variables <=> Solution
Input parameters

TIMES

(The Integrated MARKAL EFOM System)

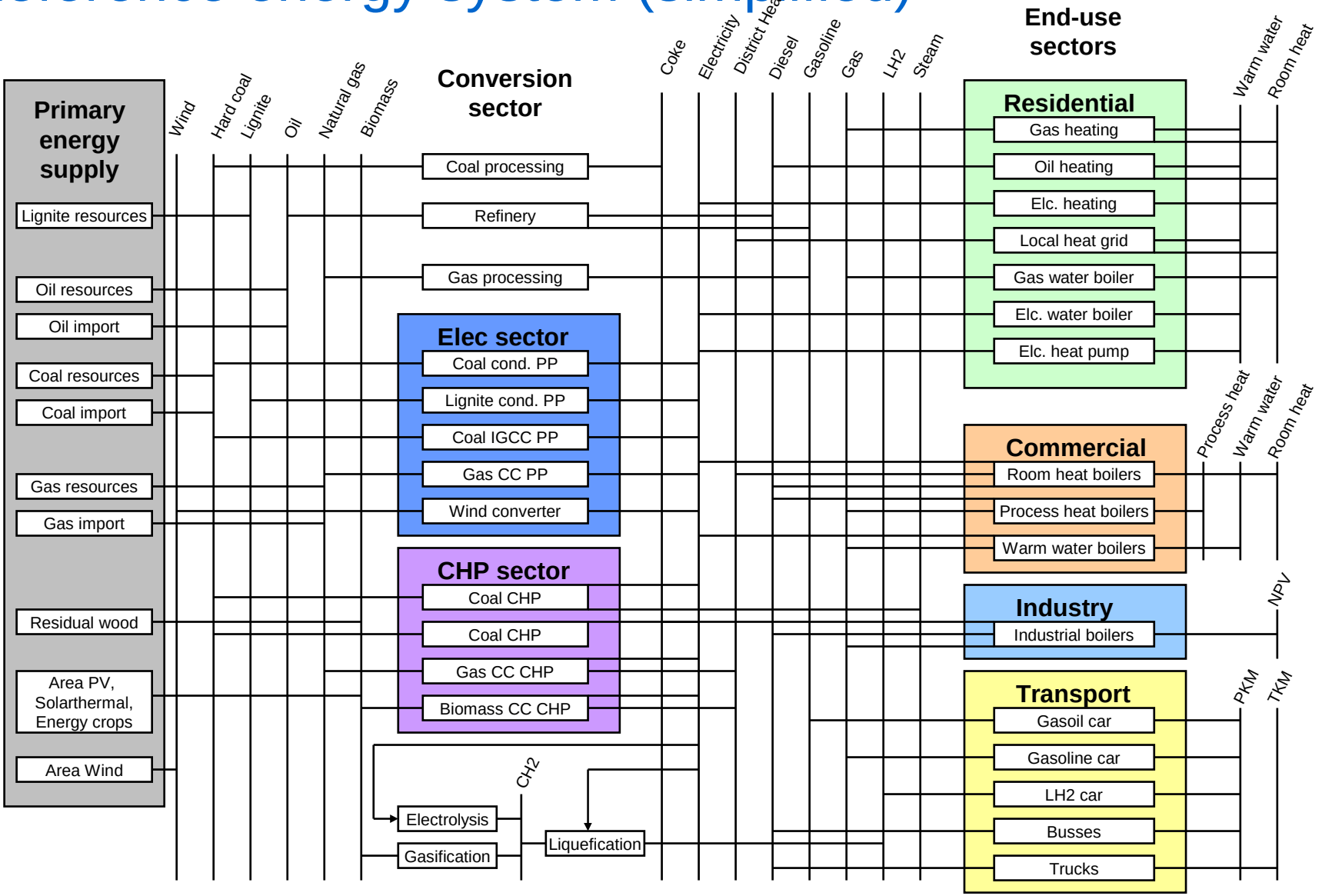
Advanced Features/Variants

- Elastic demands
- Endogeneous learning
- Discrete capacity expansion
- Macroeconomic linkage
- Climate extension
- Stochastic programming
- Alternative objective functions
- Multi-criteria optimization

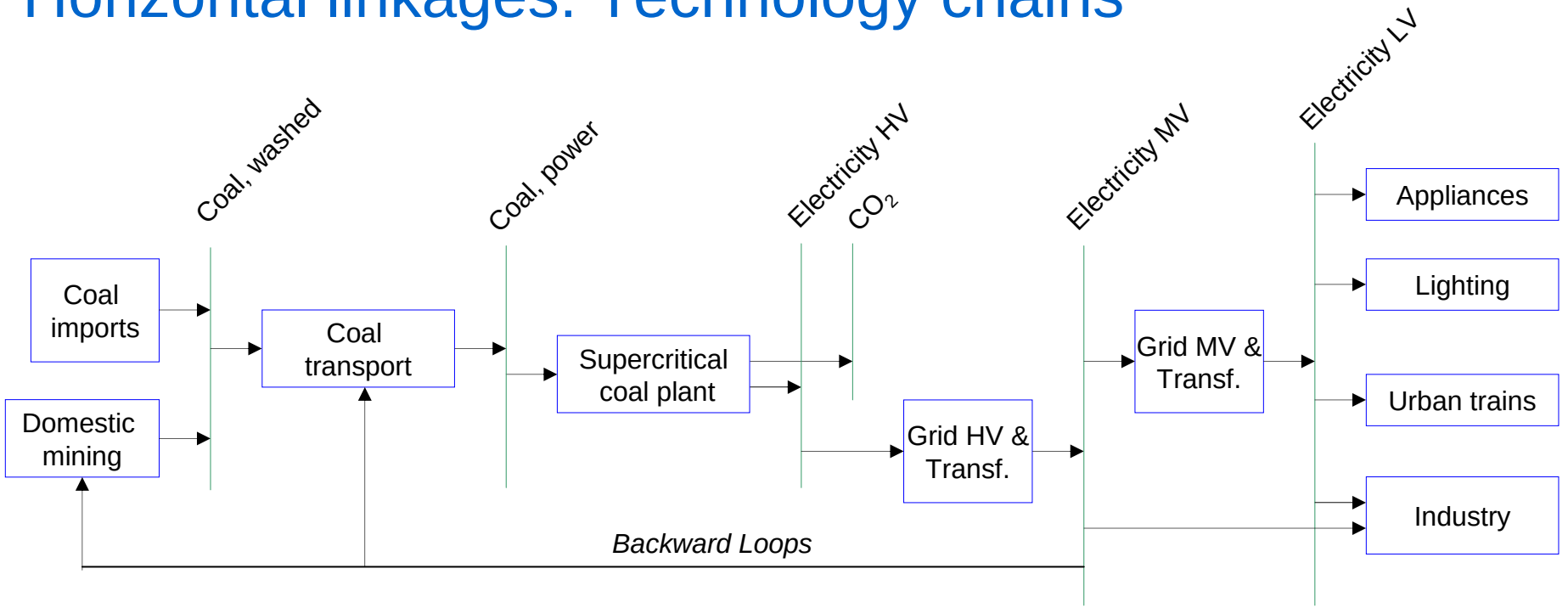
Fundamental features of TIMES

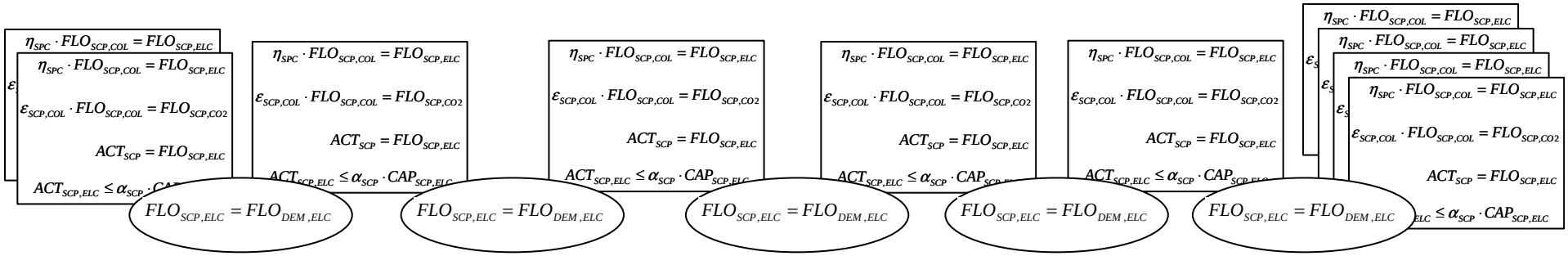
- Model structure
  i. Flexible time horizon
  ii. User-defined time slice resolution within a year
  iii. Multi-regional
- Model formulation
  i. Partial Equilibrium Model
  ii. Technology description:
    1. Single process type with access to all model features
    2. Vintaged technology properties
    3. Transformation eqn with overall and commodity-specific efficiencies
  iii. Objective function:
    1. Different treatment of technology investments based on investment lead time
    2. Other opimization functions than total system costs can be defined by modeller
- User constraints
  i. Framework to formulate virtually any linear relationship between decision variables

Reference energy system (simplified)

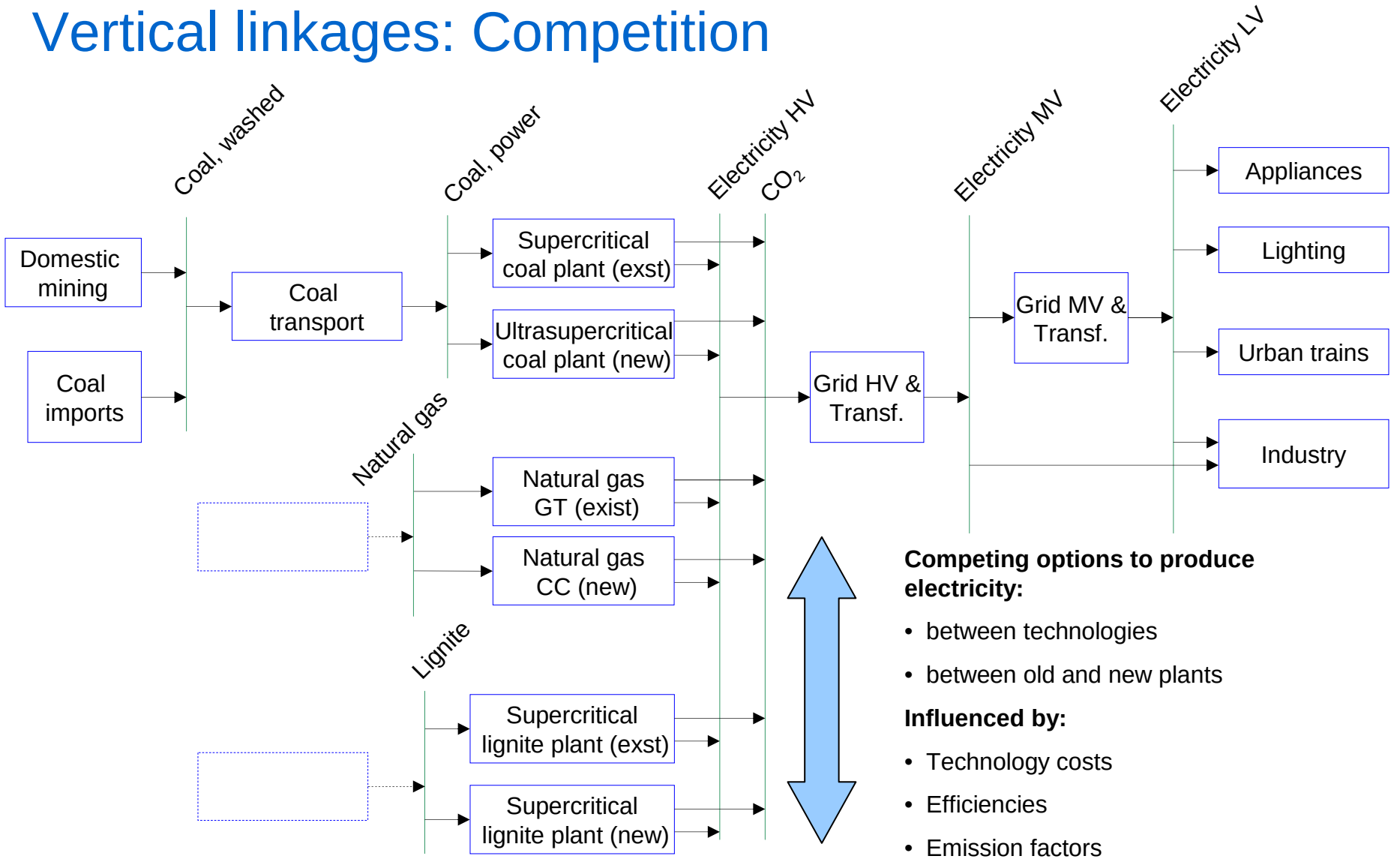


Horizontal linkages: Technology chains





Vertical linkages: Competition



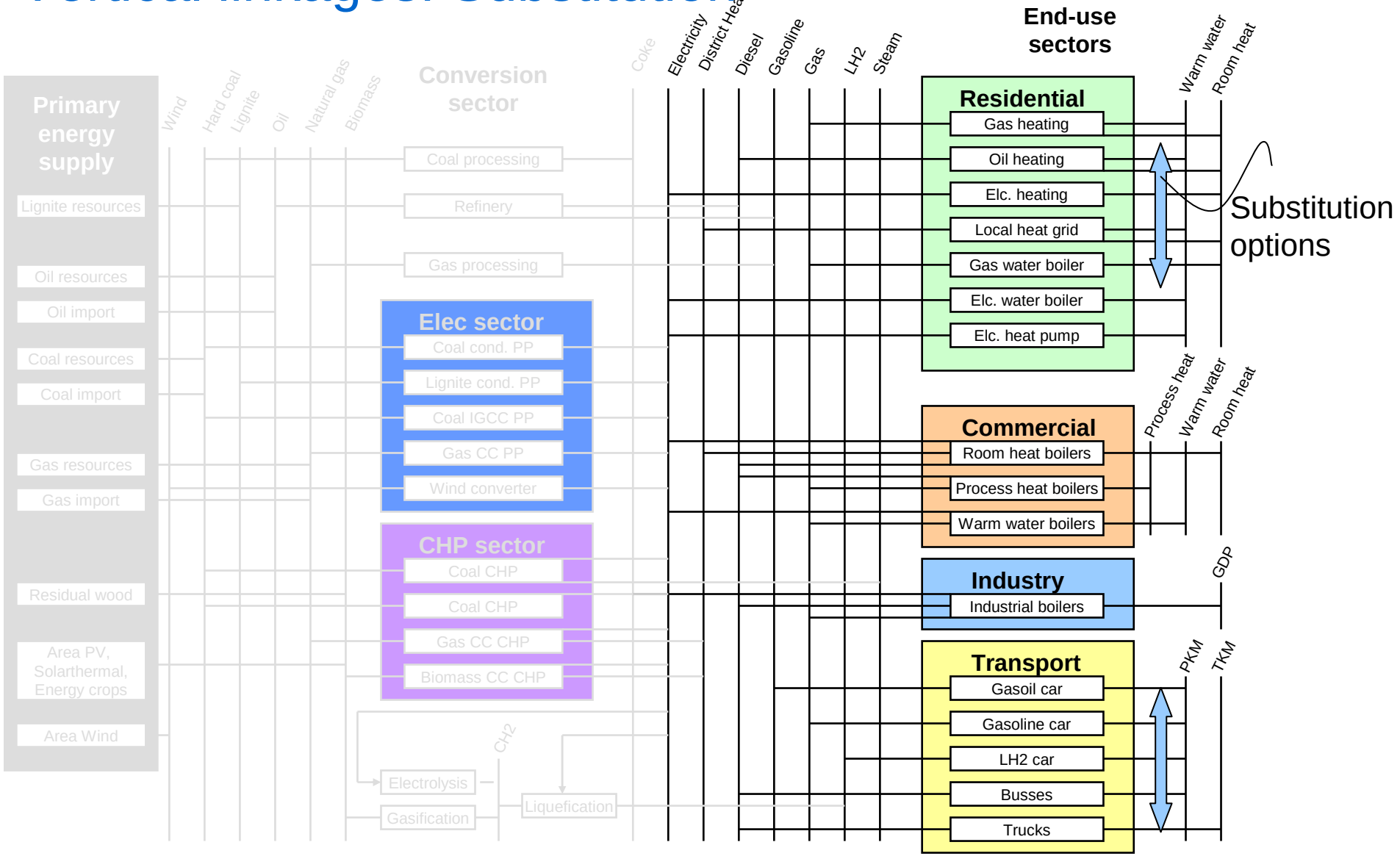
Competing options to produce electricity:

- between technologies
- between old and new plants

Influenced by:

