Energy Technology Systems Analysis Programme

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ETSAP Operating Agent

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The Programme of Energy Technology Systems Analysis …

Started after the first oil crisis, in order to understand through systems analysis, whether:

- alternatives to oil were technically feasible, economically and environmentally sustainable;
- solutions were global or dependent on national circumstances;
- global energy R&D paths were possible or advantageous.

After two years of analyses (1976-77), since the tools available at the time were not sufficient to provide answers, the group developed a new tool, **the MARKAL model generator**.

Annexes

	1976-77	Analysis of existing tools for evaluating R&D strategies	
	1978-80	MARKAL Model generator development (US-BNL, GE-KFA)	
I.	1981-83	Energy Technology Systems Analysis Project	
II.	1984-86	Information Exchange Project	
III.	1987-89	International Forum on Energy Environment Studies	
IV.	1990-92	Greenhouse Gases And National Energy Options: Technologies & Costs for Reducing GHG Emissions	
V.	1993-95	Energy Options For Sustainable Development	
VI.	1996-98	Dealing With Uncertainty Together	
VII.	1999-02	Contributing To The Kyoto Protocol	
VIII.	2002-05	Exploring Energy Technology Perspectives	
IX.	2003-05	Energy Models Users' Group	
X.	2005-08	Global Energy Systems and Common Analyses	
XI.	2008-10	JOint STudies for New And Mitigated Energy Systems	(JOSTNAMES)
XII.	**2011-13**	**Policy Analysis for Global Sustainability**	**(PAT-SUS)**
		(annual fee: 20k€ per participant)	

Objectives

ETSAP experts assist decision-makers in assessing policies intended to meet the challenges of

- energy needs,
- technological progress,
- environmental concerns, and
- economic development,

… by carrying out

- a programme of co-operative energy technology systems analysis, and
- modelling studies of possible developments of the energy system.

Strategy

The objectives are achieved through a twofold strategy:

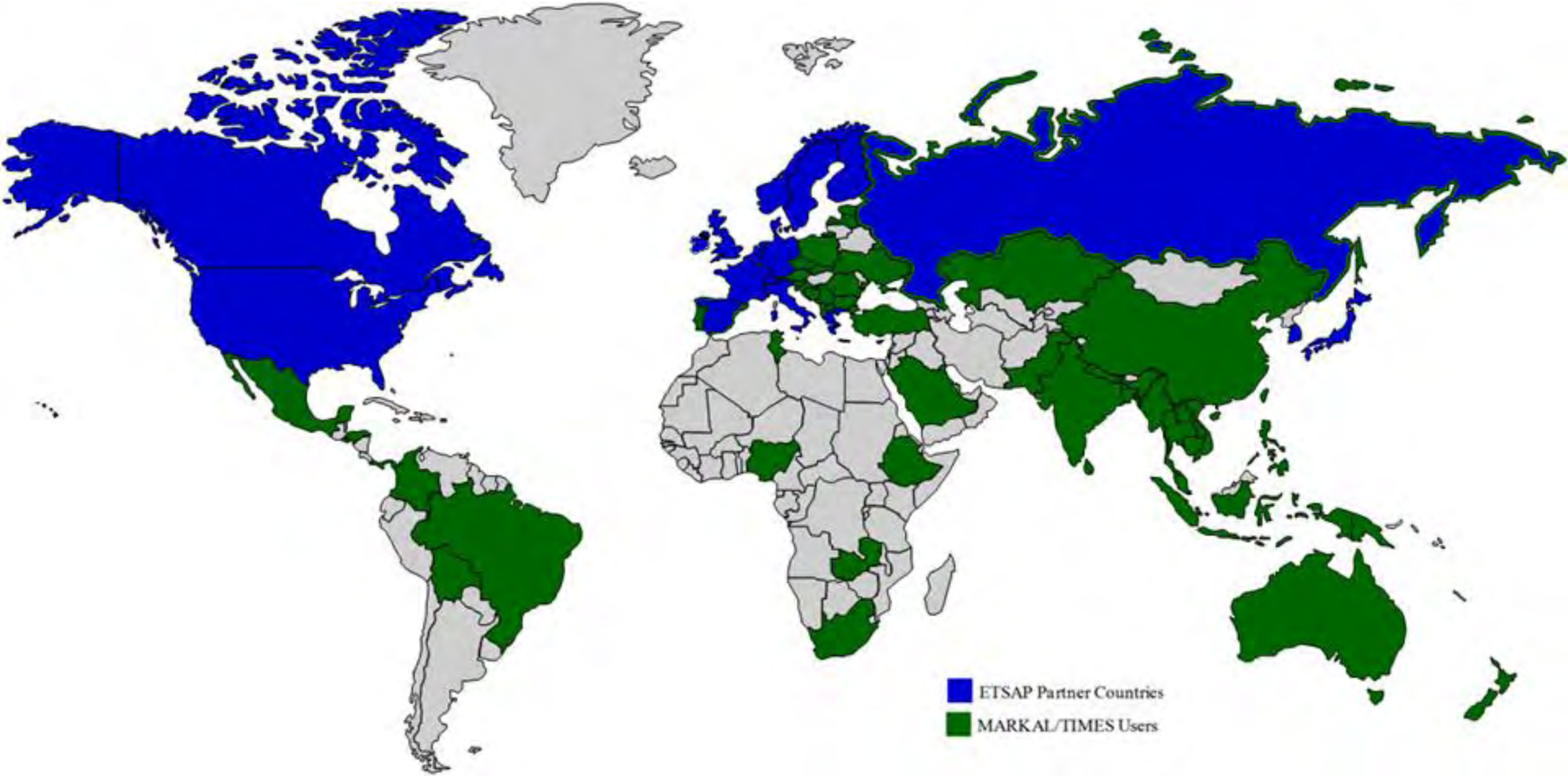
1. ETSAP has established, and now maintains / enhances the flexibility of consistent **multi-country energy / engineering / economy / environment** analytical tools and capability **(the MARKAL-TIMES family of models)**, through a common research programme.

2. ETSAP members also assist and support government officials and decision-makers by applying these tools for energy technology assessment and analyses of other energy and environment related policy issues. In fact they implement several economic-equilibrium technology-explicit models of global, regional, national, and local energy systems.

Participants - Annex XII (2011-2013)

Country	CP/Institution	Country	CP/Institution
Belgium	FPP/ VITO-KUL	**Japan**	
Canada	NRCan/GERAD	**Korea**	KEMCO
Denmark	DEA/Risoe	**Netherlands**	ECN
EC	DGRTD/JRC (IET,IPTS)	**Norway**	IFE
Finland	TEKES/VTT	**Russia**	ERI-RAS
France	DGEMPEDAD/ADEME-EDMP	**Spain**	CIEMAT
Germany	IER	**Sweden**	STEM/Chalmers
Greece	CRES	**Switzerland**	PSI
Ireland	SEAI/UCC	**UK**	DECC/AEAT
Italy	CNR-IMAA / ENEA	**US**	DOE/BNL

MARKAL–TIMES licensed tools users (>200)



Only those countries with at least one MARKAL/TIMES modelling team active during the period are "painted."

A. Technology Systems

An energy technology is any device that produces, transforms, transmits, distributes or uses energy, such as refineries, power plants, pipelines, boilers, trucks, lamps, kilns, ovens, etc.

- Some technologies are complementary
- Some technologies are substitutes

Energy technologies do not work in isolation, all together they form a system, which touches several dimensions:

- **E**nergy
- **E**ngineering
- **E**conomy
- **E**nvironment

And other (social, administrative, etc.)

Systems Analysis

"Systems analysis applies systems principles to aid decision makers in problems of

a. *identifying*,

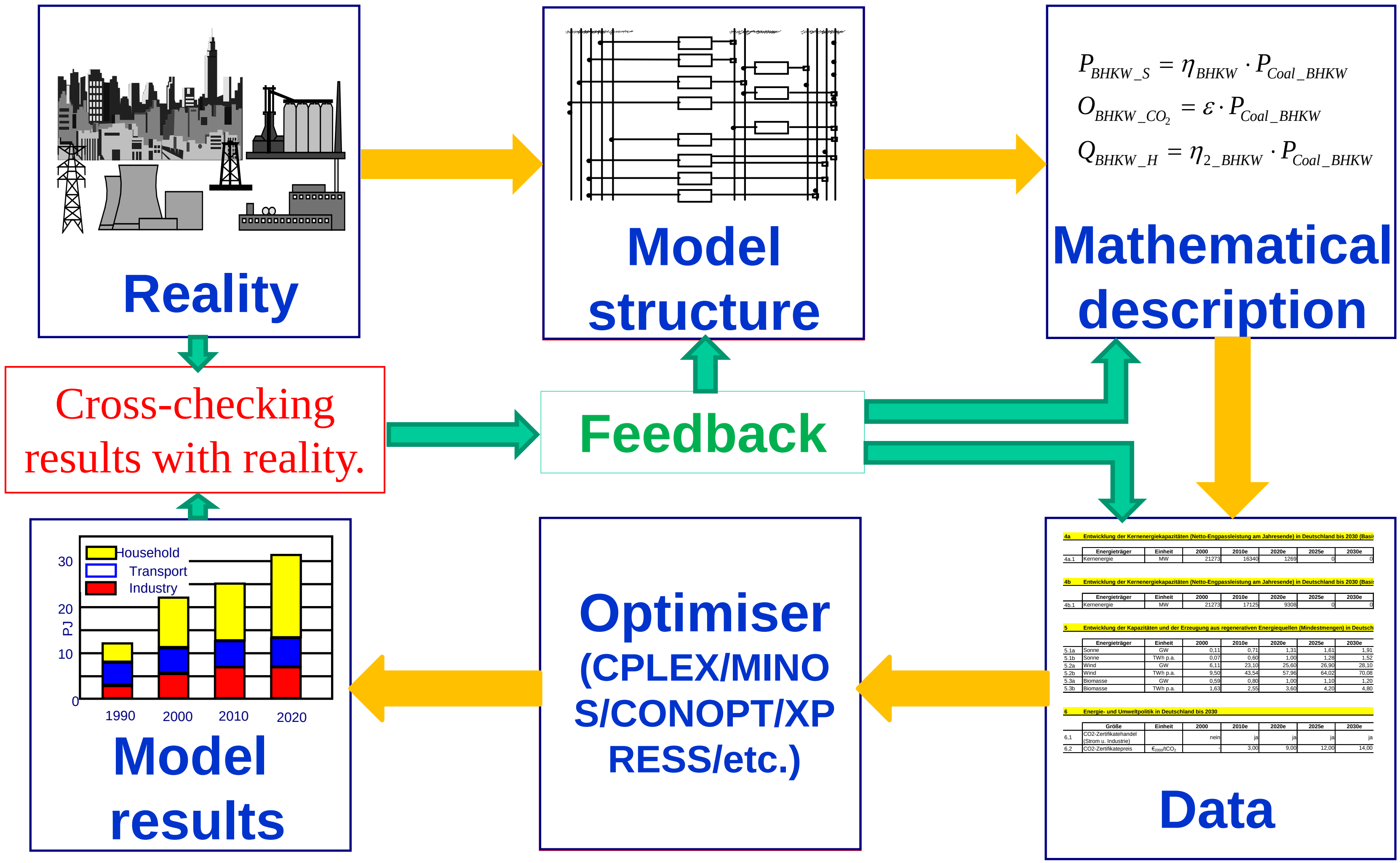
b. *quantifying*, and

c. *controlling*

a system.

"While taking into account multiple objectives, constraints, resources, it aims to specify possible courses of action, together with their risks, costs and benefits."

(quoted from Principia Cybernetica)



Depicting reality inside an energy systems model

MARKAL-TIMES features essential for representing energy storage options

1. Commodity explicit
2. Technology explicit
3. Reference Energy System approach
4. Substitution mechanism over long time horizons
5. Economic equilibrium
6. Trade-offs: economic surplus, emissions, diversity, etc.

7. Intra-year modulation, time slices
8. Storage technologies

1a. Commodity explicit: energy sources

- Non Renewable primary energy supply sources
  - Cumulative resource divided into several categories (e.g. connected gas, discovered gas, undiscovered gas), each with a total PJ in the ground
  - Unit Extraction cost per PJ for each category
    → **SUPPLY CURVE**
  - Upper bound on annual extraction from each category
- Renewable primary energy supply sources
  - List of categories (e.g. wind speeds, large vs small hydro), each with
    - Annual potential (PJ)
    - Unit cost per PJ

1b. Commodity explicit: Demands

- TIMES is normally driven by a vector of (several dozens) demands for energy services
  - Examples:
    - Car travel (vehicle-Kms)
    - Steel produced (tonnes)
    - Residential lighting (PJ of useful energy)
- Each demand may be satisfied by many competing technologies, using different energy forms:
    - Gasoline car, ethanol car, electric car, etc.
- Therefore, final energy is endogenous to TIMES.

2a. Technology explicit

Each technology is described in TIMES by a number of technical and economic parameters.

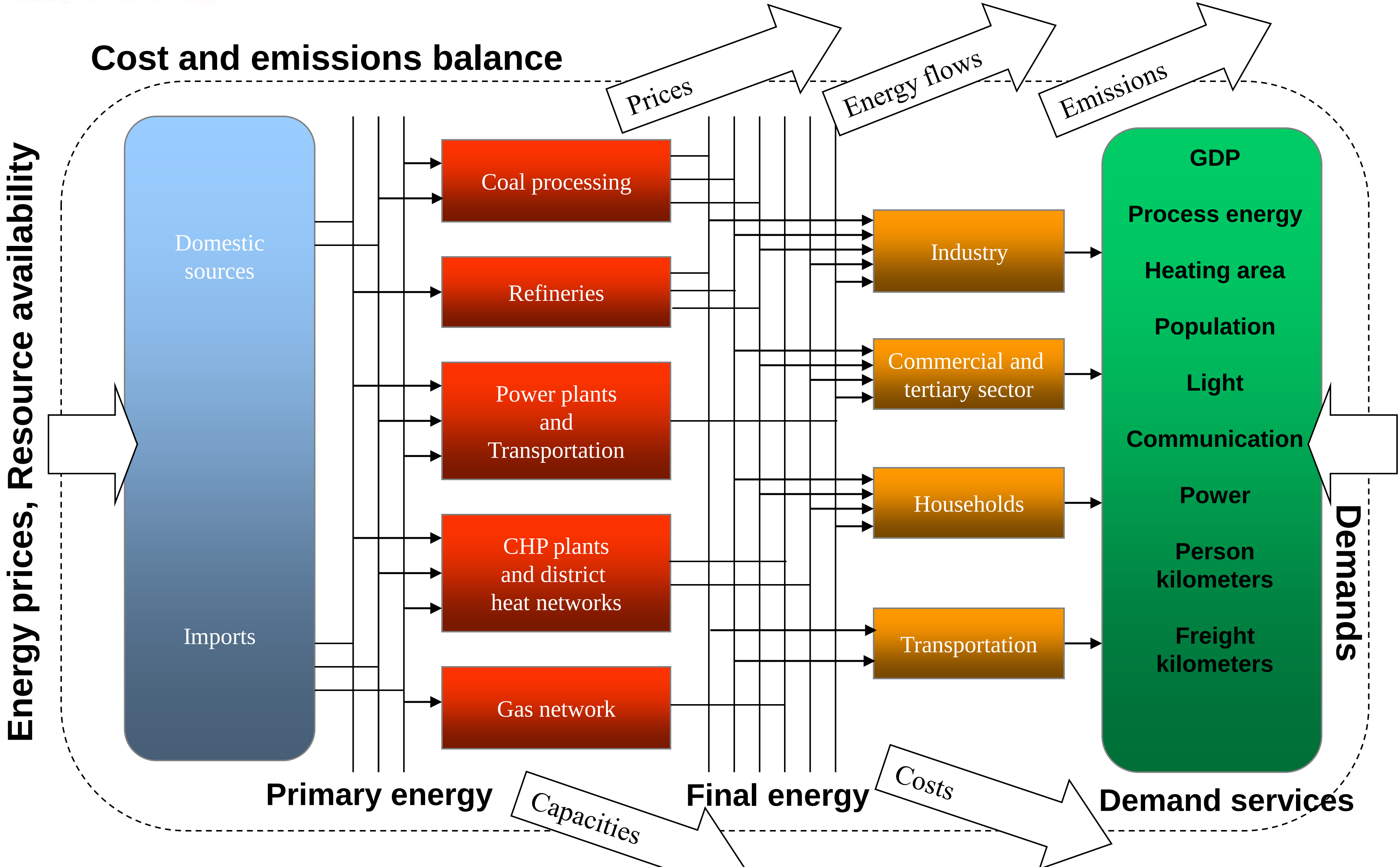
A mature TIMES model may include several thousand technologies in all sectors of the energy system (energy procurement, conversion, processing, transmission, and end-uses) in each region.

TIMES is not only technology explicit, it is technology rich as well.

The number of technologies and their relative topology may be changed at will, purely via data input specification, without the user ever having to modify the model's equations. The model is to a large extent **data driven**.

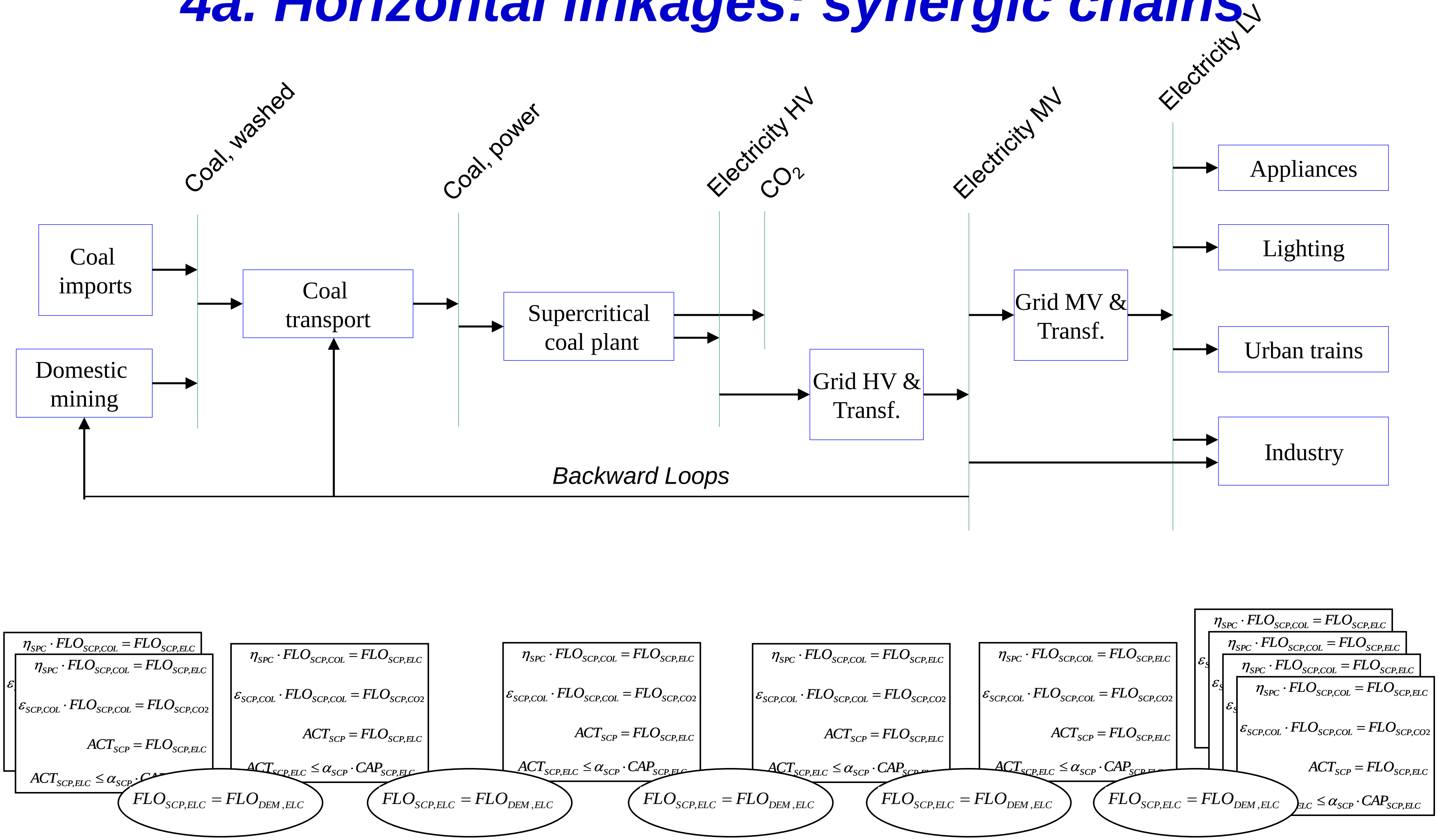
2b. Technologies explicit

- A technology is described by several parameters:
  - Technical life (years)
  - Availability factor (%)
  - List and amounts of (energy, materials, emissions) inputs and outputs per unit of activity
  - Efficiency (%)
  - Unit Investment cost (per unit of capacity) and decommissioning cost
  - Unit fixed annual O&M cost (per unit cap per year)
  - Unit variable operating cost (per unit of activity)
  - Hurdle rate (used to annualise investment costs)
  - START year