- Technology costs
- Efficiencies
- Emission factors
- Fuel prices…

Vertical linkages: Substitution



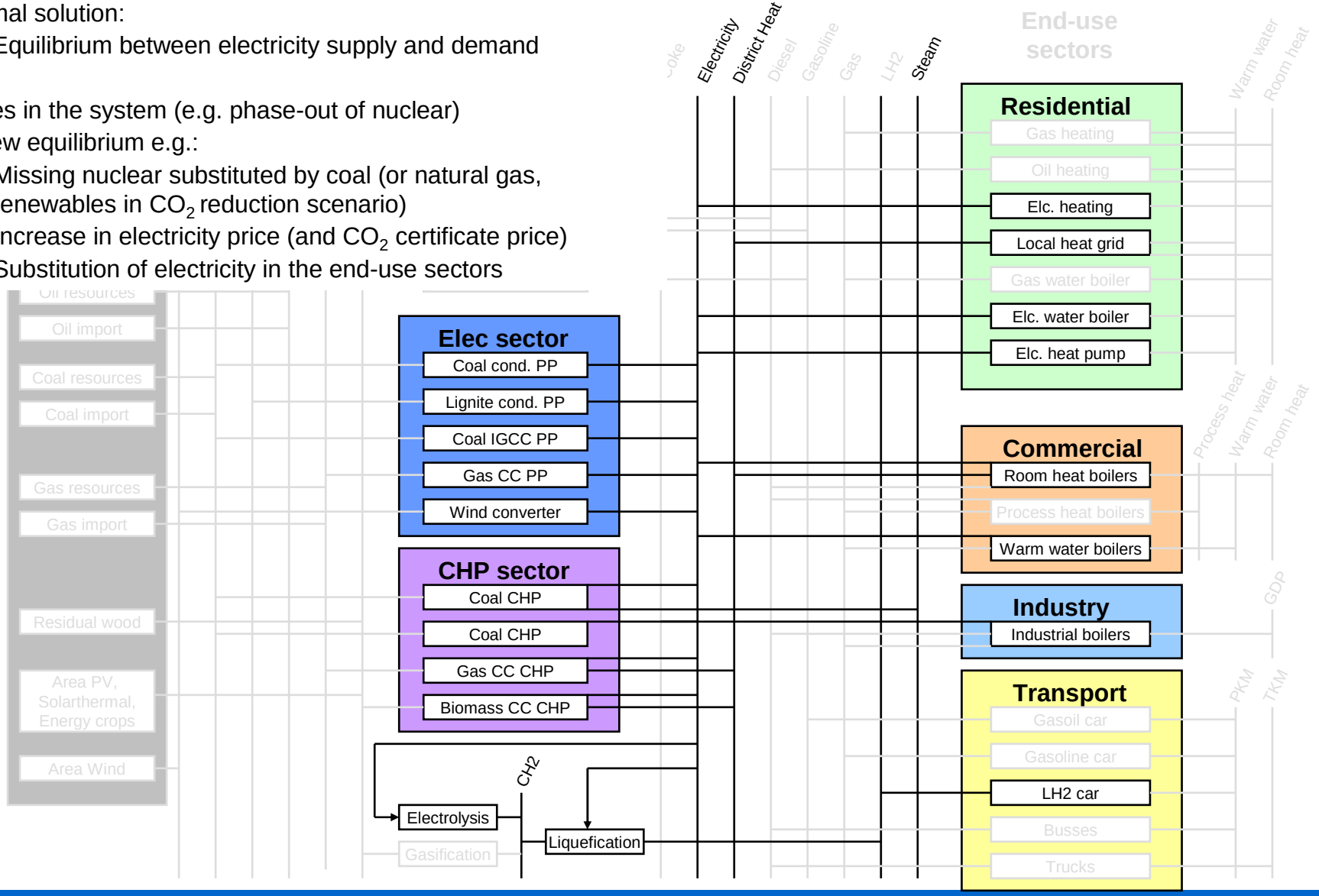
Interdependencies in the energy system

At optimal solution:

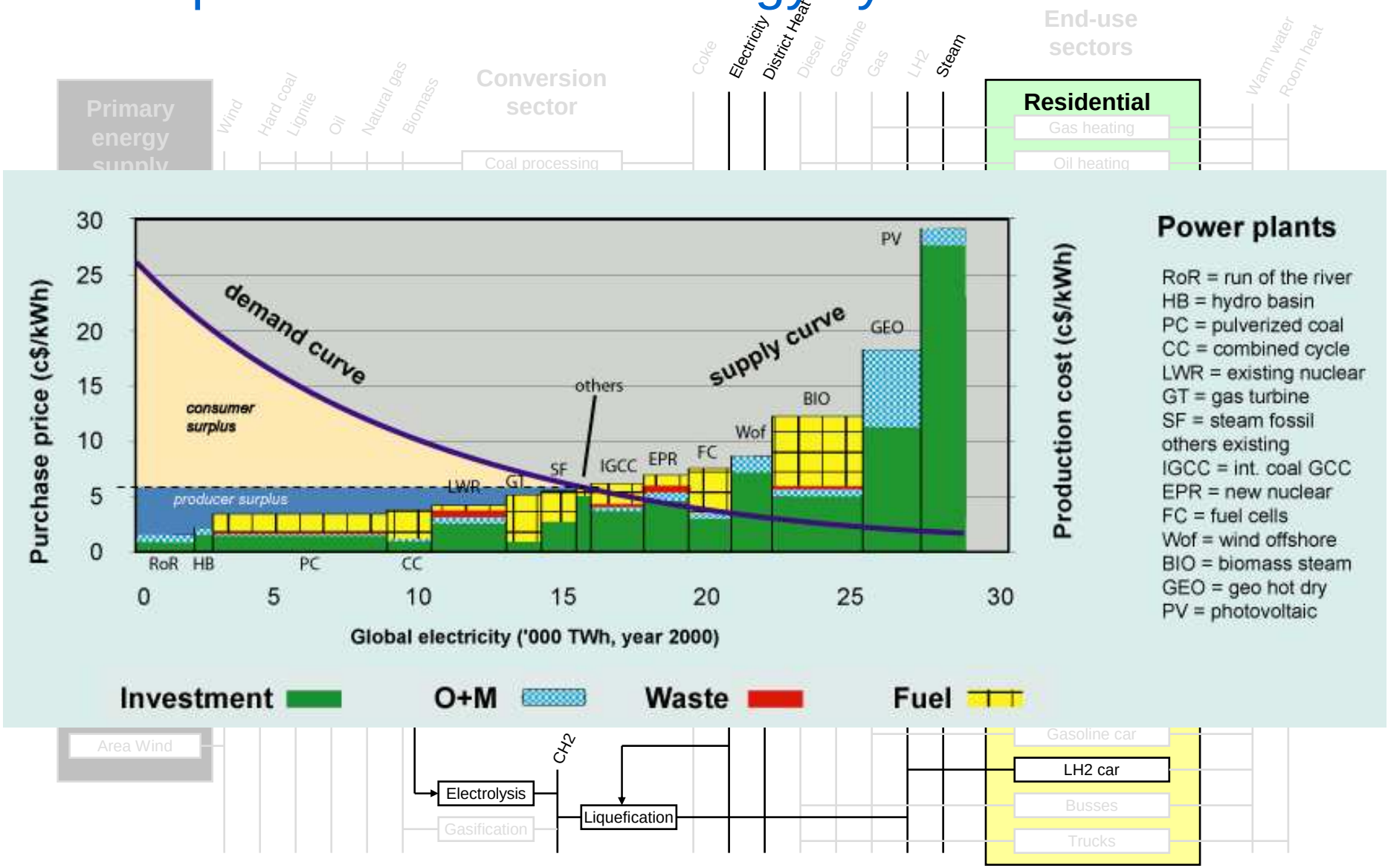
- Equilibrium between electricity supply and demand

Changes in the system (e.g. phase-out of nuclear) yield new equilibrium e.g.:

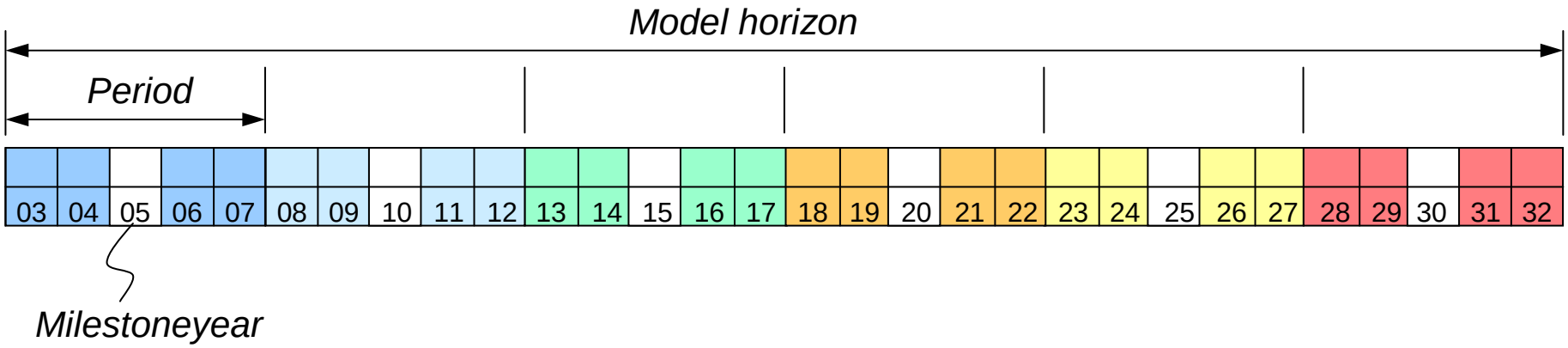
1) Missing nuclear substituted by coal (or natural gas, renewables in CO_2 reduction scenario)
2) Increase in electricity price (and CO_2 certificate price)
3) Substitution of electricity in the end-use sectors

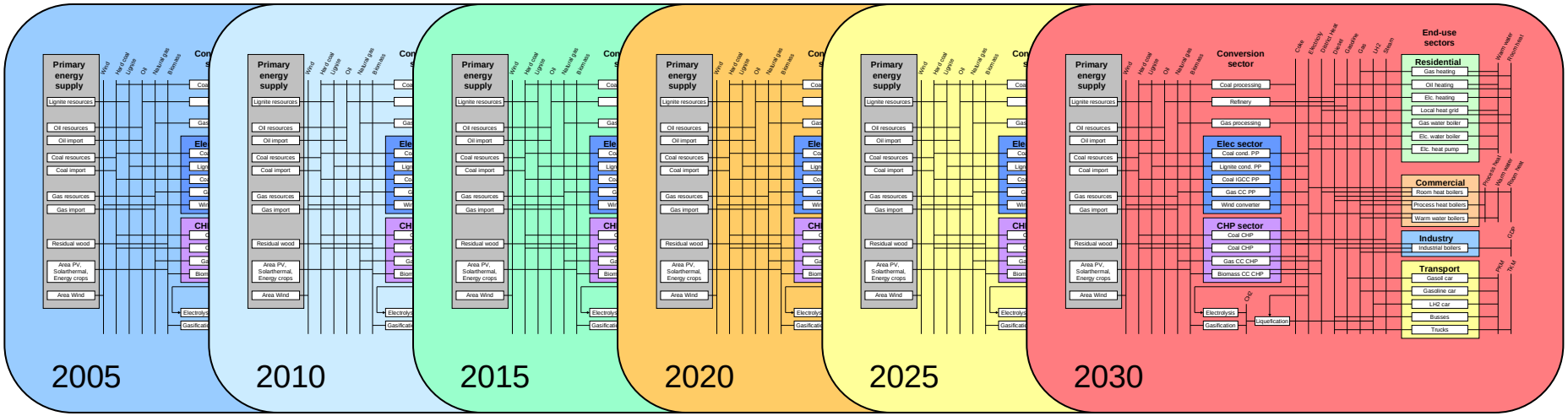


Interdependencies in the energy system



Dynamic model





Objective function: List of cost components

- **Discounted sum of the annual costs minus revenues:**

Construction
+ Investment costs
+ Costs for sunk material during construction time

Operation
+ Variable costs
+ Fix operating and maintenance costs
+ Imports
+ Taxes

Decommissioning
+ Surveillance costs
+ Decommissioning costs

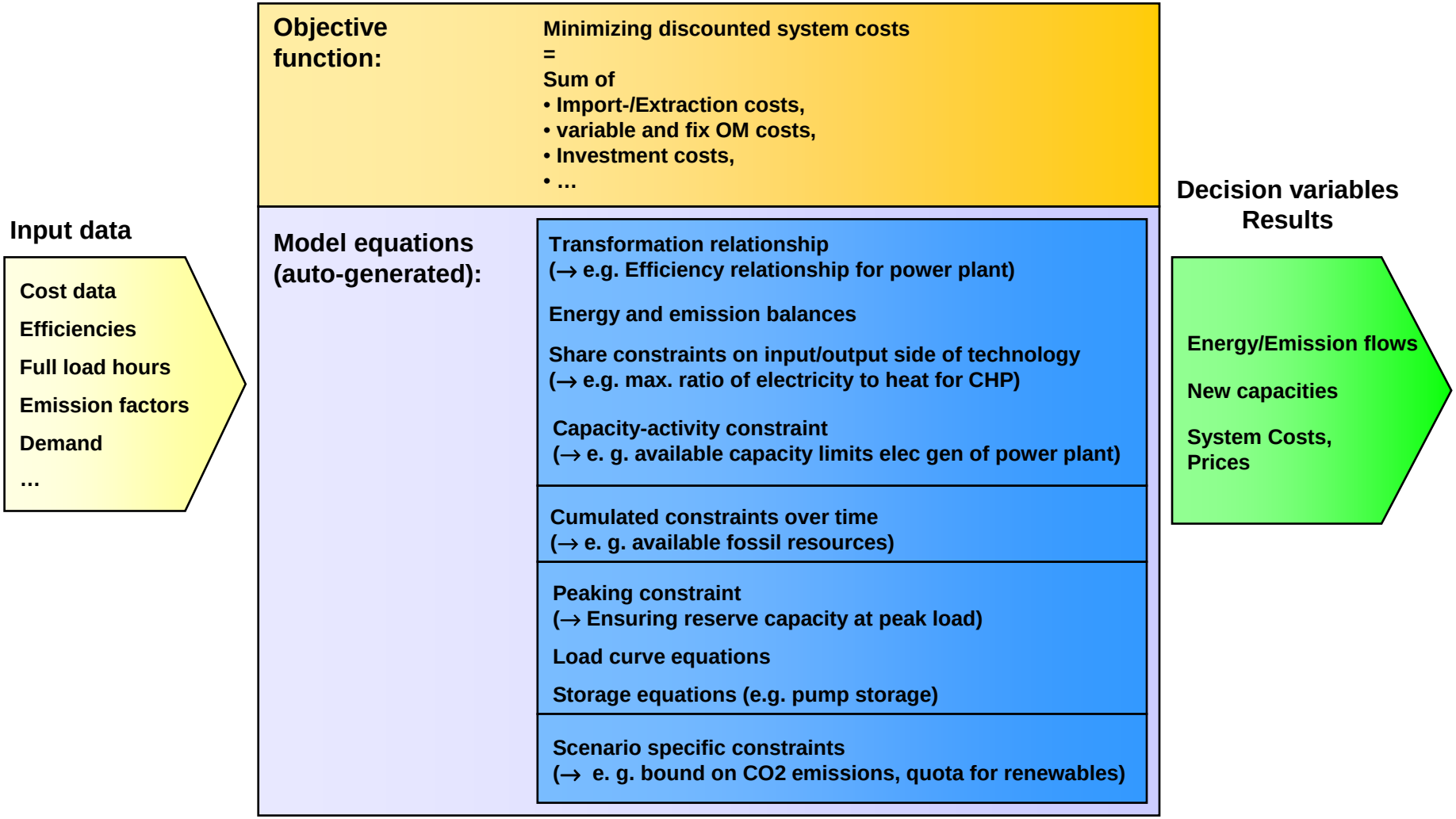
Operation
- Subsidies
- Exports

Decommissioning
- Recuperation of sunk material

Construction
- Salvage value

- Distinction between technical and economic lifetime
- General discount rate (discounting to base year) and technology specific discount rate (calculating annuities)
- Investment and decommissioning lead-times

Model formulation of TIMES



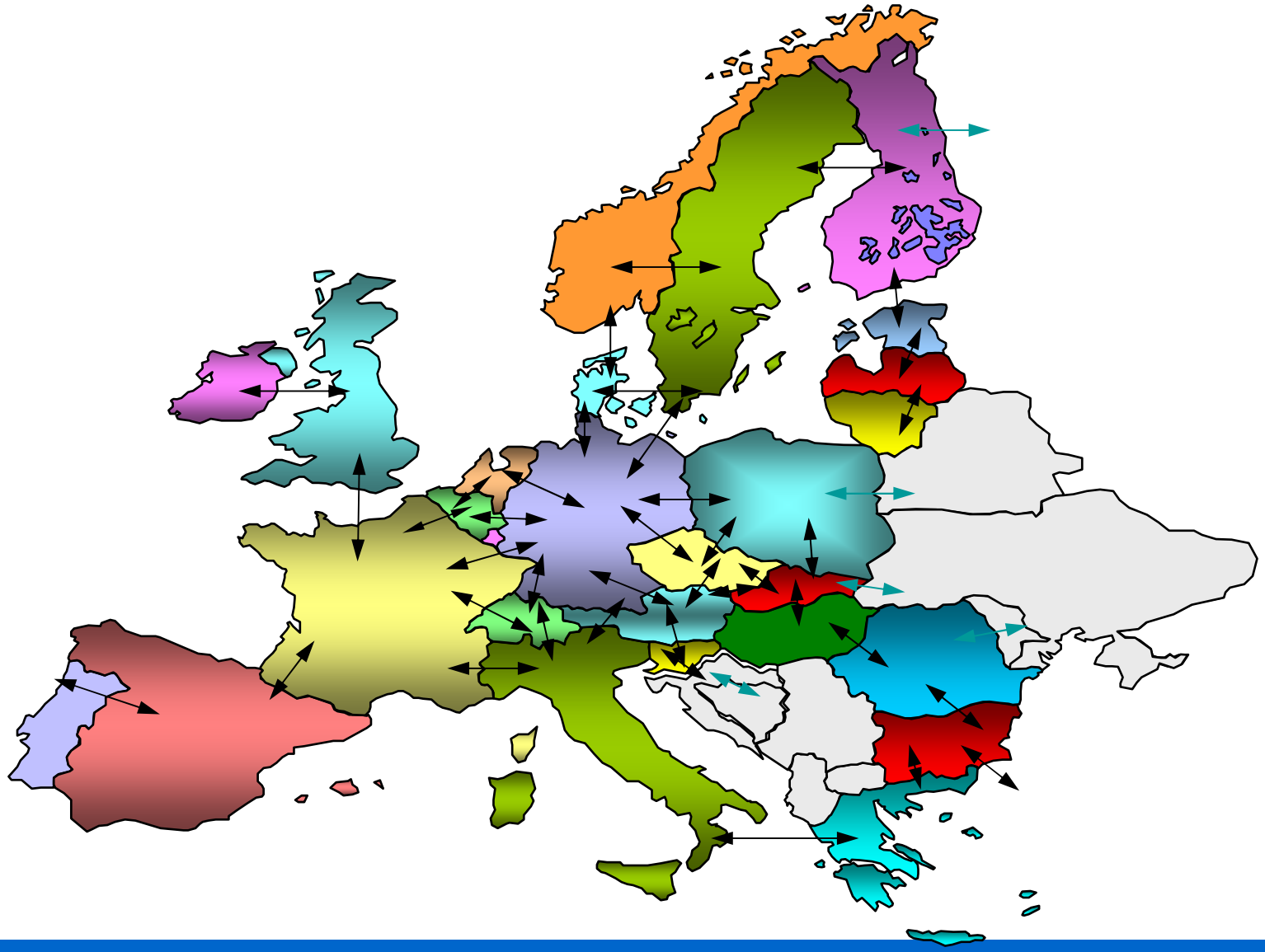
The Pan-European model (TIMES PanEU)