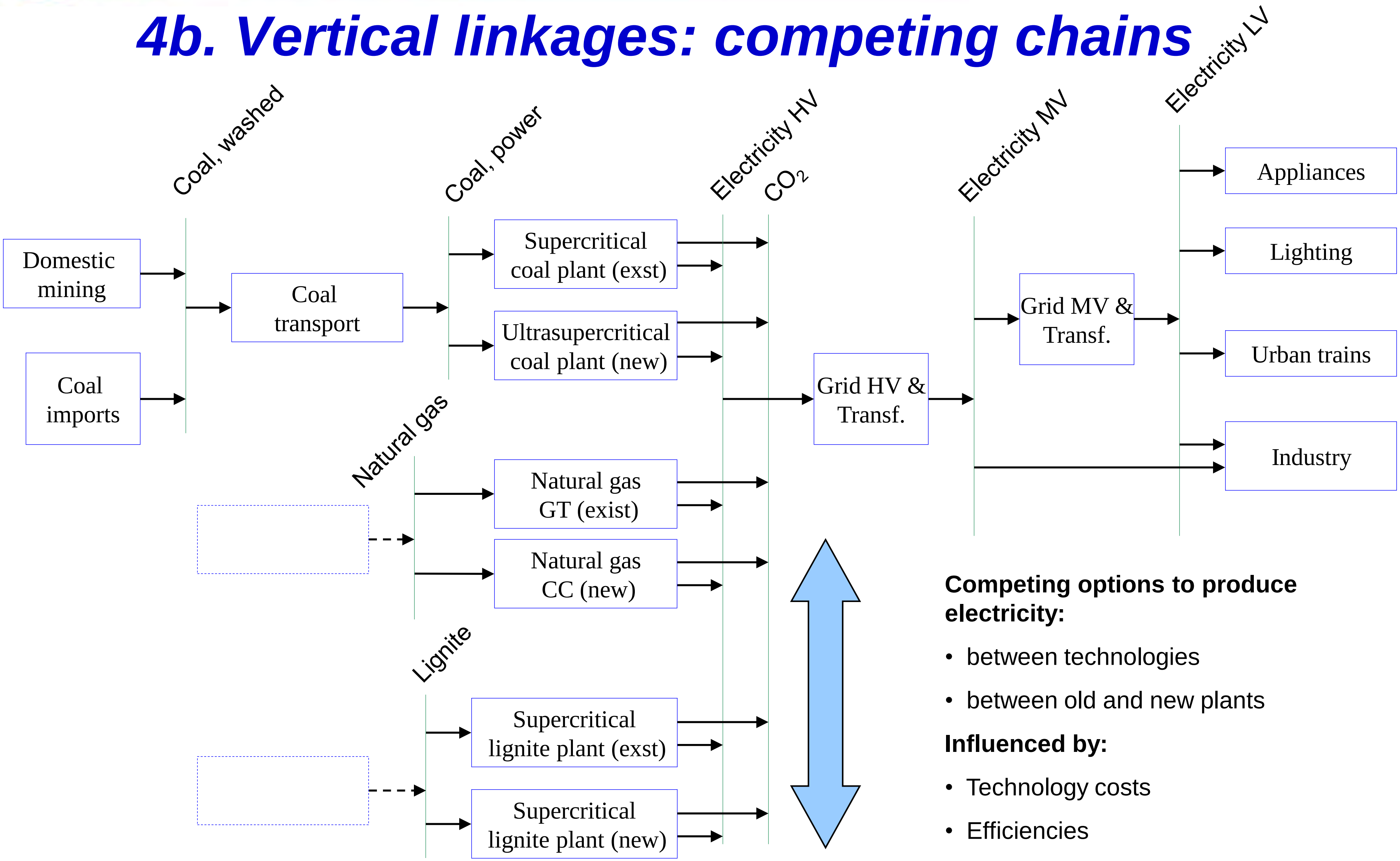


3. Reference Energy System

4a. Horizontal linkages: synergic chains



4b. Vertical linkages: competing chains



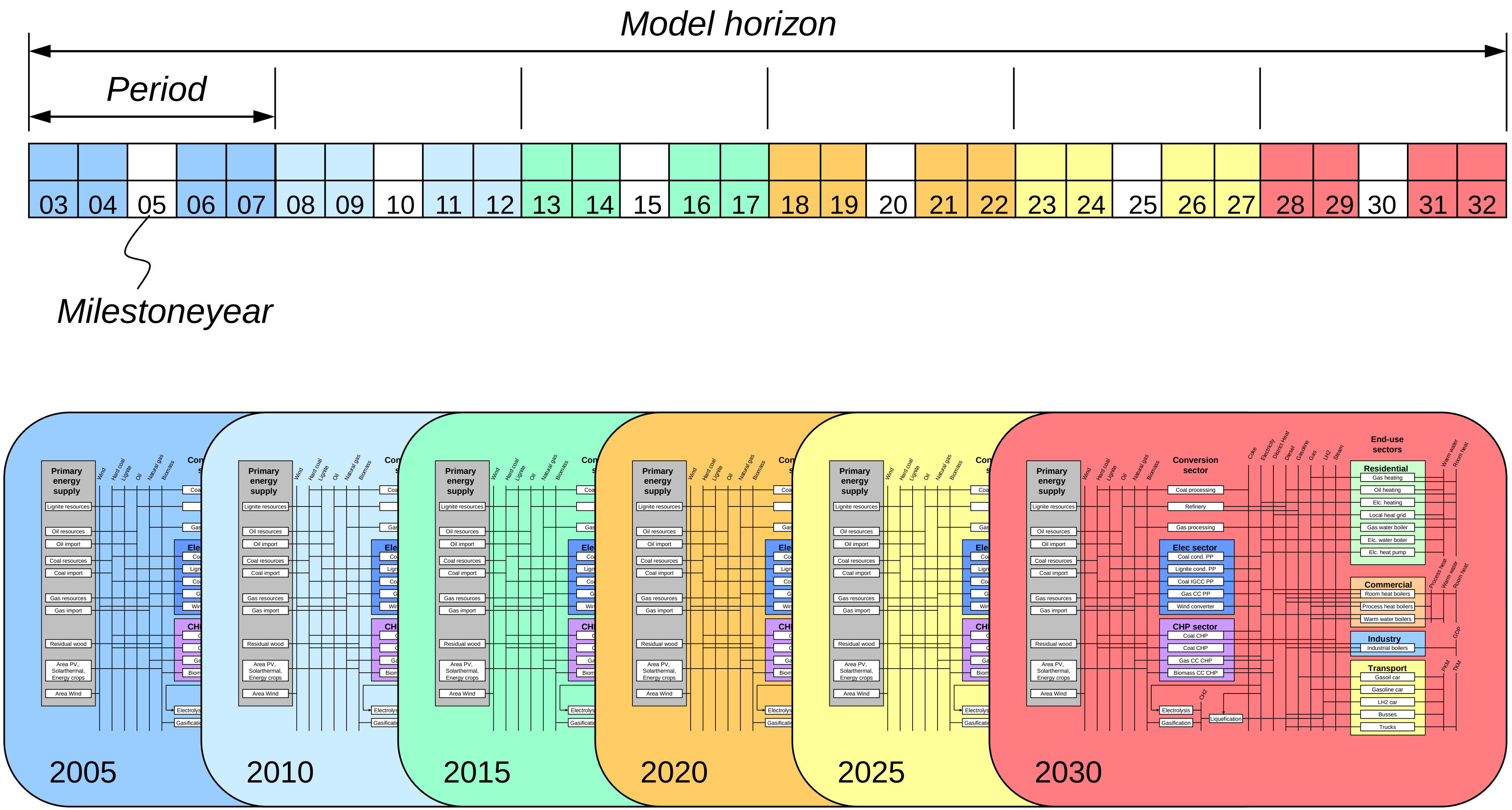
Competing options to produce electricity:

- between technologies
- between old and new plants

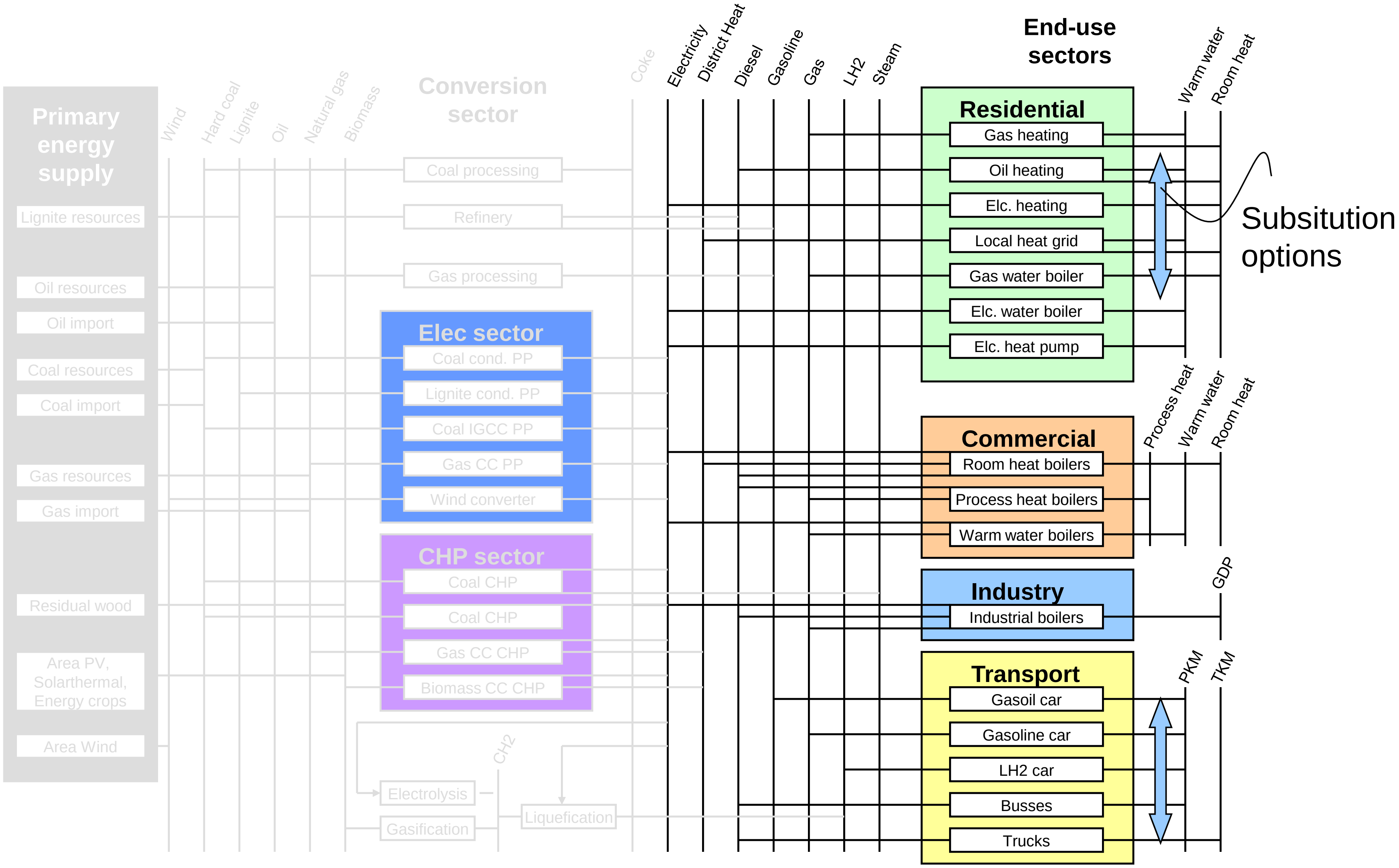
Influenced by:

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

4c. Dynamic model, time horizon



4e. Substitution



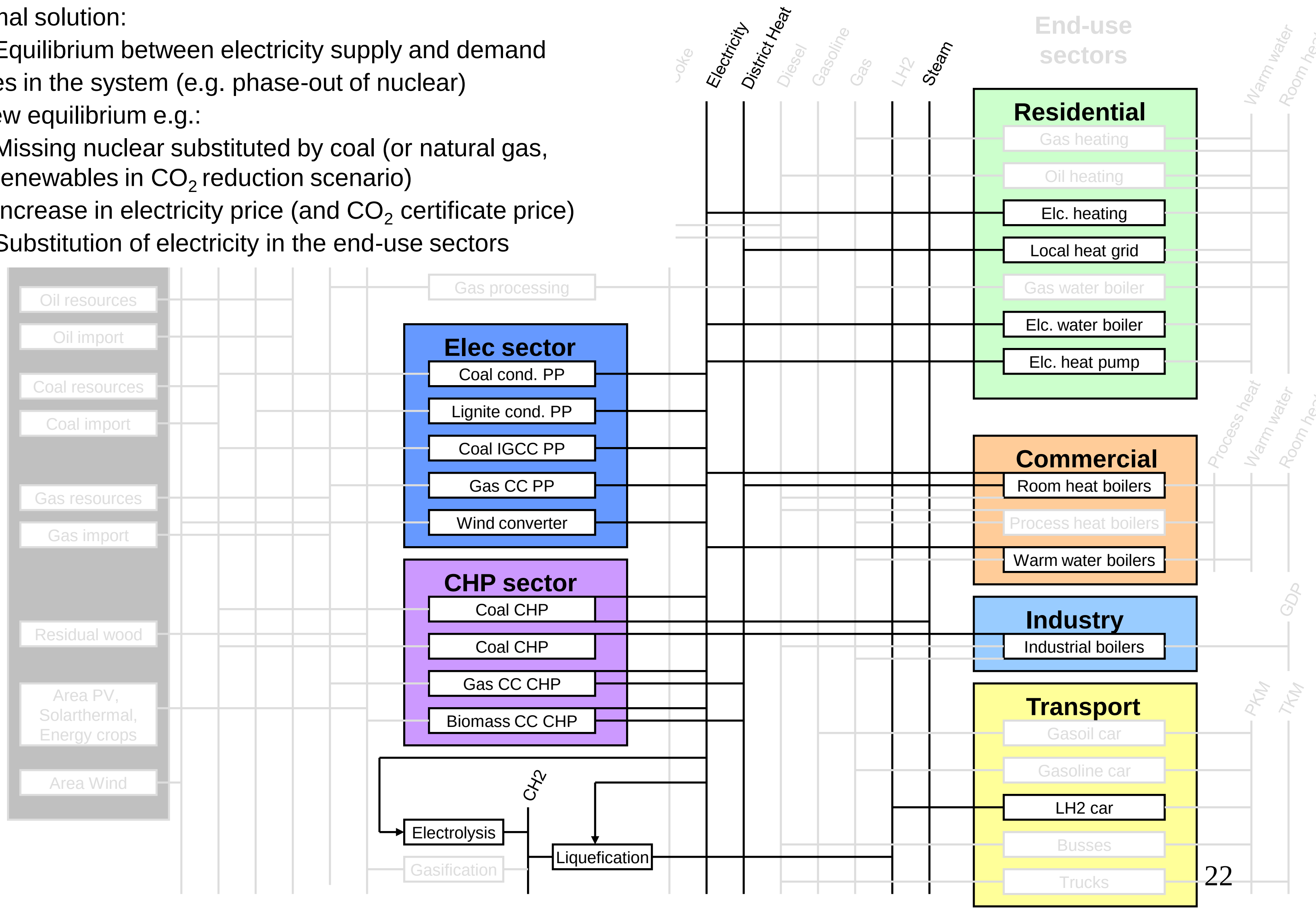
4f. Interdependence

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



5a. TIMES computes an economic equilibrium on energy markets, from supply to the end use services

The model computes flows of energy (and materials, and emissions) and their prices, in such a way that, at the prices computed by the model, the suppliers of energy produce exactly the amounts that the consumers are willing to buy.

The following properties hold:

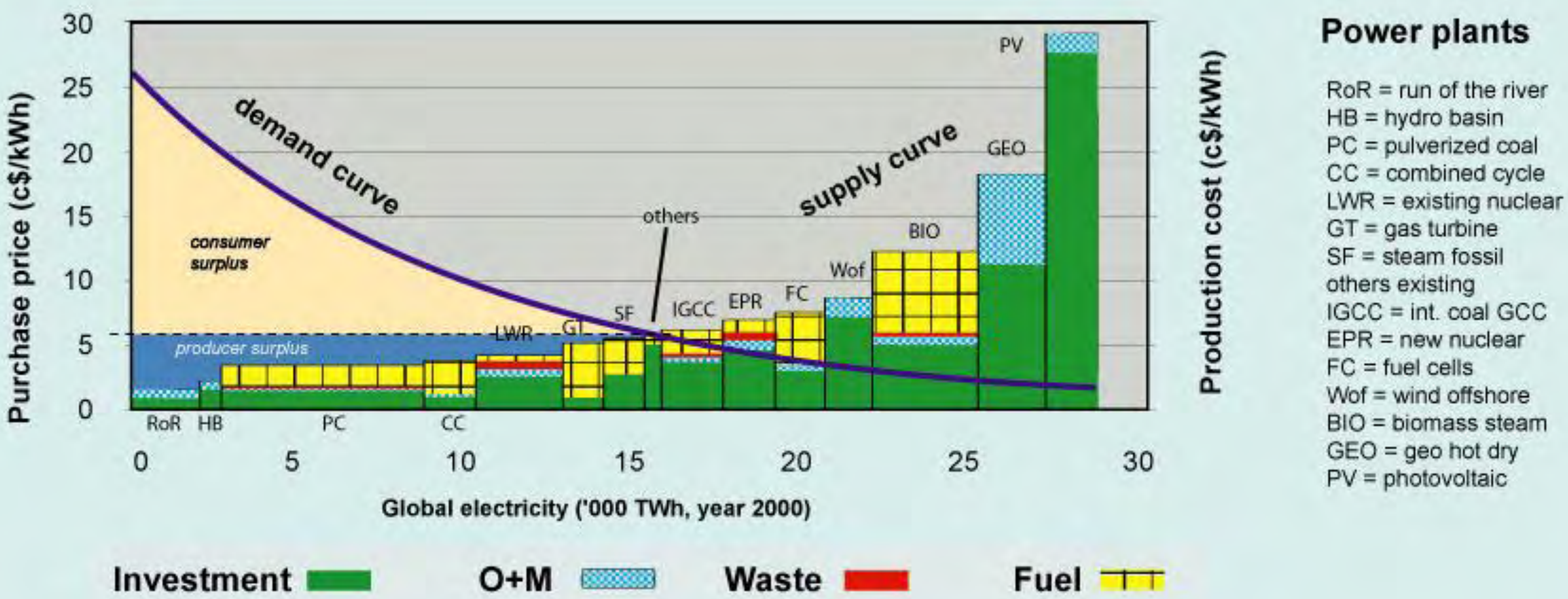
a. Technology outputs are linear functions of inputs