- **PEM is a, 30 region (EU 27 + NO, CH, IS) partial equilibrium energy systems, technology oriented bottom-up model.**
- **Time horizon: 2000-2050**
- **12 time slices (4 seasonal, 3 day level)**
- **GHG: CO2, CH4, N2O, SF6**
- **Others pollutants: SO2, NOx, CO, NMVOC, PM2.5, PM10**
- **The database integrates results of LCI and specific Damages with the aim to integrate the treatment of Externalities in the optimization procedure**

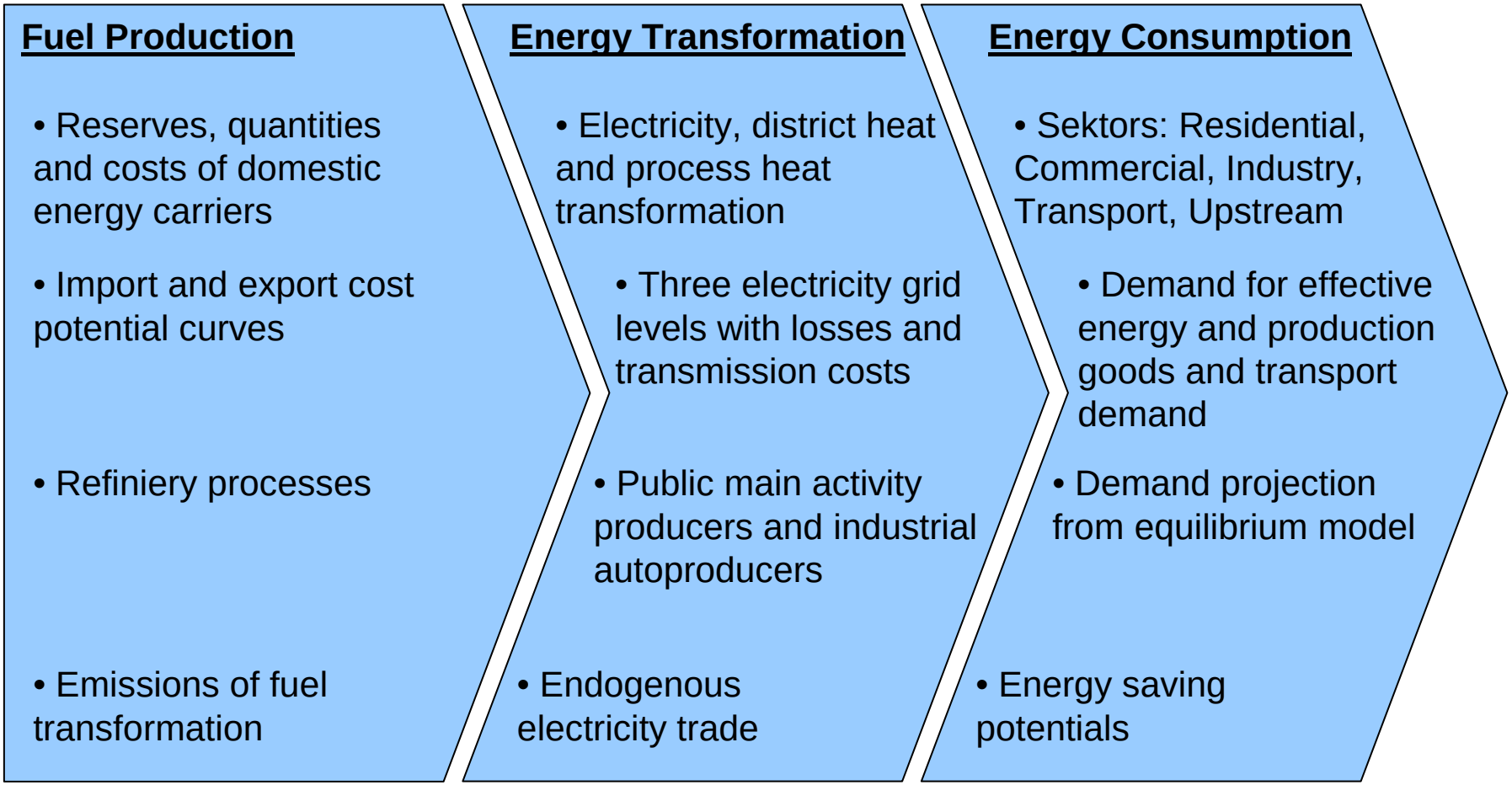
The Pan-European Model (2)

- **SUPPLY: Explicit modeling of reserves, resources, exploration and conversion**
- **Electricity:**
  1. **Public electricity plants, CHP plants, heating plants, auto-producers**
  2. **Country specific renewable potential and availability**
     (onshore / offshore wind, geothermal, biomass, solar, hydro)
  3. **Country specific characterization of conversion technologies (in-use and new)**
- **DEMAND: is based on a simulation routine linked with GEM-E3 /NEWAGE**
  1. **Agriculture**
  2. **Industry: Energy intensive industry (iron and steel, aluminum, copper, ammonia and chlorine, cement, glass, lime, pulp and paper), Other industries**
  3. **Residential and Commercial: Space heating/cooling, water heating, appliances and others)**
  4. **Transport: Passenger, Freight (different transport modes: cars, buses, motorcycles, trucks, passenger trains, freight trains) Air, Navigation.**
  5. **Country specific characterization of end-use technologies**

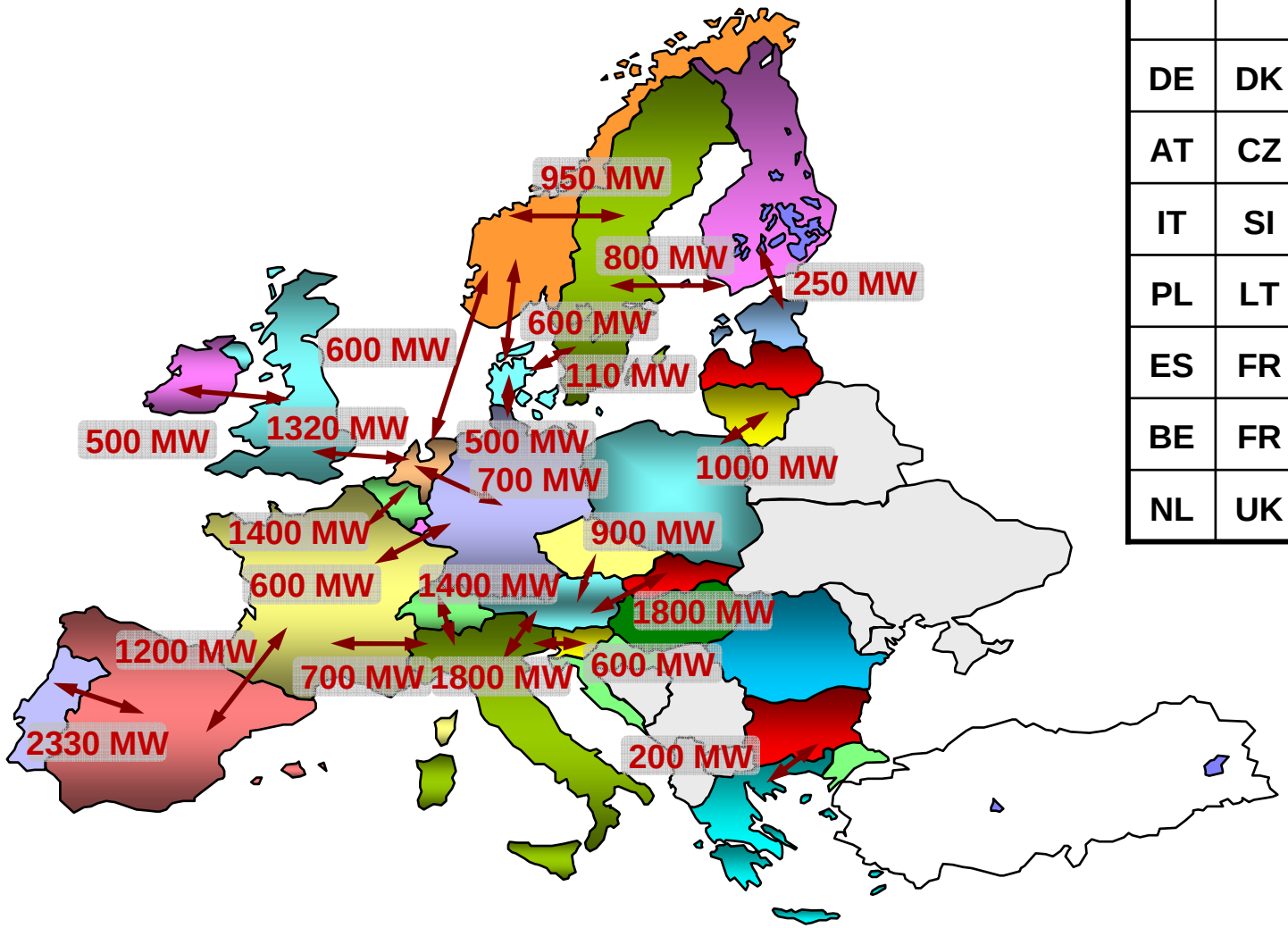
Regional Coverage Pan-European TIMES model



The Environment of the Energy Transformation Sector in TIMES PanEU



Regions in TIMES PanEU and planned Interconnection Extensions



European Priority Projects			
		P in MW	Year
DE	DK	500	2012
AT	CZ	900	2009
IT	SI	800	2011
PL	LT	1000	2013
ES	FR	1200	2009
BE	FR	400	2015
NL	UK	1320	2010

Interregional Electricity Trade in TIMES PanEU

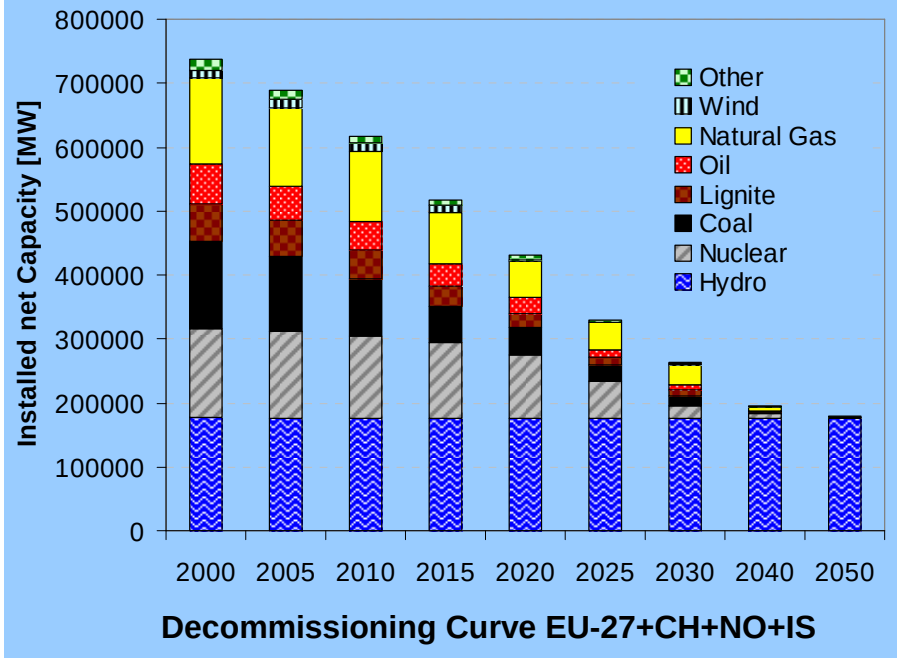
- Endogenous trade between Regions
  - Bidirectionale trading processes → no simultaneous import and export between regions in the same time slice
  - Interconnection capacities according to ETSO
  - Trade driven by marginal electricity generation costs per time slice and transmission costs (incl. losses)
  - Limitted trade in peak time slice, since import capacities not secure (auctioning of interconnection capacities at various European borders)

- Exogenous trade with non-EU countries
  - e. g. Poland – Ukraine
  - constant trade quantities over modeling horizon at 2005 level

Energy Generation Units in TIMES PanEU

Existing Capacities

- Clusterd by fuel and technologies for public and industrial generation units
- Country specific decommissioning curves



Decommissioning Curve EU-27+CH+NO+IS

Commissioning Capacities

- Technology database for public and industrial power plants, CHP and heating plants
- Commisssioning of electricity gerneration units in industry sector as CHP plants with coupled production of process heat and steam
- Country specific restrictions concerning fuel use and unit size of power plants
- Nuclear phase out in DE, BE, SE, ES, NL as well as commissining of new capacity only in coutries with existing nuclear capacity (except PL)
- Minimum electricity quantities from renewable energy resources according national policies

Technology Database – New Public Fossil Power Plants (excerpt)

Hard Coal

- PCC condensing 350 / 600 / 800 MW
- PCC CCS Post Combustion 560 MW
- IGCC 450 MW
- IGCC CCS 425 MW
- Oxyfuel 600 MW
- Extraction Condensing CHP 200 / 500 MW
- IGCC CHP with CCS

Lignite

- PCC condensing 965 MW
- PCC CCS Post Combustion 560 MW
- IGCC 450 MW
- IGCC CCS 425 MW
- Oxyfuel 760 MW
- Extraction Condensing CHP 500 MW

Natural Gas

- CC 420 / 800 MW
- CC with CCS 475 MW
- Gas Turbine 130 MW
- CC CHP 50 / 100 / 200 MW
- CC CHP with CCS 200 MW
- Internal Combustion small CHP 0.01 / 0.2 / 2 MW
- Fuel Cell MCFC 0.5 MW
- Fuel Cell SOFC 1 MW

CO_2 Storage Potentials of selected European Countries

	Oil Fields [1]	Gas Fields [1]	Aquifers [1]	Coal Seams [2]
	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2
Denmark	176	452	16000	
Germany	103	2227	23000 - 43000	4400
Greece	17	0	2200	
Netherlands	54	10907	1600	5700 - 39700
Norway	3453	9156	13000	
UK	3005	7451	15000	
France				590 – 860

- Total Europe: 122 Gt CO_2
  - Saline aquifers 54%
  - Depleted oil and gas fields 32%
  - Enhanced coal bed methan recovery 14%

Sources: [1] GESTCO 2004, [2] Recopol 2006

Technology Database – Renewable Power Plants (excerpt)

Biomass / Biogas

- Internal combustion engines biogas
- Fuel cell biogas
- Condensing CHP wood, straw
- Internal gasification wood
- IGCC CCS Biomass

Hydro

- Run of river small / medium / large
- Dam storage large
- Pump storage

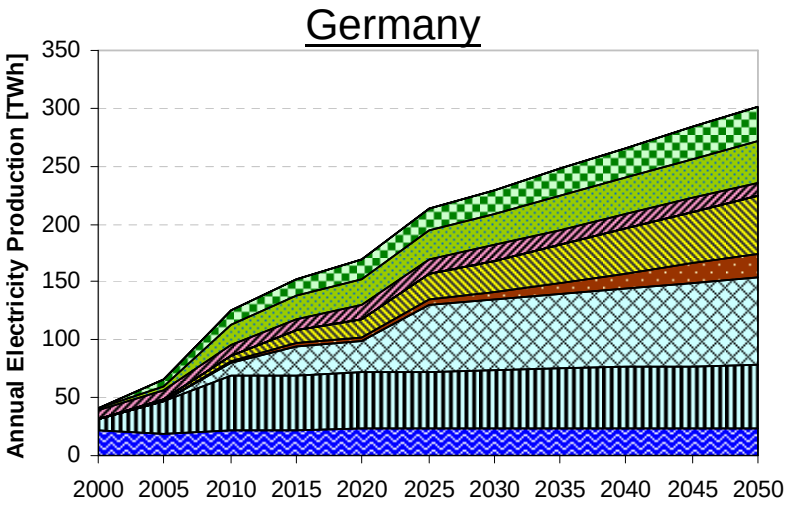
Wind and Solar

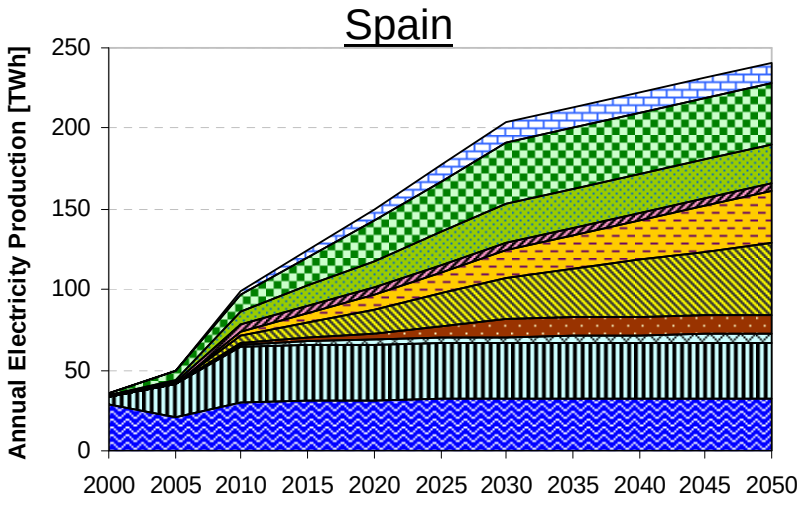
- Wind onshore (differentiated by three wind classes)
- Wind offshore
- Solar PV (roof and plant size)
- Solar thermal