b. Energy markets are competitive, with perfect foresight

c. The market price = marginal value in the overall system

d. Each economic agent maximises its own profit or utility

5b. Market prices equal marginal values



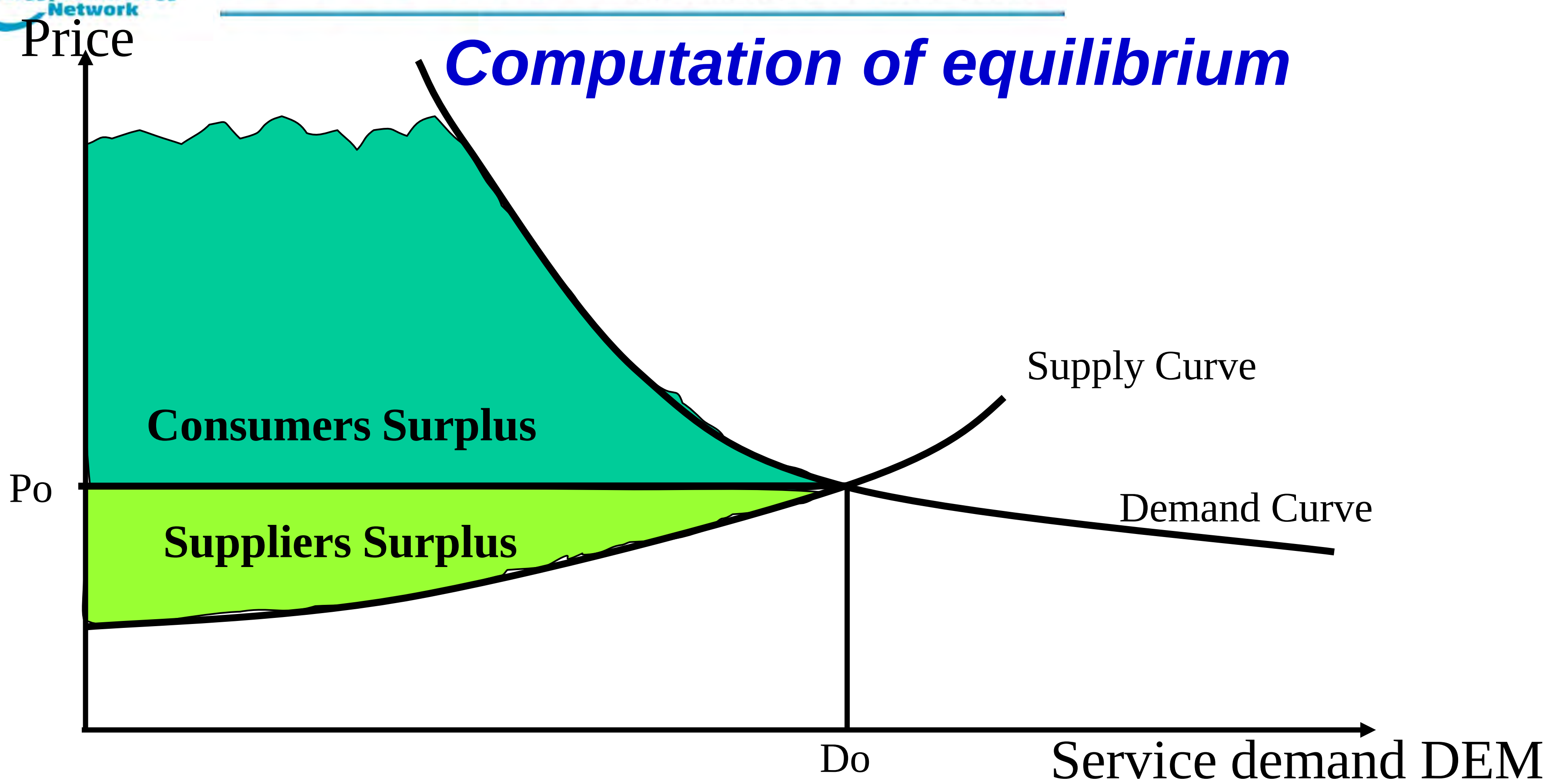
Typical representation of an energy commodity in MARKAL - TIMES.
The algorithm maximises the global surplus over thousands such markets.

What sort of economic equilibrium?

Depending on the scope of the system and the policies to be evaluated, different economic equilibrium levels are calculated:

1. Supply side technological optimum: the total system cost is minimized
2. Supply side plus demand side technological optimum: the total system cost is minimized
3. Energy service demand equilibrium: the total surplus is maximised
4. General economic equilibrium: the consumer utility is maximised

Computation of equilibrium



THEOREM: to find the equilibrium point is equivalent to maximize the Total Surplus (sum of suppliers and consumers surpluses)

Additional objectives: maximise supply diversity

f = fuel index

s = source of supply

Q(f,s) = supply of fuel f from source s

R(f,s) = risk parameter of supply Q(f,s)

The **Risk Indicator of supply** is given by:

$$\mathbf{RI(f,s) = SUM_f\ of\ (Max_{s=imports}\ \{R(f,s)*Q(f,s))\}}$$

Minimising RI(f,s) essentially **penalizes excessive reliance on imports from a single risky source (or from a few large risky sources)** while putting more emphasis on riskier corridors than on less risky ones.

It encourages diversification of importation sources, weighted by their risk coefficients.

Additional objectives: diversify technologies

f = fuel index

s = source of supply

F(f,p) = flow of fuel f from technology p

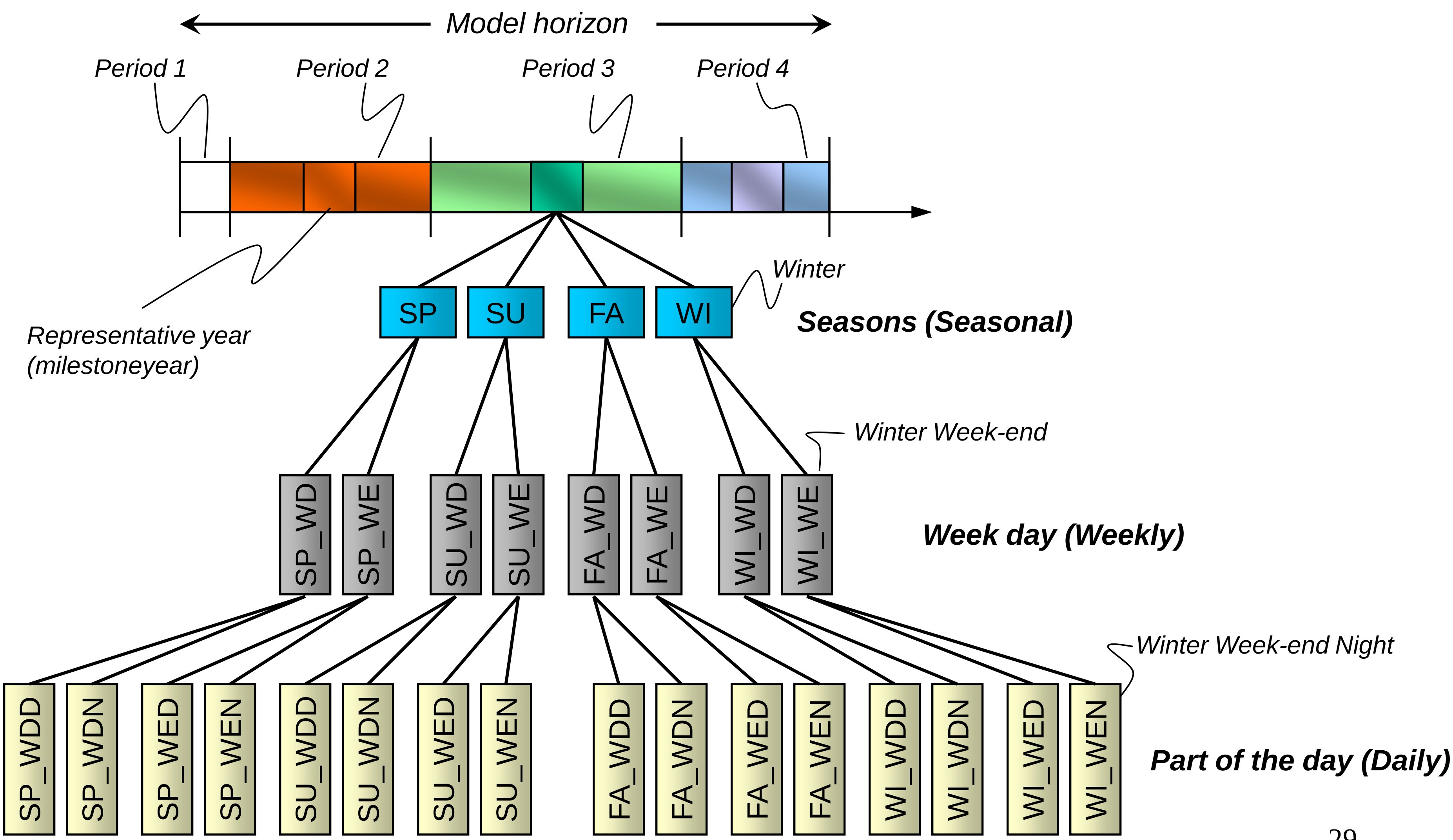
R(p) = risk parameter of technology p

The **Risk Indicator of fuels** chain f is given by

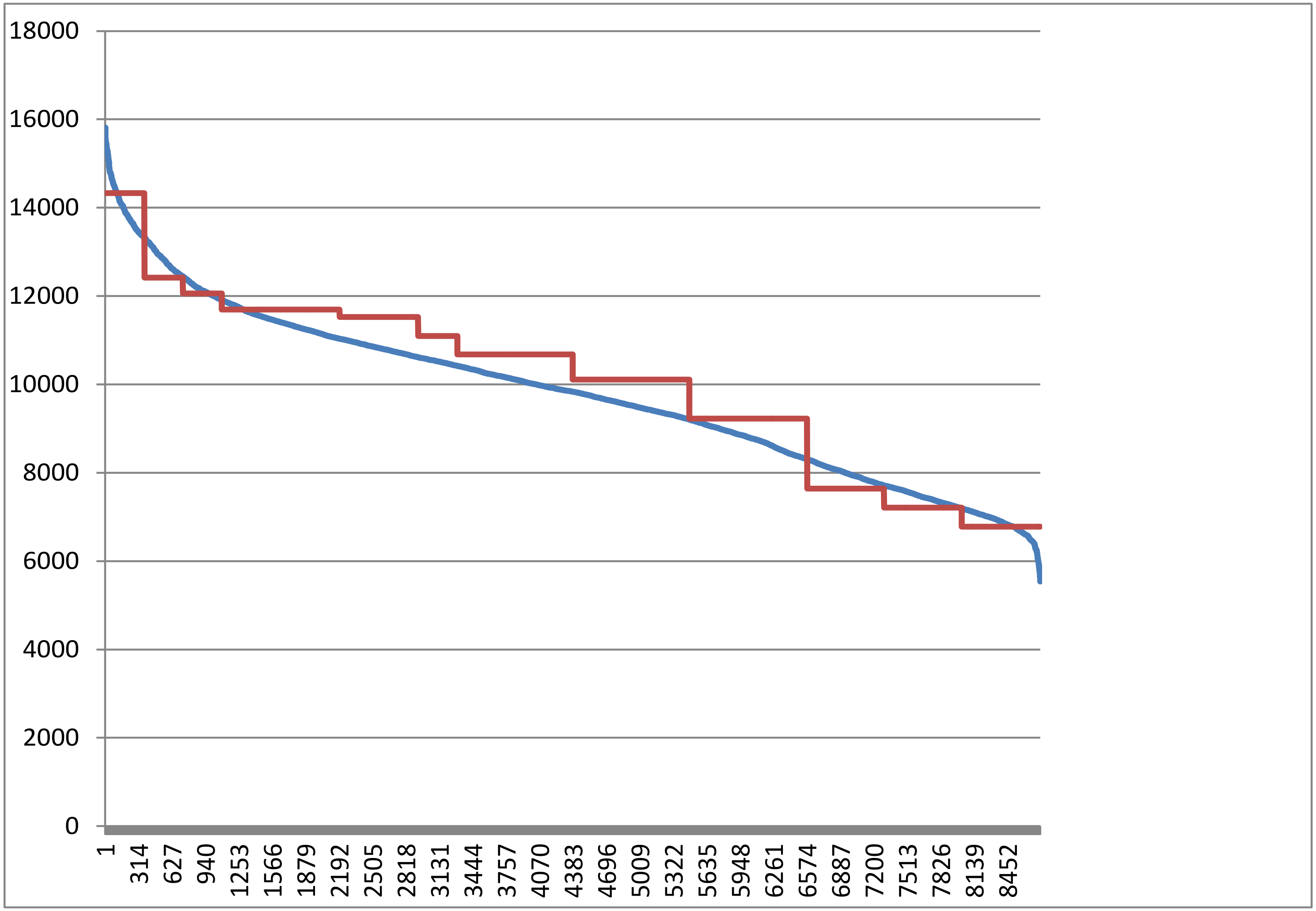
$$\mathbf{RI(f) = Max_f\ (\ SUM_p\ R(p)*F(f,p))}$$

Minimising this indicator penalizes excessive reliance on a small number of technologies, with emphasis on the riskier ones. It encourages diversification of technologies in the same fuel chain.

Intra-year time slices in TIMES



Load duration curves translated to the Model time slices

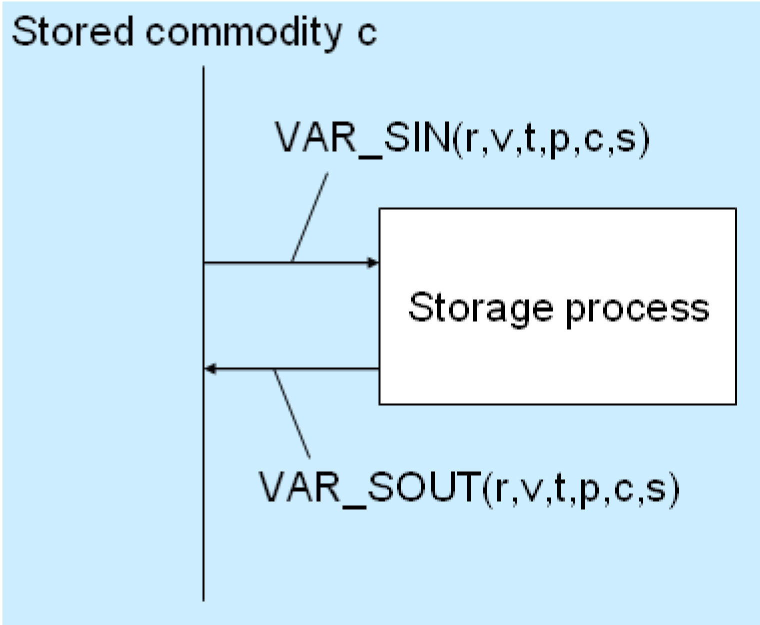


Storage Technologies

The flexible nature of the TIMES year (time)-slices is supported by storage processes that 'consume' commodities at one year (time)-slice and release them at another.

Three types of storage processes:

- **Inter-period** storage process
- **Time-slice** storage process
- **Night storage** device



Inter-period storage (IPS) process

- Storage between periods
- Operates on an ANNUAL level
- Specified by set PRC_STGIPS(r,p,c)
- Input and output commodities are the same

Time-slice storage (TSS)

- Storage between timeslices
- Specified by set PRC_STGTSS(r,p,c)
- Operates on timeslice level specified by COM_TSL(r,c,tslvl)
- Input and output commodities are the same

Storage Technologies

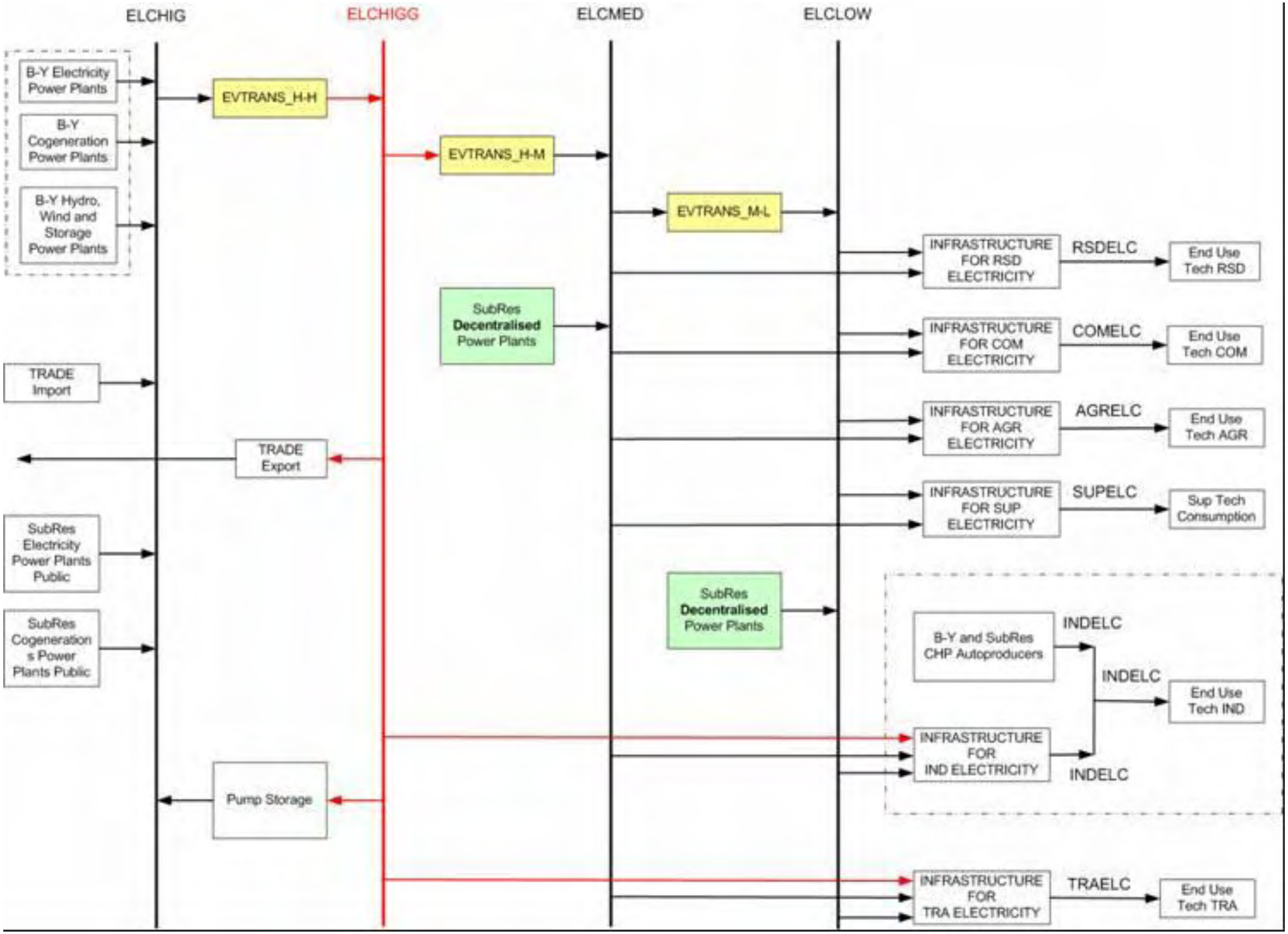
Night storage device similar to timeslice storage process, in addition,

- Input and output commodities may be different (specified by set TOP)
- Charging only in timeslices specified by set PRC_NSTTS(r,p,s)