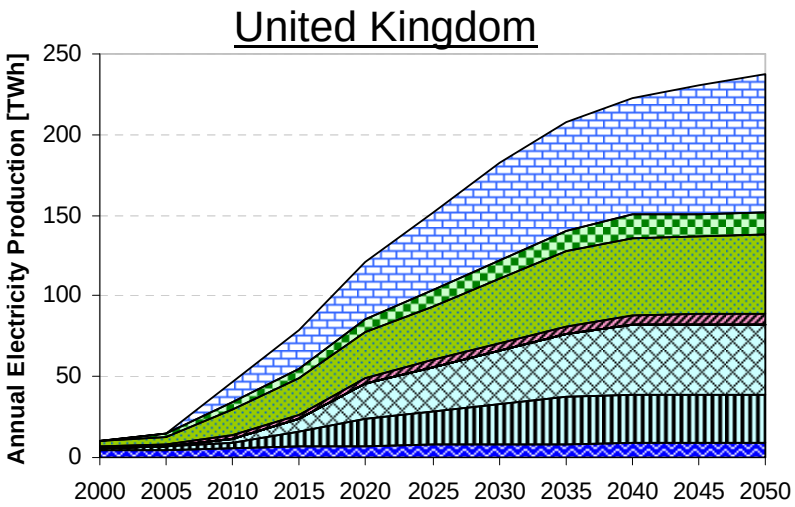
Other Renewable

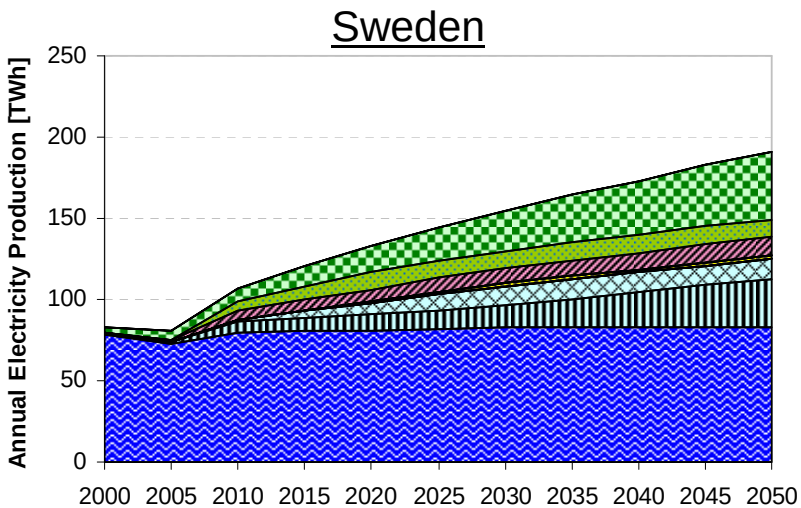
- Geothermal Hot dry rock
- Geothermal Steam turbine
- Tidal stream generator
- Wave energy converter

„Hot Spots“ of Renewable Energy Production in Europe









Hydro small + large | Wind onshore | Wind offshore | Geothermal | Photovoltaic | Solarthermal | Waste | Biomass gas / liquid | Biomass solid | Tide + Wave

General structure of the industry

Energy intensive Industry

- Iron&Steel
- Aluminium
- Copper
- Cement
- Ammonia
- Chlorine
- Lime
- Glass
- Pulp&Paper

Other Industries

- Other nonferrous metals
- Other chemicals
- Other non-metallic minerals
- Other Industries

General structure of the industry

Energy intensive Industry

- Process orientated Reference Energy System (RES)
- Demand of final products in natural units (Mt)
- Demand based on a simulation routine linked with GEM-E3 / NEWAGE

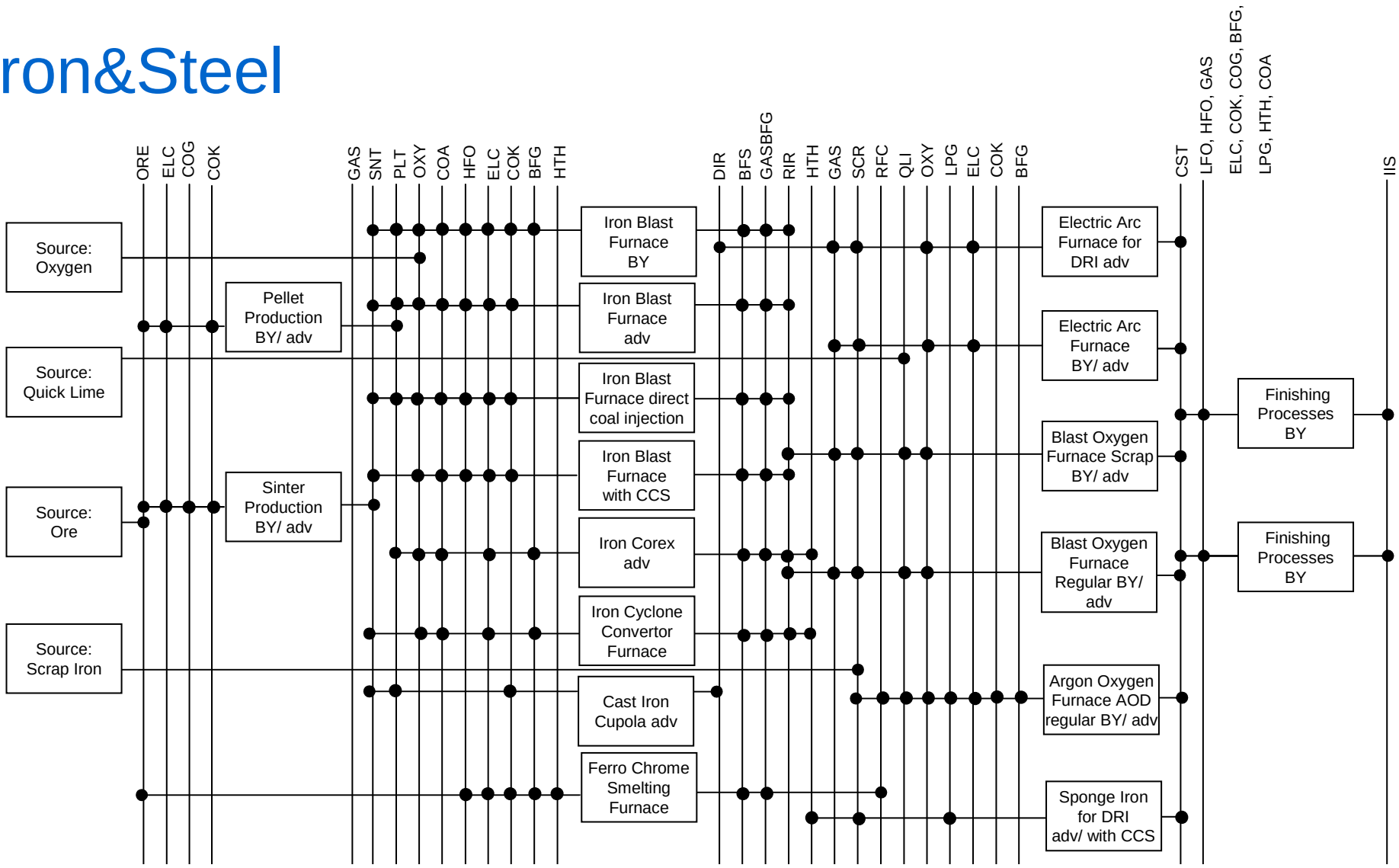
Other Industries

- Standard structure
- Mix of 5 main energy uses (Steam, Process Heat, Machine Drive, Electrochemical, Others)
- Fuel demand (PJ)
- Demand based on a simulation routine linked with GEM-E3 / NEWAGE

Energy intensive Branches: Iron&Steel

Process step	Available technologies
Finished steel	• Finishing process
Crude steel	• Blast Oxygen Furnace regular (base; CCS), • Blast Oxygen Furnace scrap • Electric arc furnace, EAF for DRI • Cast iron cupola
Row Iron	• Iron blast furnace (base; direct coal injection); COREX, Sponge Iron for DRI, Cyclone Converter Furnace
Pellet production	• Pellet production
Sinter production	• Sinter production

Iron&Steel

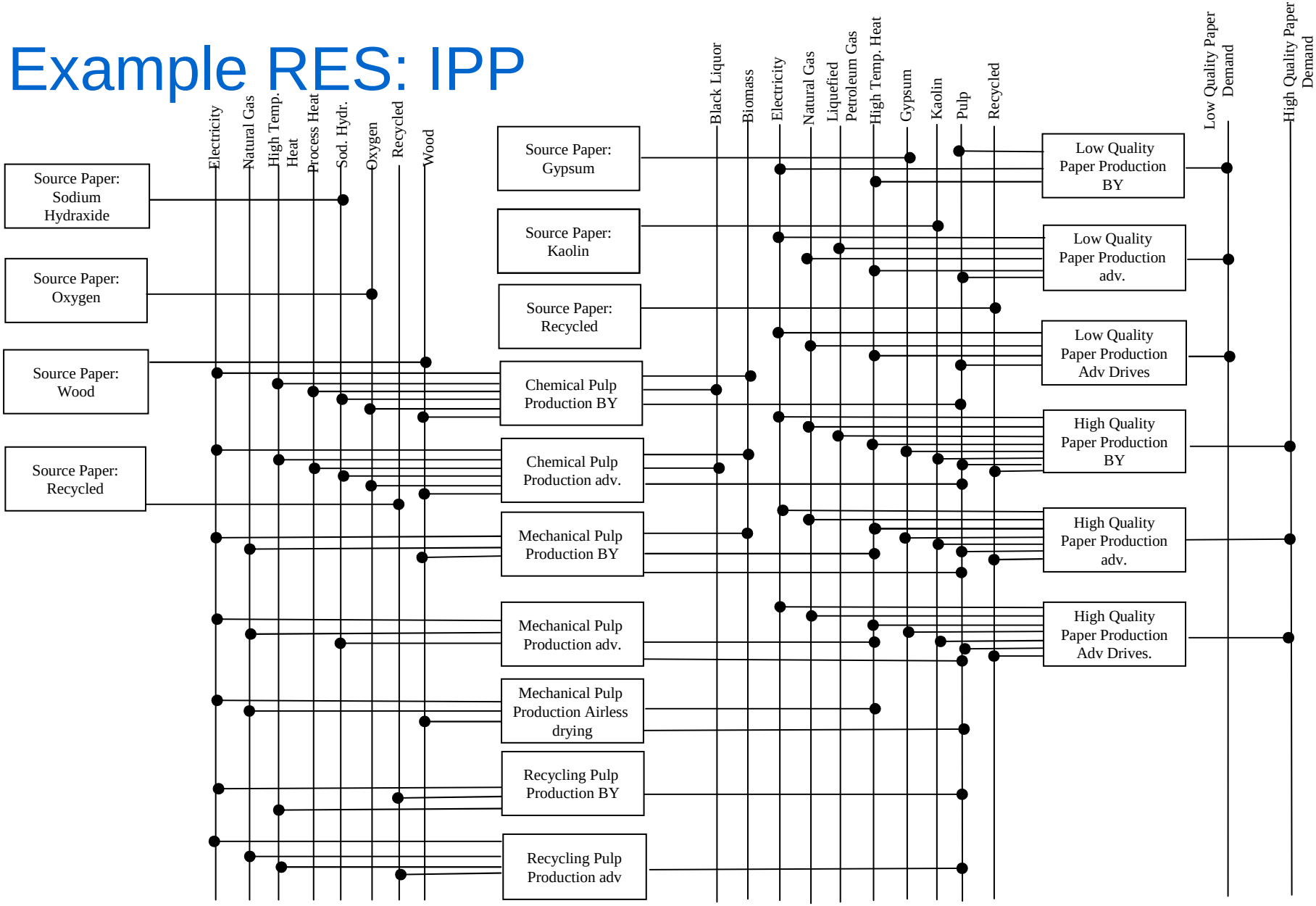


COK-Coke; Gas- Natural Gas; COG- Coke-Oven Gas; COA- Hard coal; BFG- Blast Furnace Gas; ELC- Electricity; LPG- Liquefied Petroleum Gas; OXY- Oxygen; HFO- Heavy Fuel Oil; LFO- Light Fuel Oil; HTH- Higth Temp. Heat; RIR- Raw Iron; SCR- Scrap Iron; RFC- Ferrochrome; QLI- Quick Lime; SNT- Sinter; PLT- Pellet; CST- Crude Steel; ORE- Ore; IIS- Iron and Steel Demand; DIR- DRI Iron; BFS- Blast Furnace slag

Energy intensive Branches: Paper&Pulp

Process step	Available technologies
Production of high quality paper	• High quality production process
Production of low quality paper	• Low quality production process
Pulp production	• Mechanical pulp production • Chemical pulp production • Recycling pulp production

Example RES: IPP



Heat supply in industry sector

Possibilities of HEAT supply

- Public district heat
- Industrial CHPs
- Boiler (modeled as boilers for branches (BY) and generic industrial boiler (> 2000)
- Kilns (for extra high temperature) [separate heat commodity]

Residential and Commercial Sectors

RSD Demand categories

- Space Heating
- Water Heating
- Space Cooling
- Lightning
- Cooking
- Refrigeration
- Cloth Washing
- Cloth Drying
- Dish Washing
- Other Electric
- Other Energy

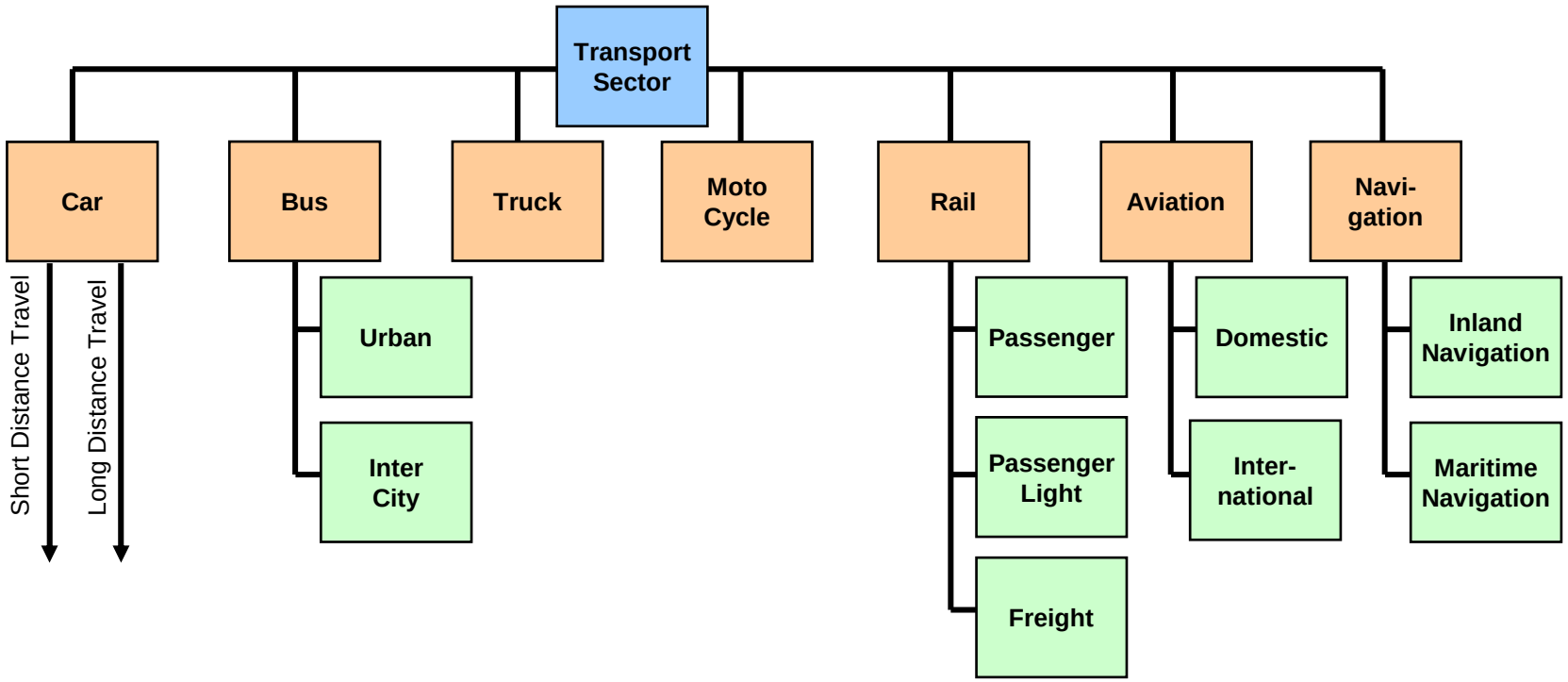
COM Demand categories

- Space Heating
- Water Heating
- Space Cooling
- Lightning
- Cooking
- Refrigeration
- Public Lightning
- Other Electric
- Other Energy

Technology options (examples)

- Heat pumps, Fuel Cells, Biomass based Heating Systems, Energy Saving Lamps, Energy Saving Options (Improved Building Isolation)...