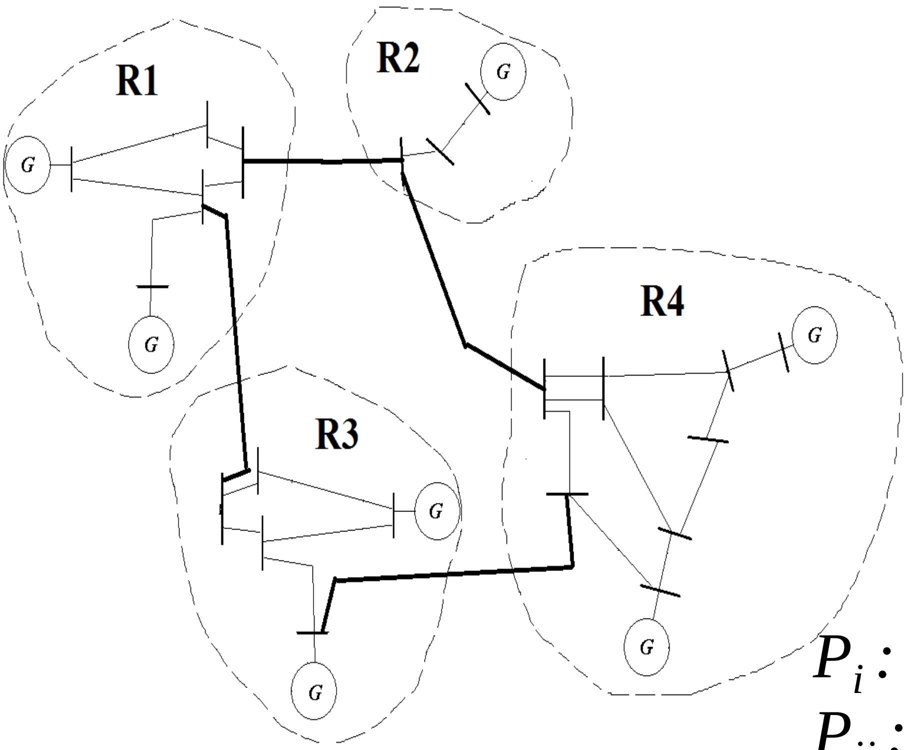
Common to all three storage processes

- Storage level is described by an activity variable
- Parameters:
  - NCAP_STLOS(r,t,p,s): annual energy loss from a storage per unit of average energy stored
  - STG_OUTBND/STG_INBND(r,t,p,c,s,l): bound on VAR_SOUT/VAR_SIN
  - STG_EFF(r,t,p): Storage efficiency
  - other process parameters applicable

Pan European TIMES Model Electricity



Electricity Network modeling in TIMES

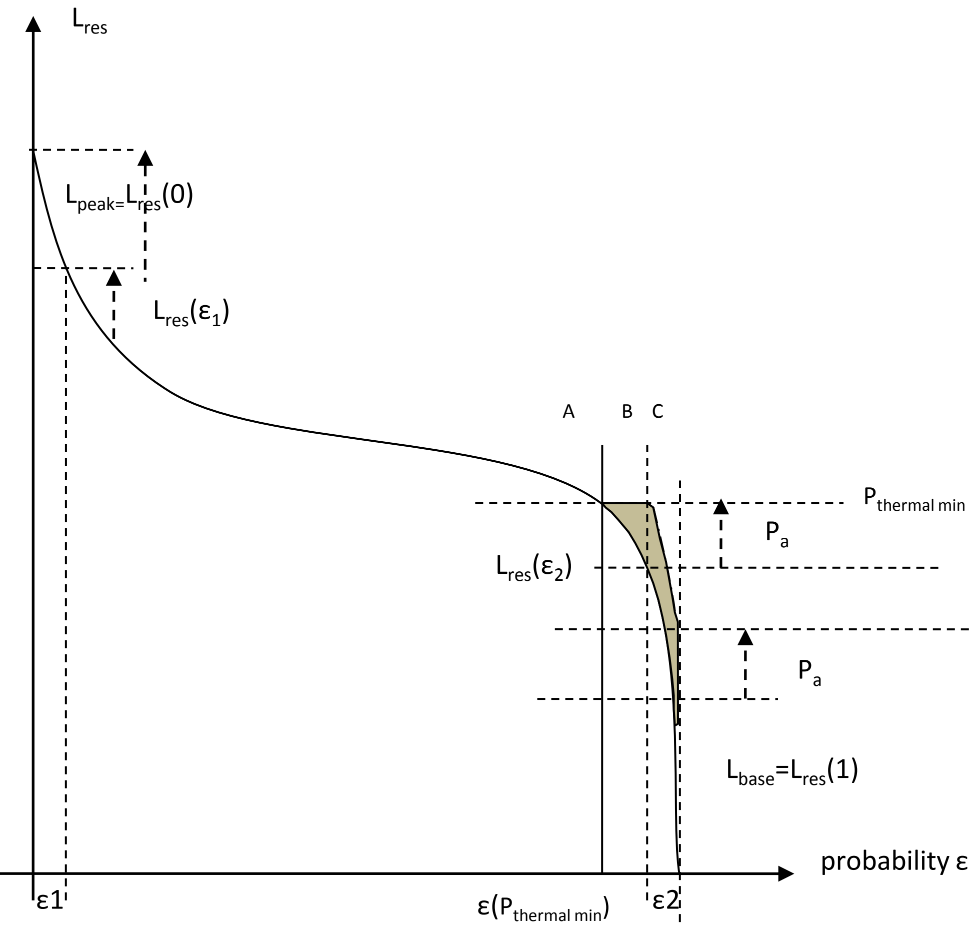


- DC Load Flow equations into TIMES

$$P_i = \sum_{j=1}^{M} P_{i,j} = \sum_{j=1}^{M} B_{i,j} \cdot (\delta_i - \delta_j)$$

P_i : power injected into node i
P_{ij} : branch flow between nodes i and j
B_{ij} susceptance of the branch connecting nodes i and j
δ_i voltage phase angles of node i with respect to a reference angle

Residual Load Duration Curve approach for calculating storage needs



The energy curtailment is the area below the Thermal Minimum Load and above the Customer Load

necessary storage in order to secure that the probability for curtailment is less than ε_2

$$Prob\left[L_{res} \geq \sum_i p_i C_i^{th-min}\right] = 1 - F_{L_{res}}\left(\sum_i p_i C_i^{th-min}\right) \geq \varepsilon_2$$

Then total available storage capacity P_a required is :

$$P_a = \sum_i p_i C_i^{pump} = \sum_i p_i C_i^{th-min} - L_{res}(\varepsilon_2)$$

Summary: TIMES in a nutshell

- Technology explicit (hundreds of technologies, commodities in a Reference Energy System)
- Long term (multi-period), perfect foresight (decisions are made with advance knowledge of the future)
  - Partial foresight possible (a few periods)
  - Imperfect foresight feature: decision under uncertainty
- Quantities and prices are endogenously computed for all commodities, technologies
- Multi-regional, with endogenous trade

Further details: www.etsap.org/documentation

Examples of use are given in ETSAP Annexes **final reports** at http://www.iea-etsap.org/official.asp

Overview of ETSAP-TIAM
TIMES Integrated Assessment Model

- Global multi-regional energy model: 15 regions (+ OPEC/Non-OPEC) linked by trade of energy + emissions
- CO2, N2O and CH4 from all anthropic sources (energy-related, land, agriculture, and waste) + exogenous radiative forcing for the other gases and forcing factors
- Climate module included
- Time horizon 2005-2100, 9 periods of different lengths, time-slices (eg. seasons, day/night) ⇒ load curves, peak

ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM

Regions of ETSAP-TIAM (16 regions)

Africa*
Australia-New Zealand
Canada
Central Asia and Caucase
Central and South America*
China
Europe (EU30)
India
Japan
Mexico
Middle-East*
Other Developing Asia*
Other Eastern Europe
Russian Federation
South Korea
United States

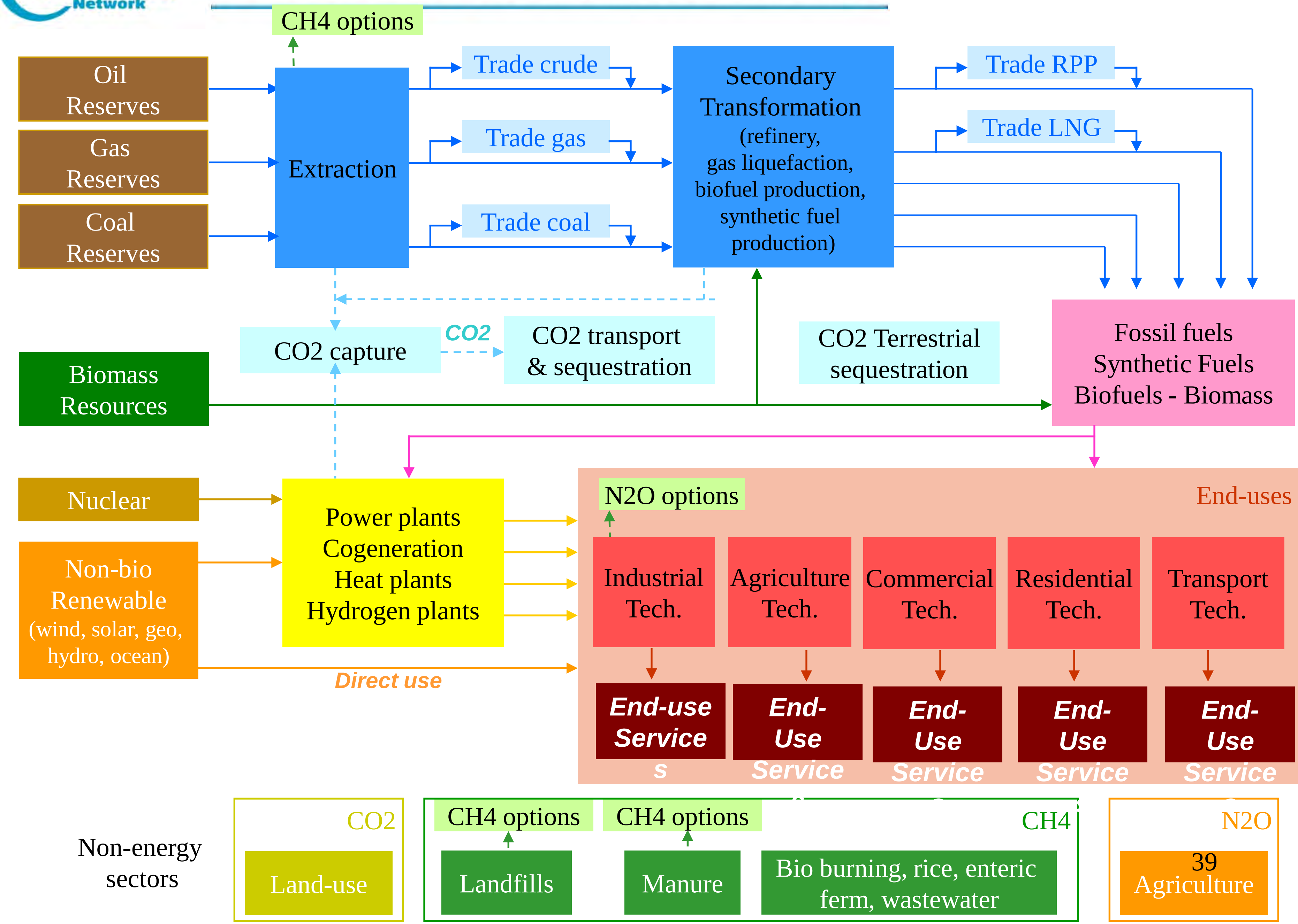
* OPEC and Non-OPEC countries are separated in primary and secondary sectors
⇒ appropriate modelling of oil production strategies and oil price control by OPEC countries