Structure of the Transport Sector in the TIMES Pan EU Model



Implemented Transport Technologies

Fuel/Vehicle	Car	Bus	Truck	Motocycle	Rail	Aviation	Navigation
Gasoline	+*	+*	+*	+*		+	
hybrid	+*		+*				
plug in hybrid	+*						
Diesel	+*	+*	+*		+*		+
hybrid	+*	+*	+*				
plug in hybrid	+*						
Ethanol (E85)	+	+	+				
hybrid	+		+				
plug in hybrid	+						
Biodiesel	+	+	+		+		
FT-Diesel (BTL/GTL/CTL)	+	+	+			+	+
Electricity	+			+	+		
LPG	+						
Natural Gas/Biogas	+	+	+				
hybrid	+	+					
plug in hybrid	+						
Methanol IC	+	+	+				
Methanol FC	+						
Dimethyleter	+	+	+				
Kerosene						+	
Heavy fuel oil							+
Hydrogen (g) IC	+						
Hydrogen (g) FC	+	+	+				
hybrid	+	+	+				
Hydrogen (l) IC	+						

+ implemented

* Blending with biofuels or synthetic fuels possible

Objective and Scope

The Energy and Climate Package aims at achieving 20-20-20-2020 via

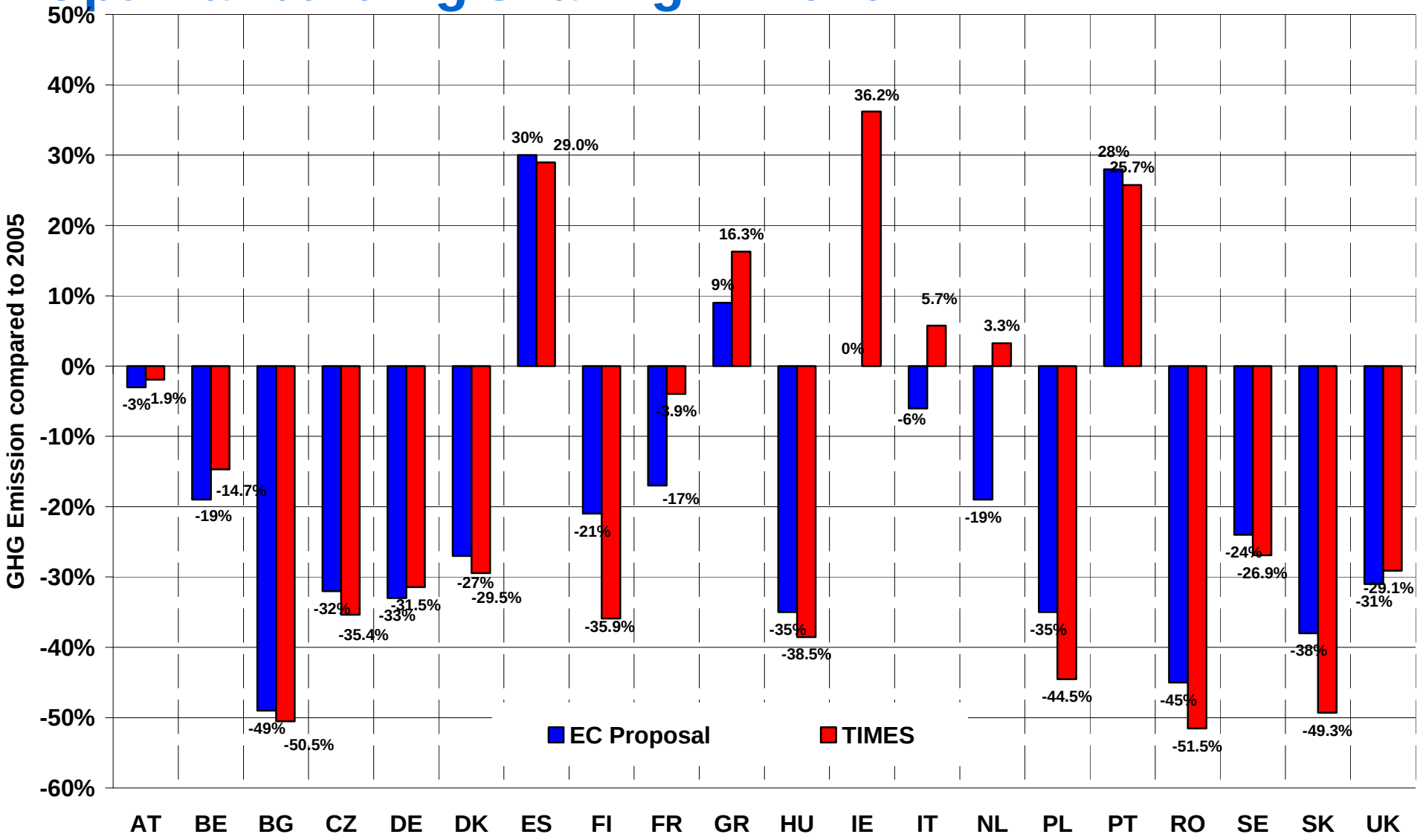
- EU Emission Trading Scheme: -21% GHG in 2020 compared to 2005
- Non-ETS: -10% GHG in 2020 compared to 2005
- RES: 20% of final energy consumption in 2020

Assessment of the…

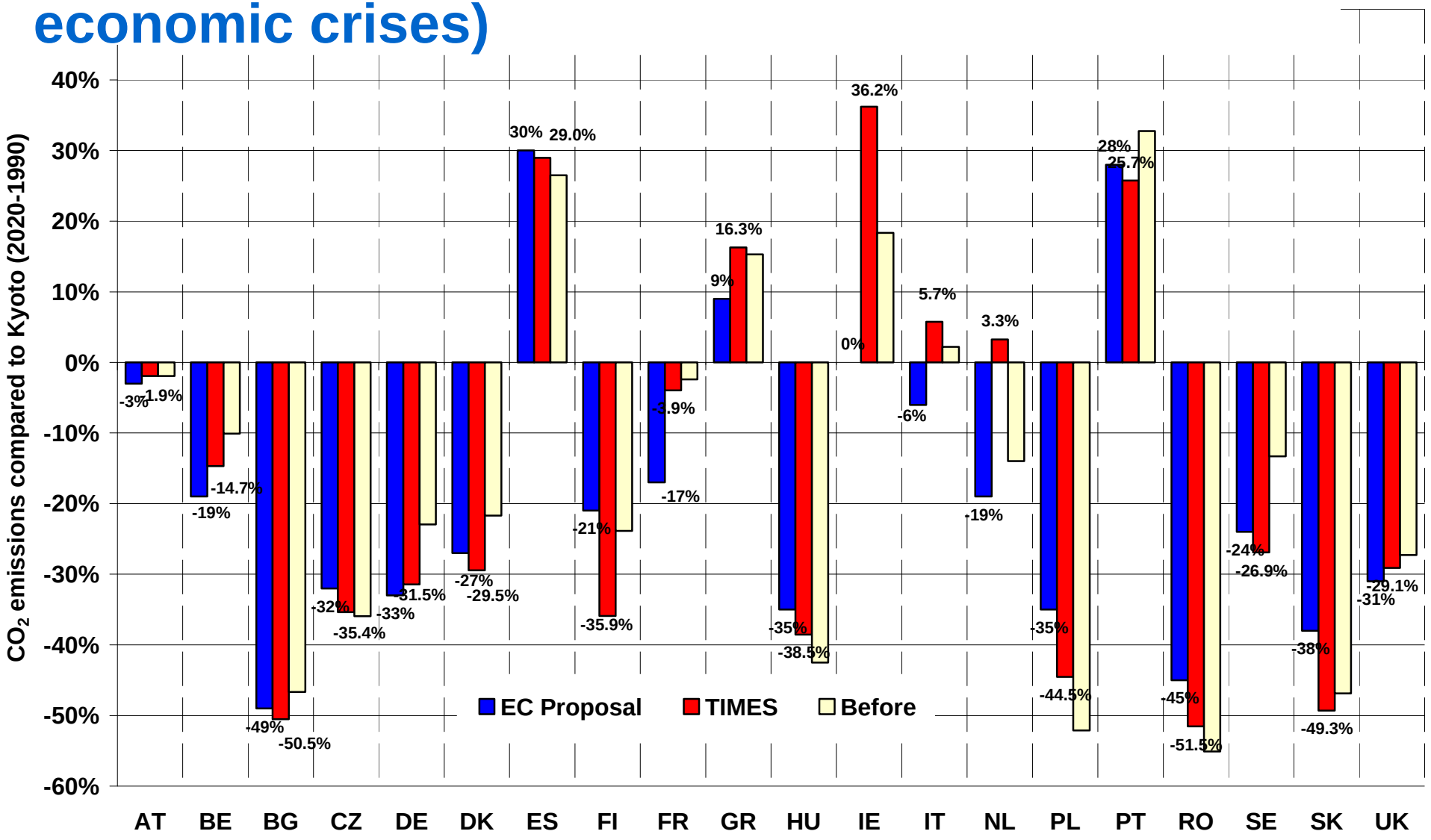
- Proposed target distinctions for ETS and Non-ETS
- Effort sharing proposals between member states
- Role of the RES target, including its national allocation

….. and what happens beyond ?

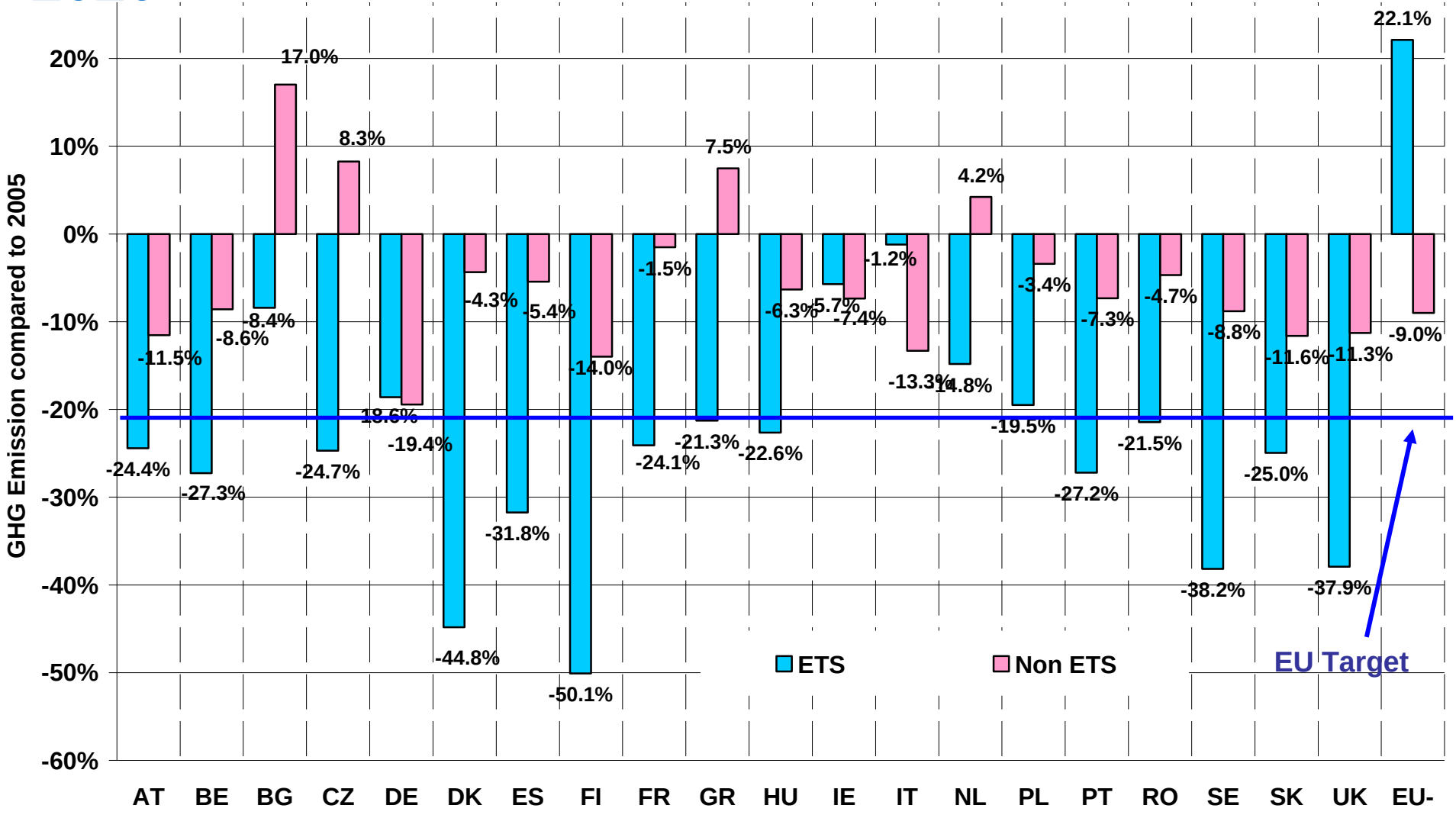
Optimal burding sharing in 2020



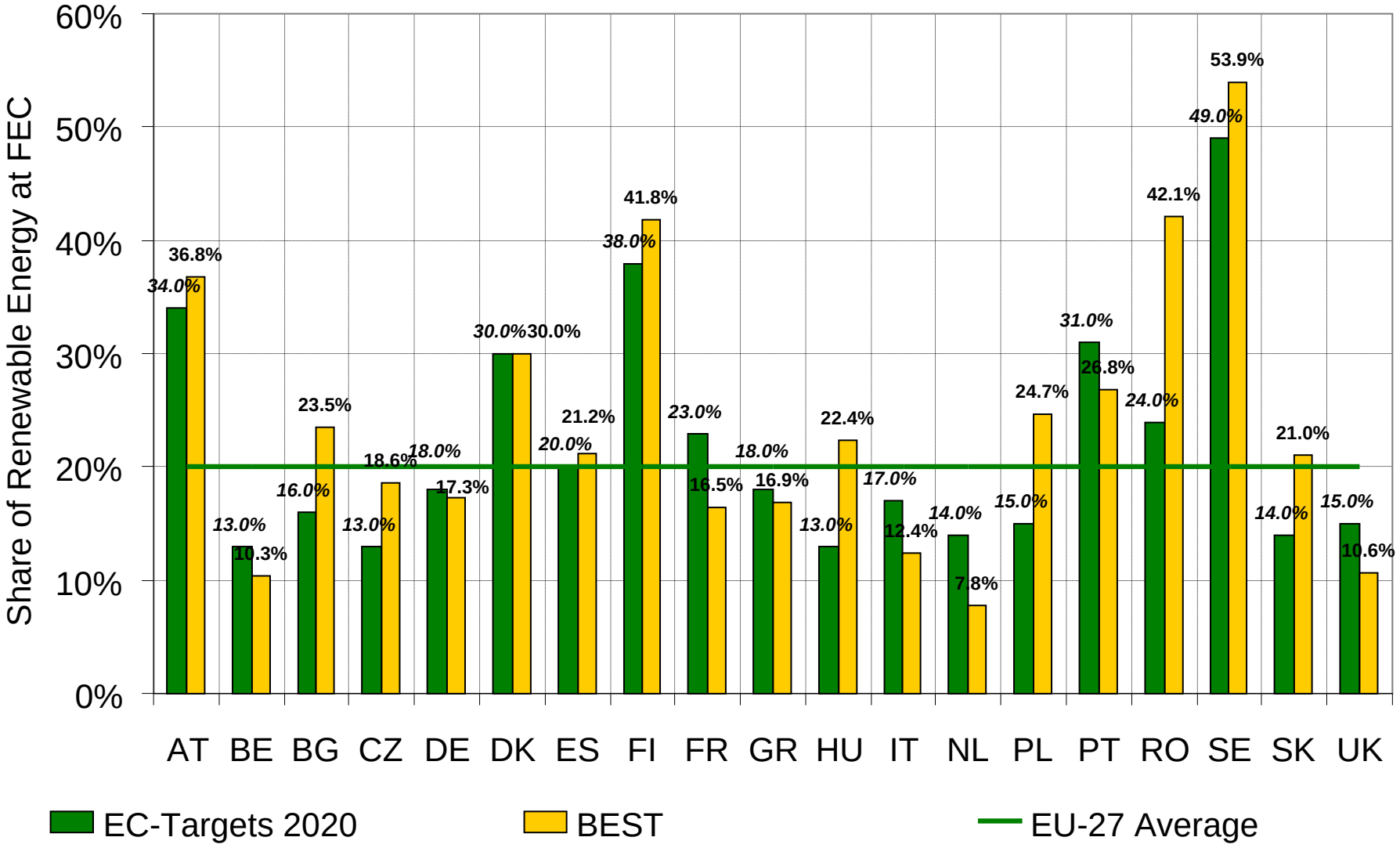
Optimal burding sharing in 2020 (and before the economic crises)



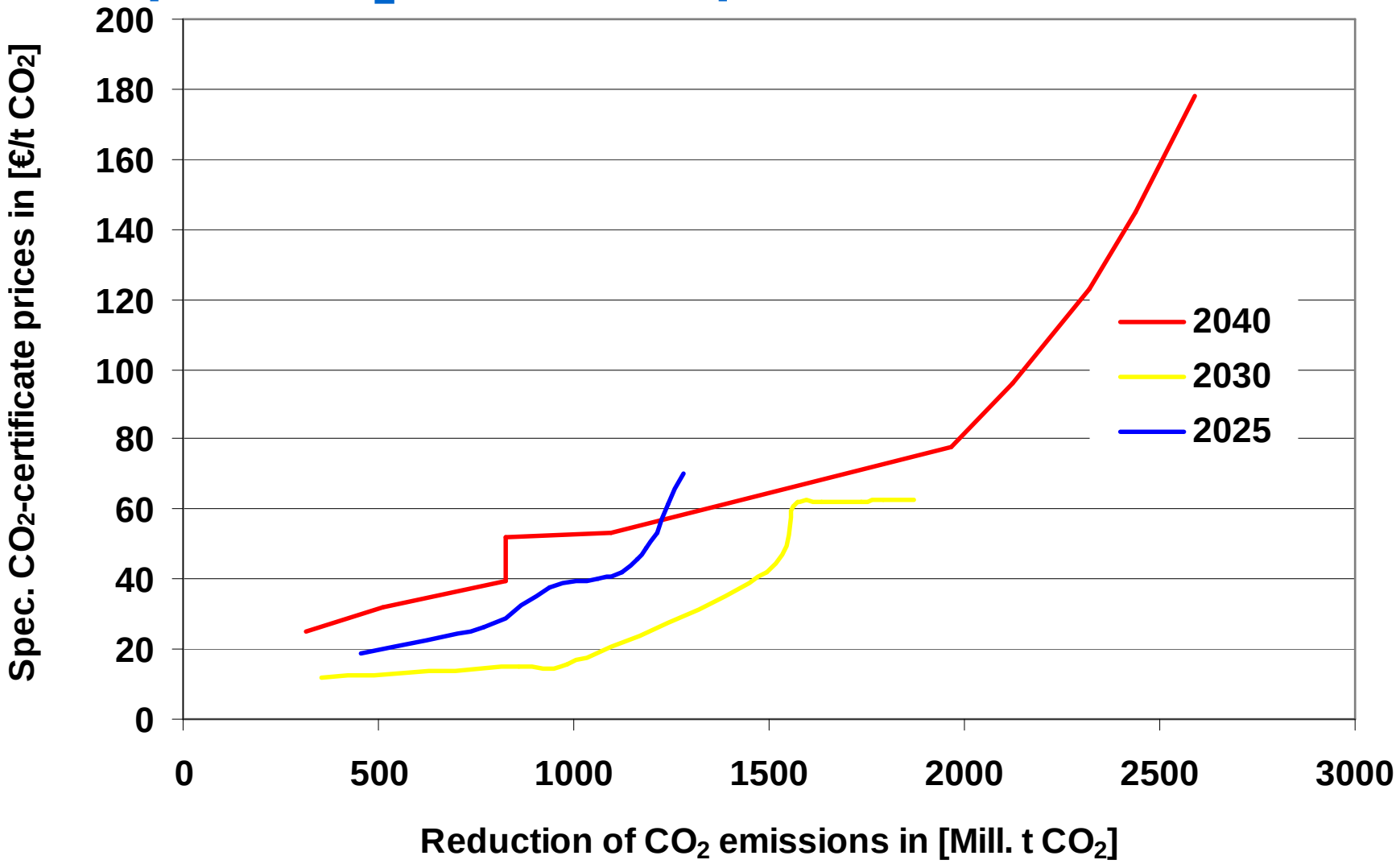
Optimal share between ETS and Non-ETS reduction 2020



Optimal RES Allocation vs. EU-Targets



Dependency of the CO_2 reduction potential on the spec. CO_2 certificate price



Scenario analysis

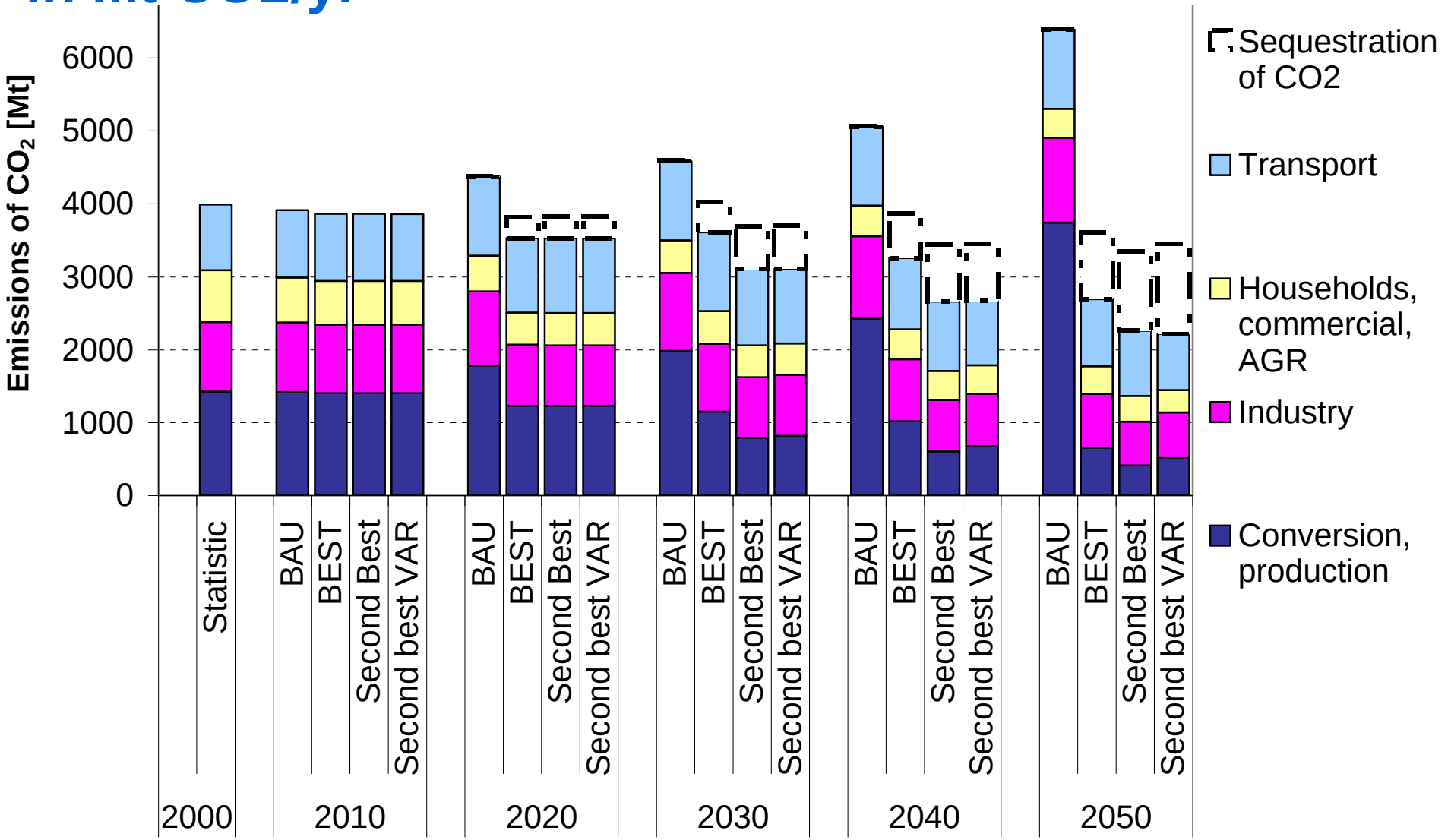
1. **Baseline case (REF)**
   - No emission reduction measures
   - Nuclear phase out according policy of respective EU countries
   - Minimum renewable energy use

2. **BEST climate policy on global trade**
   - EU 20-20 target
   - GHG emission reduction from 2020 linear to -39% by 2050

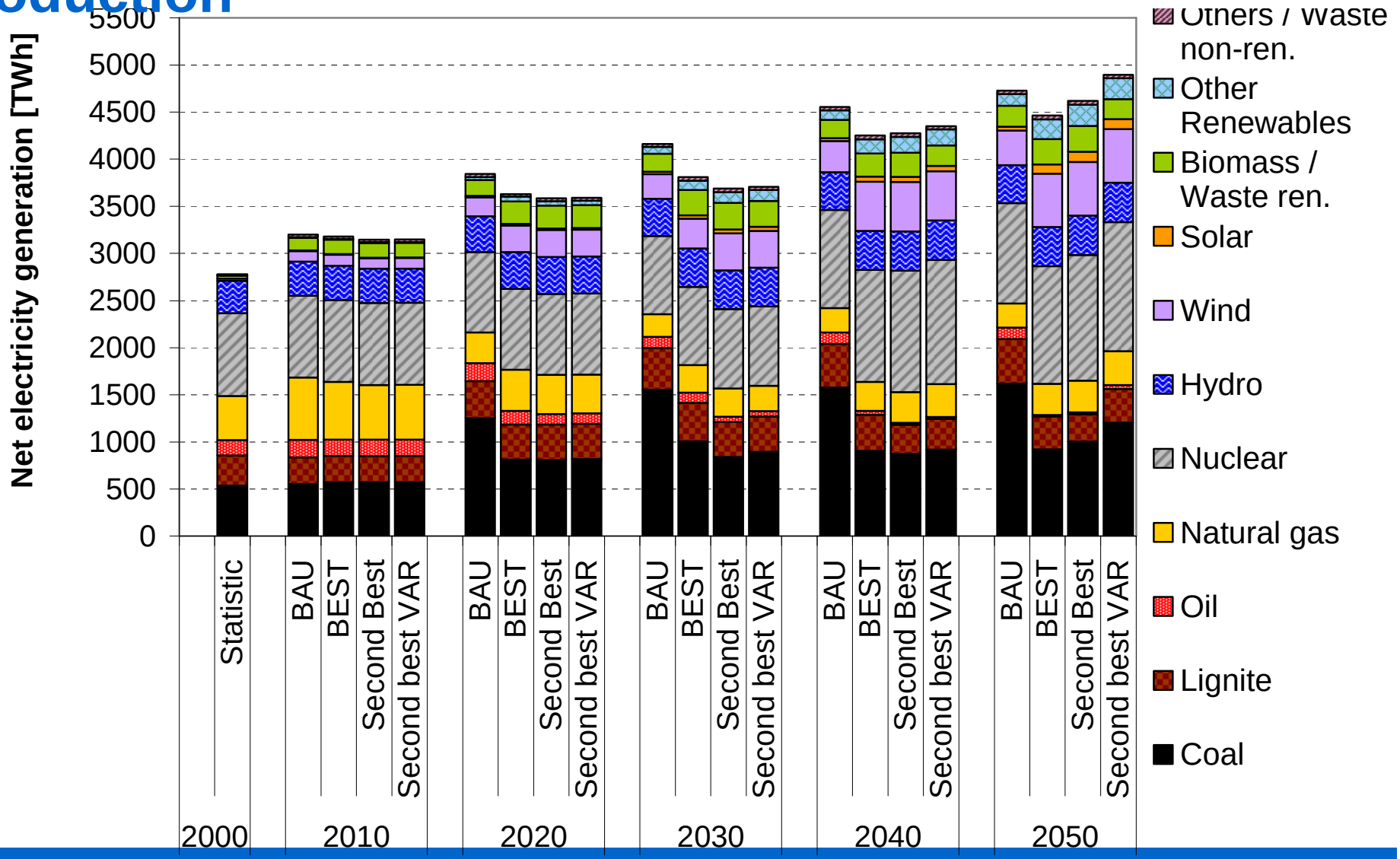
3. **Second Best**
   - EU 20-20 target
   - GHG emission reduction from 2020 linear to -50% by 2050

4. **Second Best VAR**
   - EU 20-20 target
   - GHG emission reduction from 2020 linear to -50% by 2050
   - Limit the ETS part to stress the Non-ETS sector

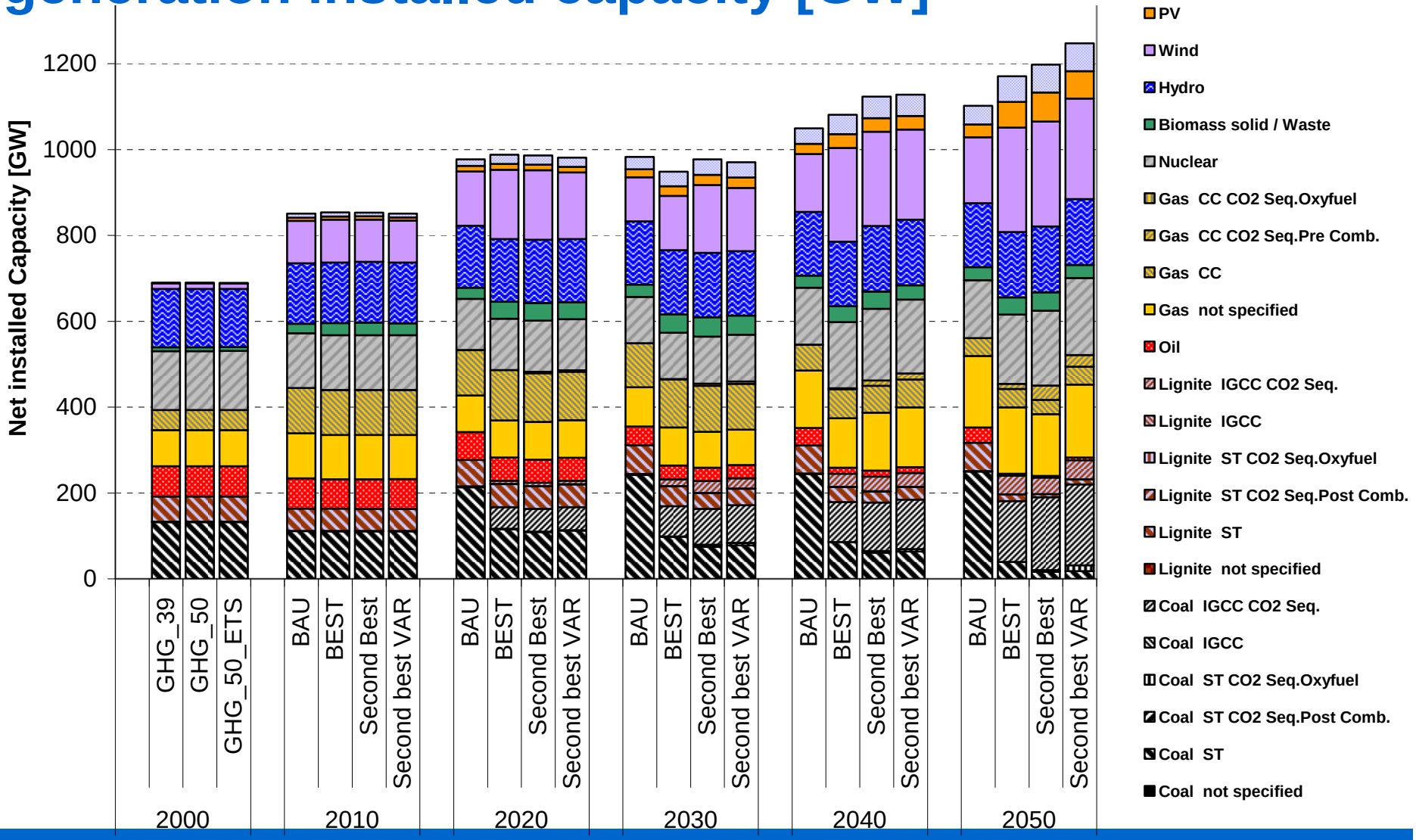
Scenario Comparison, EU27: Carbon Emissions in Mt CO2/yr



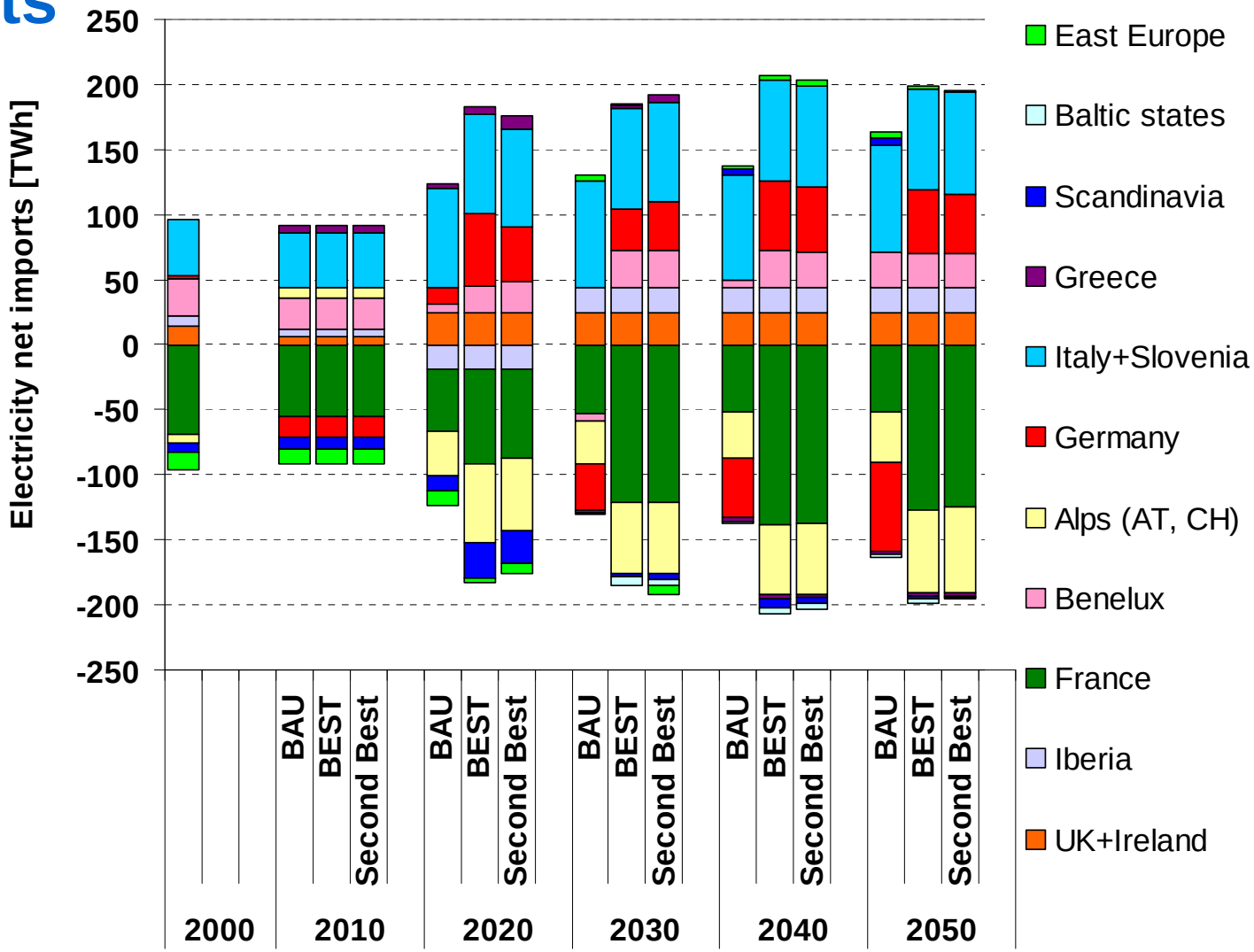
Scenario Comparison, EU27: Net Electricity Production



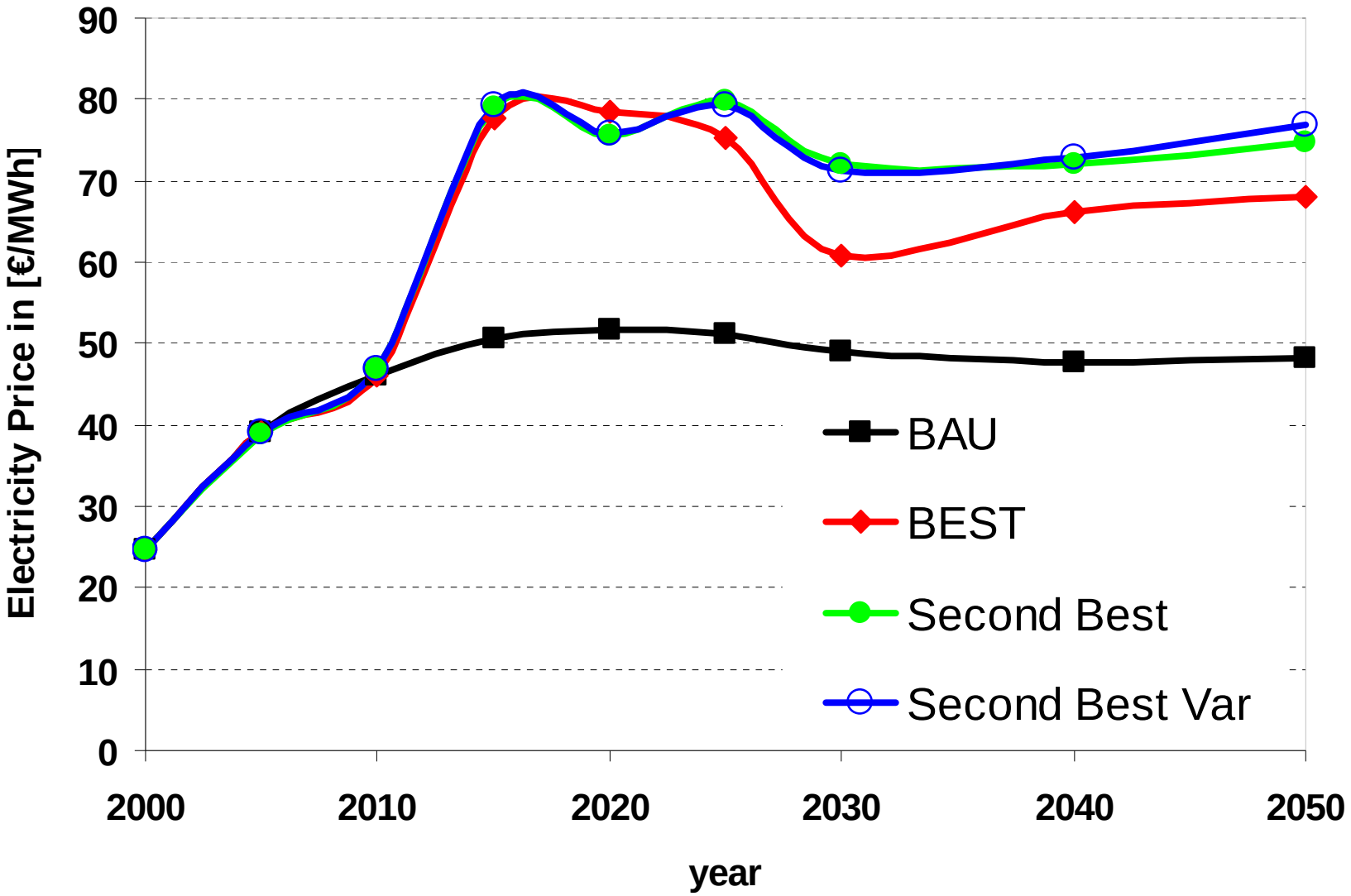
Scenario Comparison, EU27: Net electricity generation installed capacity [GW]



Scenario Comparison, EU27: Net Electricity Imports



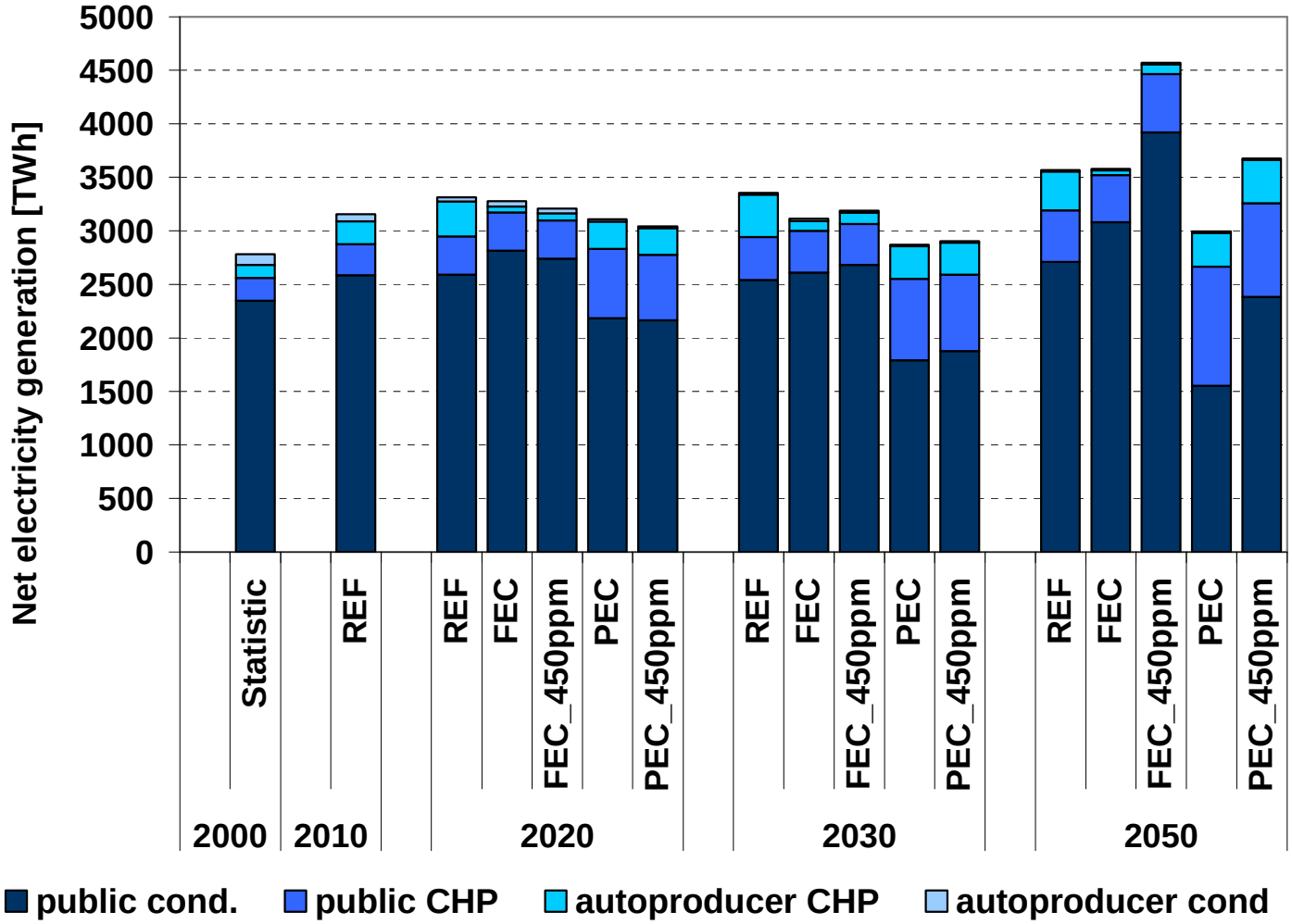
Scenario Comparison, EU27: Electricity Prices



Scenario definition and white certificates

Scenario	Description
REF	▪ Business as usual [**Ref**eren**c**e case] ▪ -21% CO_2 reduction till 2020 in ETS sector
FEC	▪ -21% CO_2 reduction till 2020 in ETS sector ▪ Reduction target **F**inal **E**nergy **C**onsumption [white certificates for FEC]
FEC_450ppm	▪ -21% CO_2 reduction till 2020 in ETS sector **+** 450ppm target till 2050 ▪ Reduction target **F**inal **E**nergy **C**onsumption [white certificates for FEC]
PEC	▪ -21% CO_2 reduction till 2020 in ETS sector ▪ Reduction target **P**rimary **E**nergy **C**onsumption [white certificates for PEC]
PEC_450ppm	▪ -21% CO_2 reduction till 2020 in ETS sector **+** 450ppm target till 2050 ▪ Reduction target **P**rimary **E**nergy **C**onsumption [white certificates for PEC]

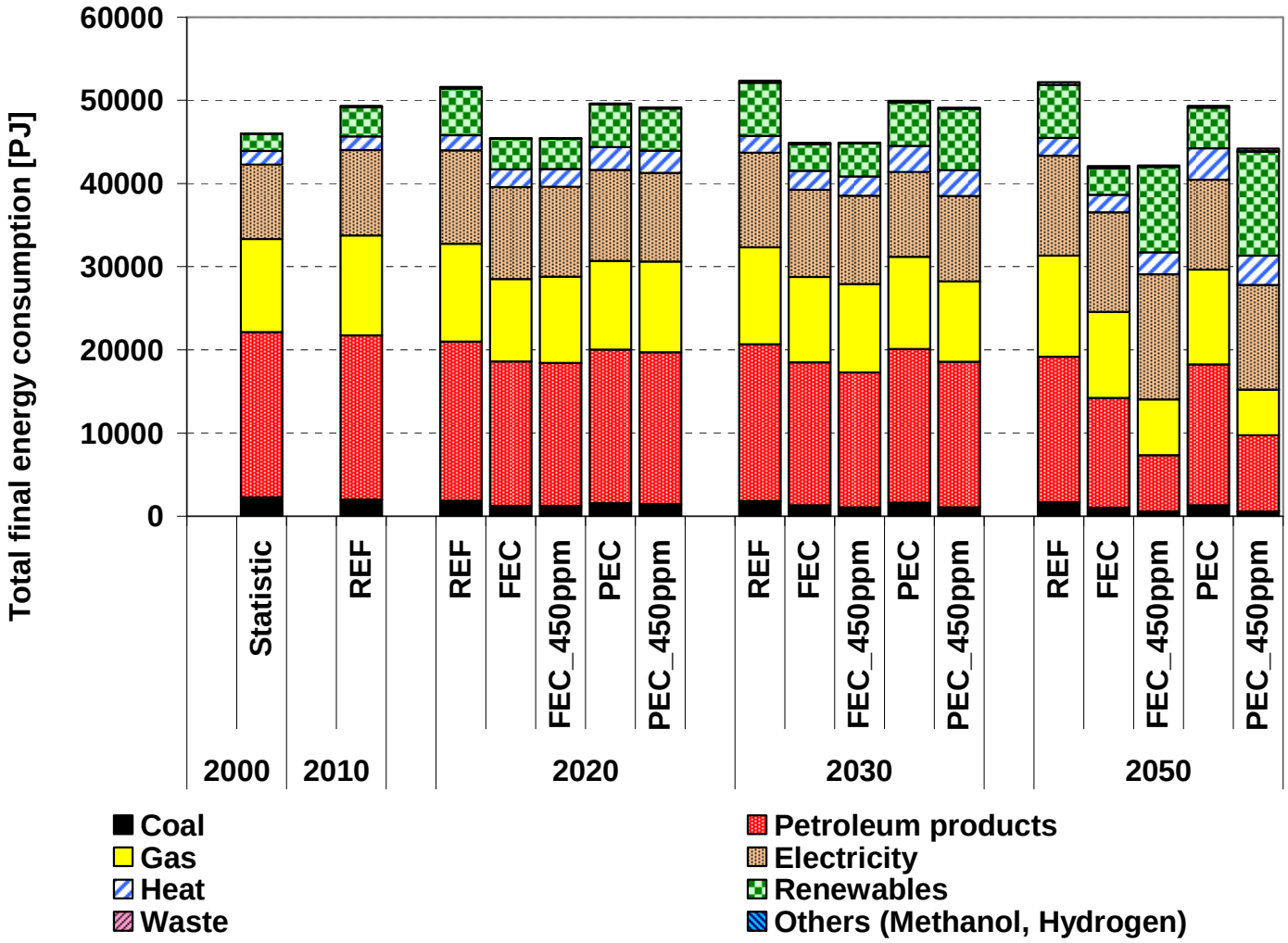
Net electricity generation by technology (EU-27)



Key effects:

- **FEC:** Increase of public generation from condensing power plants/ decrease auto production (industry)
- **PEC:** Increase public CHP/ decrease public condensing plants (total decrease)
- **450ppm:** Increase of electricity generation in both scenarios

Final energy consumption (EU-27)

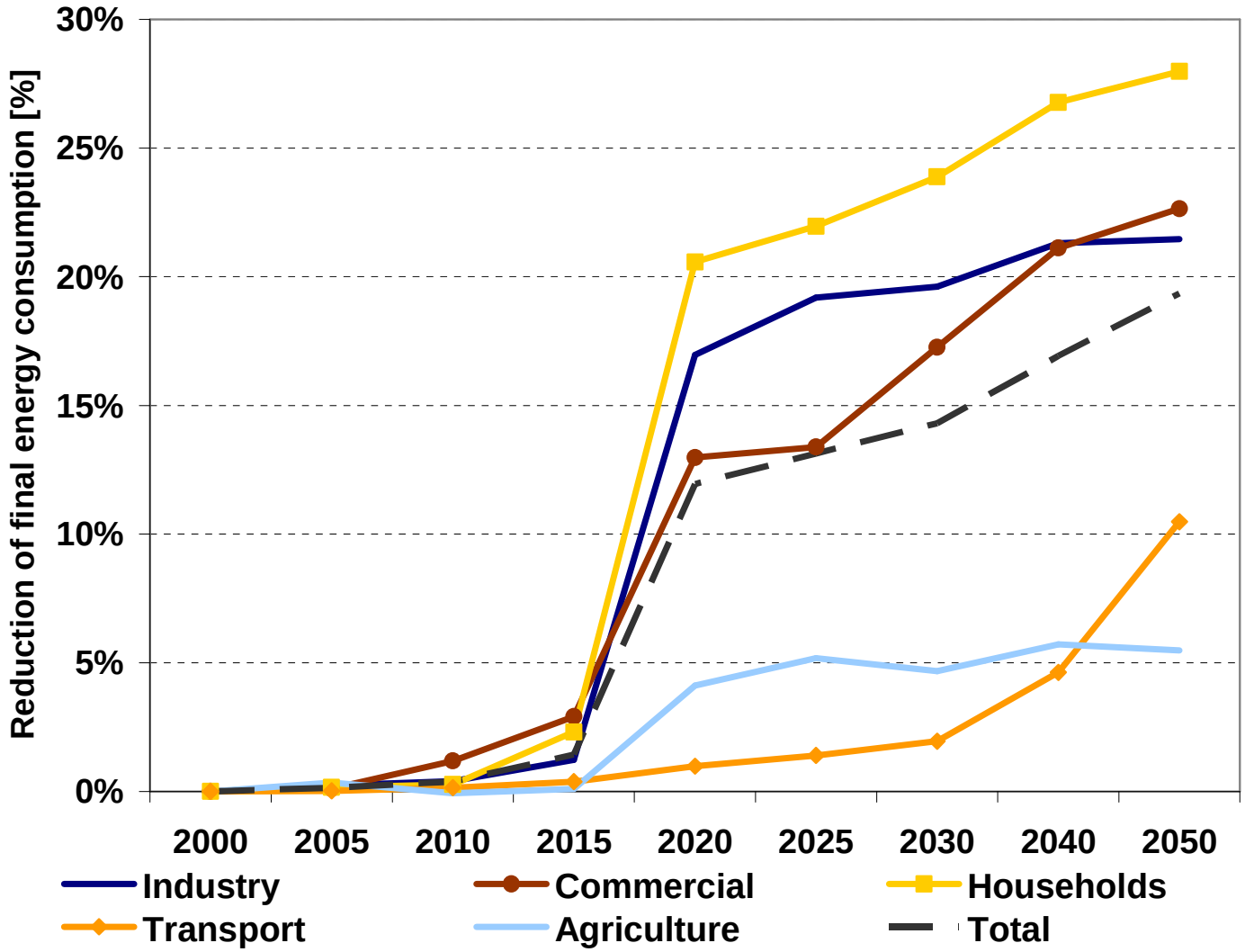


Key effects:

- **FEC:** less renewables
- **450ppm:** in both scenarios higher share of electricity and renewables, less oil
- **PEC:** just small changes compared to scenario REF (shift to district heat, less renewables)

Reduction final energy consumption by sector (EU-27)

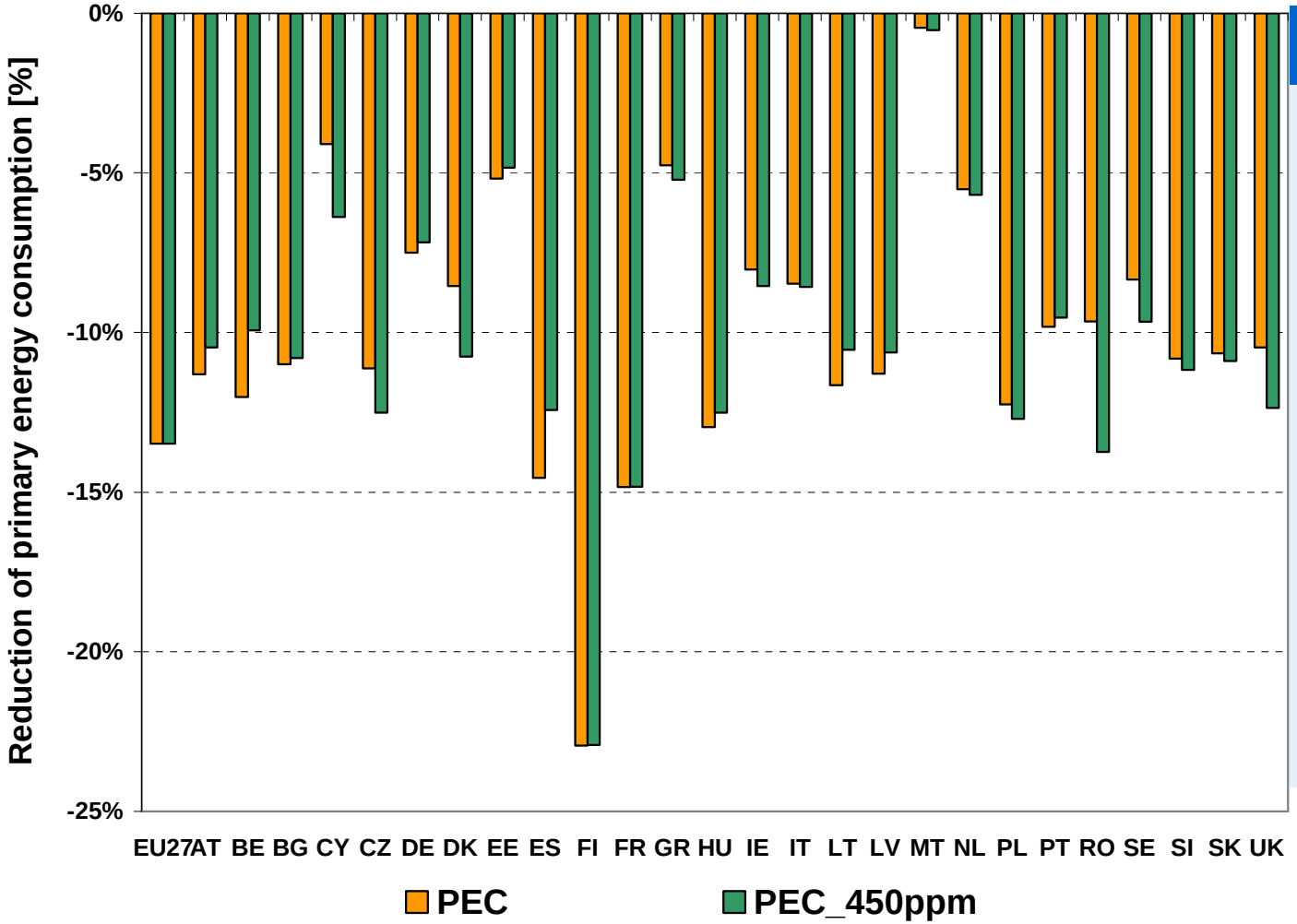
[scenario FEC compared to REF]



Key effects:

- **Sector view:** reduction mainly in residential and industry (main driver: space and process heat supply)
- **2025:** also clear reduction in commercial sector
- **Transport:** no clear reduction before 2040

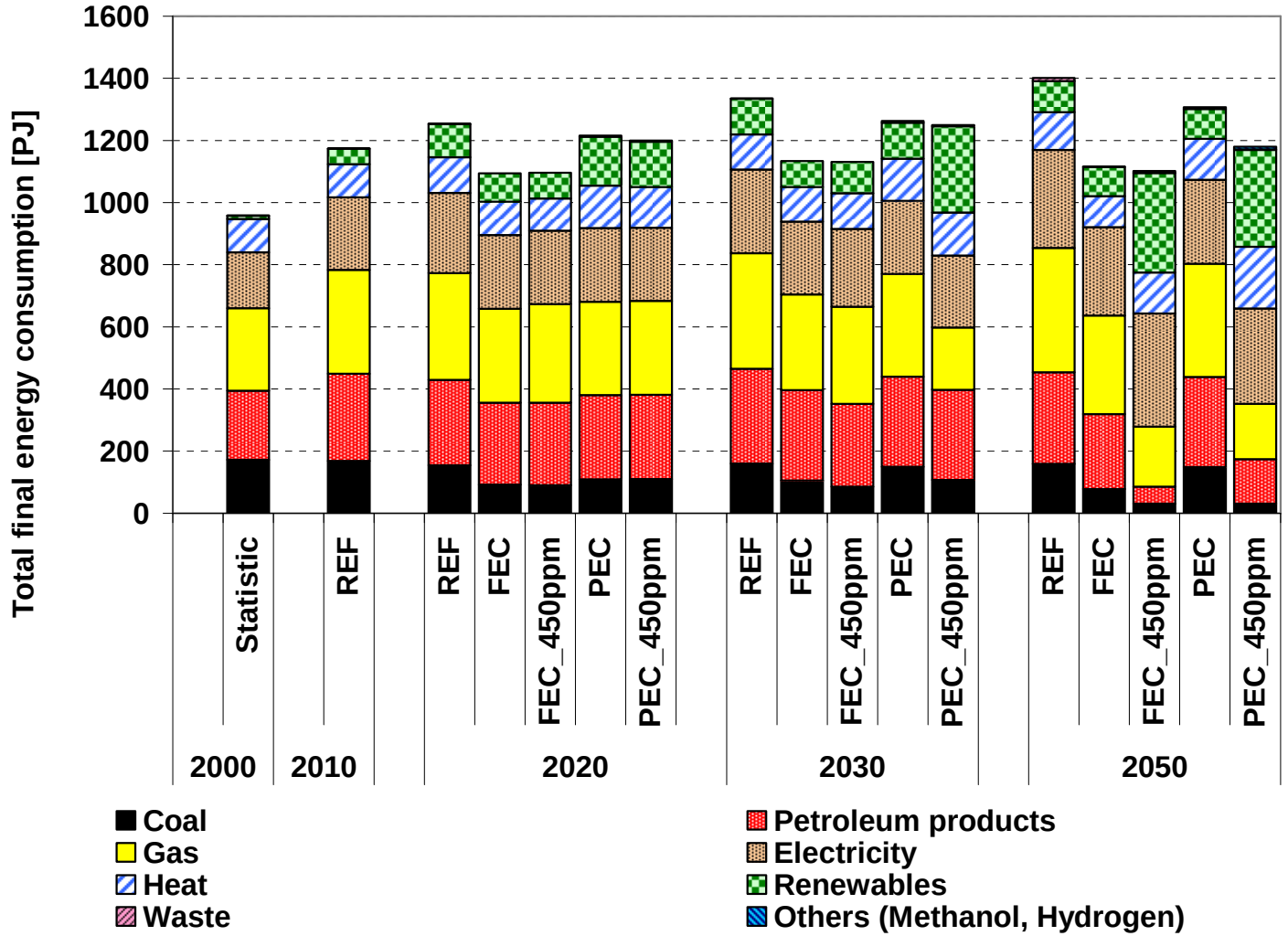
Burden sharing: Reduction of primary energy consumption [scenarios compared to REF in 2020]



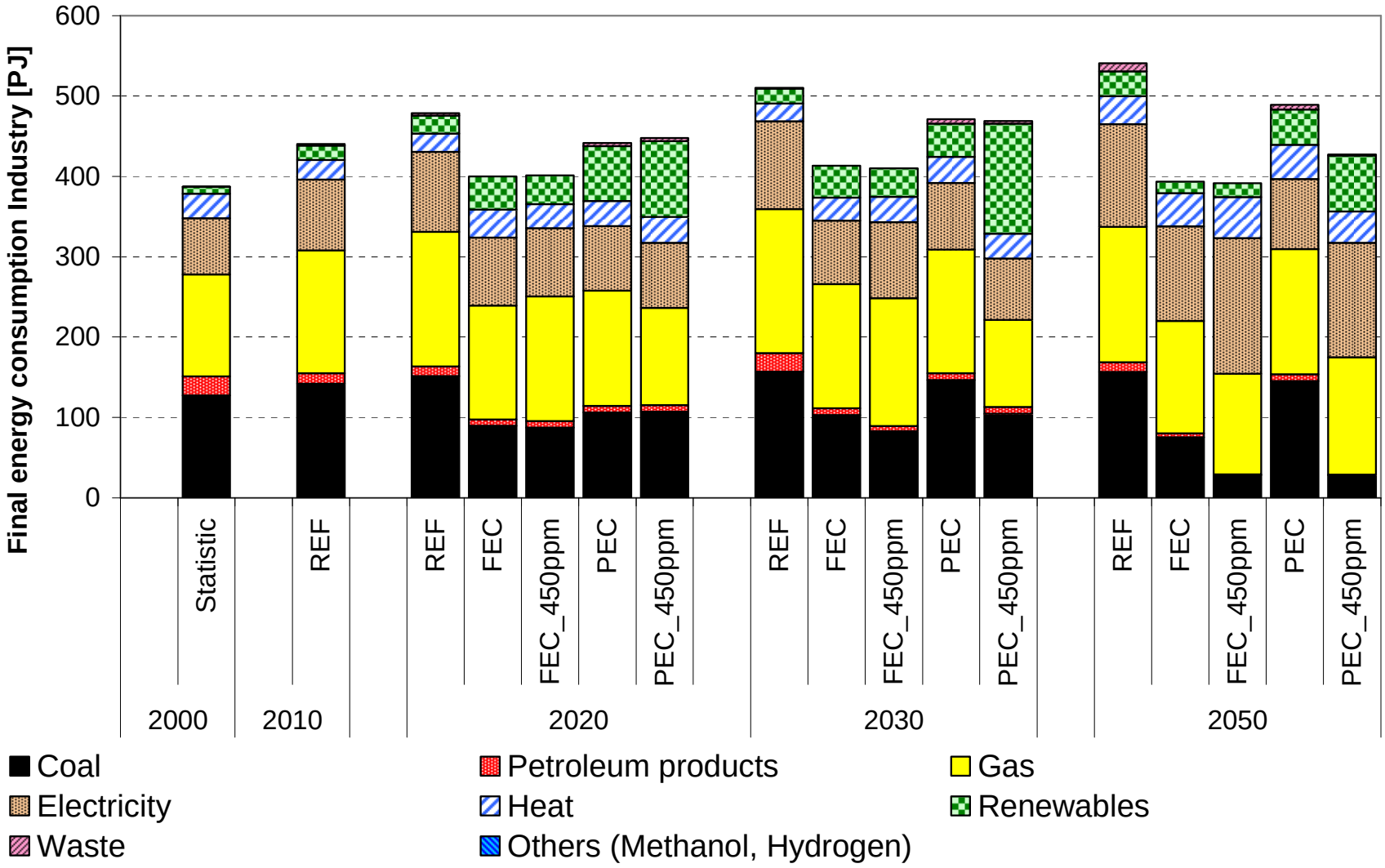
Key effects:

- **Key driver:** the main influence has the conversion/ production sector, especially the electricity generation
- **Burden sharing:** according to changes in electricity generation (less nuclear/coal); also changes in electricity trade

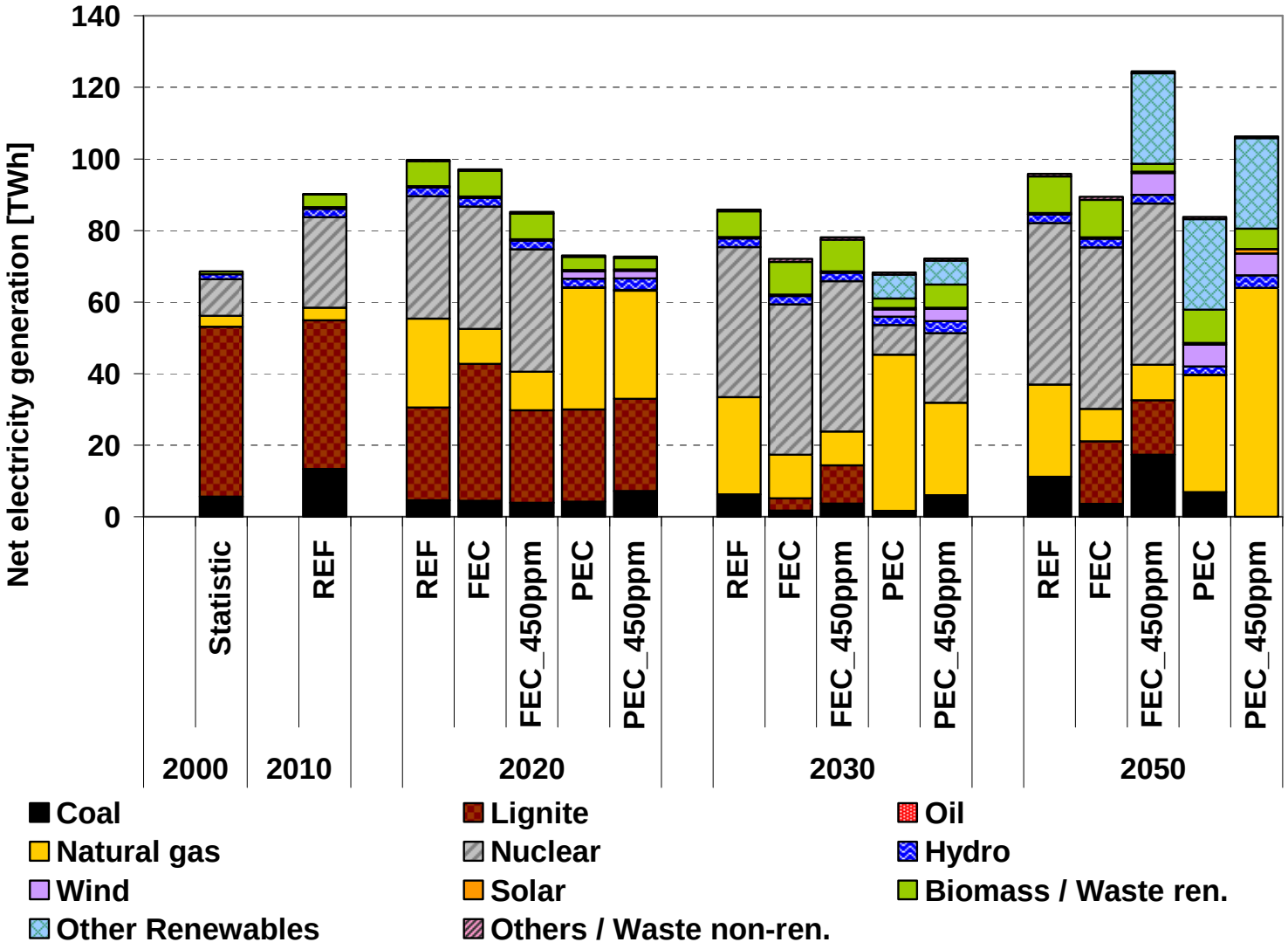
Final Energy Consumption (CZ)



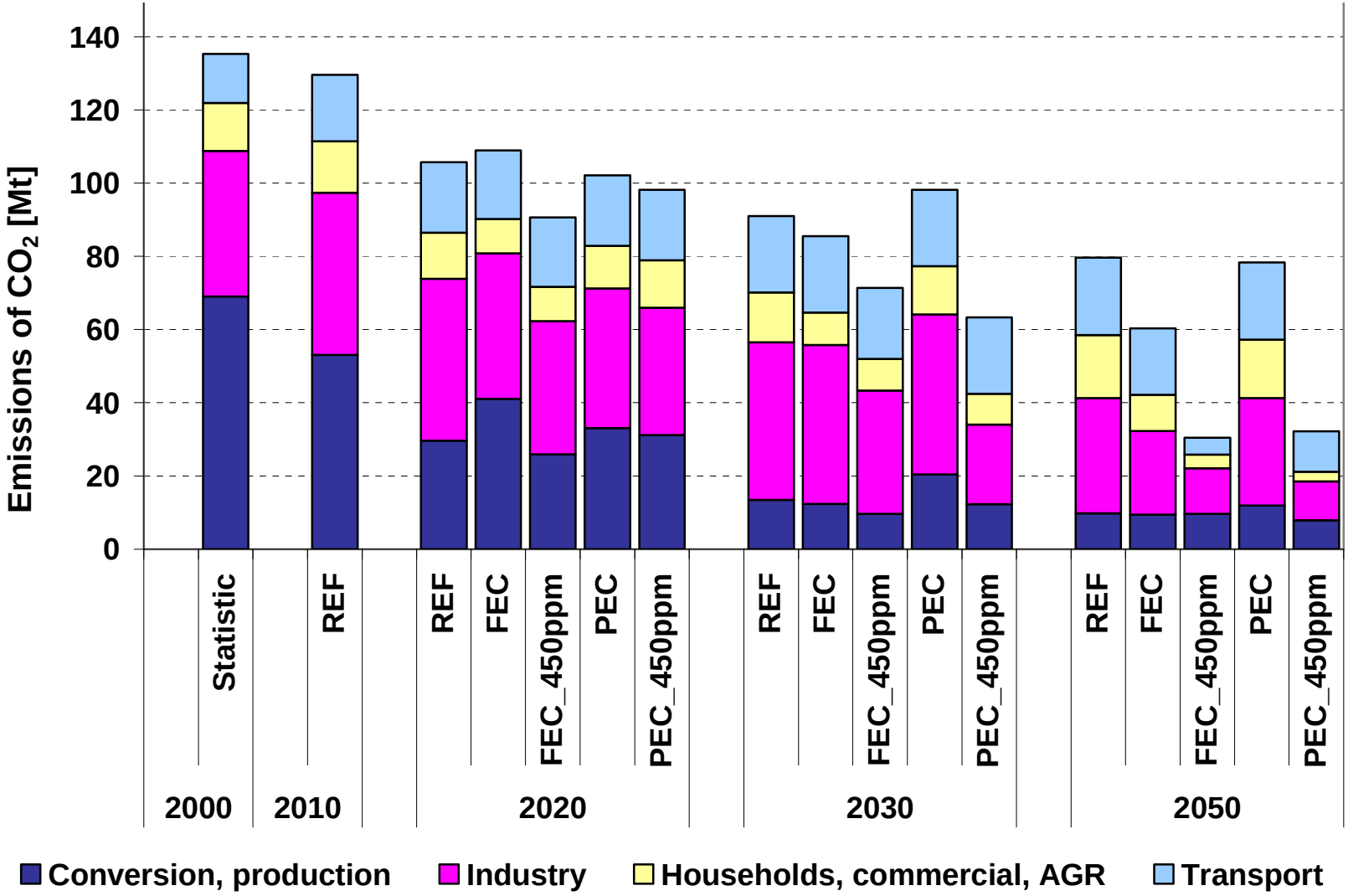
FEC Industry (CZ)



Net electricity generation (CZ)



CO_2- Emissions (CZ)



Conclusions

- **The development of the Czech energy system is not independent of the EU27 policy and the energy policy in the other member states.**

- **The economic development or in general the requested demand influence on the same level the future energy system as the technology development and availability. A linkage between a CGE model can fill this gap.**

- **In the period between 2030 and 2050 the level of the GHG reduction target for the EU27 depends on the possibility of cost effective world wide reduction potentials. In general additional policy measures which are reducing the flexibility of the energy systems are not cost efficient.**

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