Code	Name	Countries
AFR	Africa	Algeria, Angola, Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Libya, Morocco, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, United Republic of Tanzania, Togo, Tunisia, Zambia, Zimbabwe, and Other Africa*.
AUS	Australia, New-Zealand, Oceanía	Australia, New-Zealand, Oceanía
CAC	CentralAsia&Caucase	Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Armenia, Azerbaidjian, Georgia
CAN	Canada	Canada
CHI	China	China
CSA	Central & South America	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela and Other Latin America.
IND	India	India
JPN	Japan	Japan

Code	Name	Countries
MEA	Middle East	Bahrain, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen, and Turkey, Cyprus.
MEX	Mexico	Mexico
ODA	Other Developing Asia	Bangladesh, Brunei Darussalam, Cambodia, Chinese Taipei, Indonesia, DPR of Korea, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam and Other Asia**
OEE	Other EastEurope	Belarus, Moldova, Ukraine Albania, Bosnia-Herzegovina, Croatia, Macedonia, Montenegro, Serbia (Kosovo)
RUS	Russia	Russia
SKO	South Korea	South Korea
USA	USA	USA
EUR	Europe 27+	Austria, Belgium, Bulgaria, Cyprus, Switzerland, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, Greece, Hungary, Ireland, Iceland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia, United Kingdom

TIAM: Reference Energy System

ETSAP ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM



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What are ETSAP modelling tools used for?

- Integration of the four main quantitative dimensions of the problem: energy, engineering, economy and environment
- Representation of the systems and their developments in technical economic equilibrium models
- Generation of development paths of energy system flows, technologies, costs and emissions (scenarios)
- Evaluation of the energy, technological, economic and environment impact of different policy objectives and control strategies to be adopted under uncertainty.

The model is not an oracle …..

It is merely a method to produce techno-economic scenarios for the future in a logical, traceable manner

B. Energy Technology Data Source

ETech-DS is a commented energy technology database building on the basic idea of the IEA Energy Technology Essentials

- ✓ Concise profiles on today's energy technologies for producing, transporting and using energy;
- ✓ Update information and key data on status, performance, emissions, costs, markets, potential and barriers;
- ✓ Insights for decision-taking

Since September 2011, ETSAP E-TechDS is working in cooperation with the **International Renewable Energy Agency (IRENA)** to develop and update Briefs on renewable energy technologies.

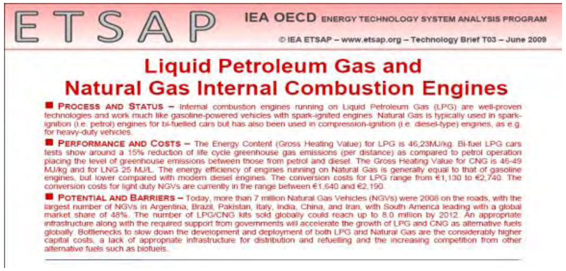
Available on line at: **http://www.iea-etsap.org/web/E-TechDS/Technology.asp**

ETSAP ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM

Energy Technology Data Source

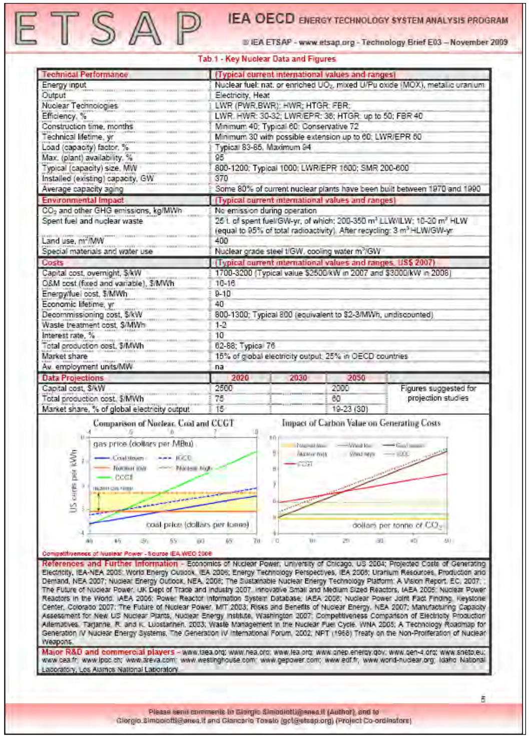
Three sections in each brief

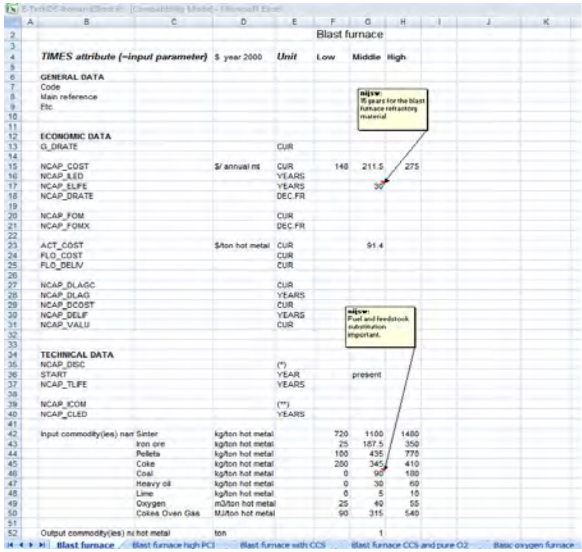
1. Summary for Policymakers



2. Technical Section

- Process and technology status,
- Technical & environmental performance, costs and projections,
- Potential (incl. market status & prospects) and Barriers, plus …
- Summary Table & References





3. Excel Spreadsheets for Modellers

Energy Technology Network

ETSAP ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM

Energy Technology Data Source

Total Brief Number	80
Posted	50
In preparation (commissioned)	17
To be commissioned	13 (Authors identified for 10 briefs)

E-TechDS STATUS - May 21, 2012 - Energy Supply Technologies

PRIMARY ENERGY SUPPLY, TRANSPORTATION AND DISTRIBUTION			
P01	Conv. Oil and Gas Production	May 2010	IFE-Norway
P02	Unconv. Oil and Gas Production	May 2010	IFE- Norway
P03	Oil and Gas Logistics	August 2011	IFE- Norway
P04	Oil refineries	Dec. 2012, to be assagned	Gerad Canada, K. Vaillancourt
P05	Syngas from Coal (coal gasific.)	May 2010	IER-Germany
P06	Liquid Fuels from Coal and Gas	May 2010	IER- Germany
P07	Coal Mining and Logistics	Dec. 2012, to be assagned	ETSAP GS?
P08	H2 Production & Distribution	March 2012	CRES –Greece
P09	Biomass Production & Logistics	June 2012, to be assagned	Maryse Labriet
P10	Biofuels Production	January 2012	ETSAP GS
P11	Biogas Production	Sept 2012, to be assagned	Maryse Labriet
P12	Biogas Production for Transportation	Sept 2012	IRENA

TRANSPORTATION			
T01	Adv. Autom. Gasoline Eng.	April 2010	AEA – UK
T02	Adv. Autom. Diesel Eng.	April 2010	AEA – UK
T03	Autom. LPG and Nat. Gas Eng.	April 2010	AEA – UK
T04	Hybrid Vehicles	June 2010	AEA – UK
T05	Electric & Plug-in Hybrid Vehicles	June 2010	AEA – UK
T06	Ethanol IC engines	June 2010	AEA – UK
T07	Hydrogen and Fuel Cell Vehicles	Under Revision	AEA – UK
T08	Light Trucks	January 2011	AEA – UK
T09	Heavy Trucks	January 2011	AEA – UK
T10	Public Transport	January 2011	AEA – UK
T11	Rail Transport	January 2011	AEA – UK
T12	Aviation Transport	January 2011	AEA – UK
T13	Shipping Transport	January 2011	AEA – UK
T14	Road Transport Infrastructures	August 2011	AEA – UK
T15	Rail Infrastructures	June 2011	AEA – UK
T16	Aviation Infrastructures	August 2011	AEA – UK
T17	Shipping Infrastructures	June 2011	AEA – UK
T18	Weight & Drag Reduction (Autom.)	January 2011	AEA – UK
T19	Two-Three Wheelers	Sept. 2012, to be assagned	AEA – UK

ELECTRICITY & HEAT PRODUCTION, TRASMISSION AND DISTRIBUTION			
E01	Coal Fired Power Plants	April 2010	ECN – Netherland
E02	Gas Fired Power Plants	April 2010	ECN– Netherland
E03	Nuclear Power	April 2010	ETSAP GS
E04	Combined Heat and Power (CHP)	May 2010	ECN– Netherland
E05	Biomass for Heat & Power	May 2010	ECN– Netherland
E06	Hydro Power	May 2010	ECN– Netherland
E07	Geothermal Power	May 2010	ECN– Netherland
E08	Marine Power	November 2010	ECN– Netherland
E09	Wind Energy	Sept. 2012	IRENA
E10	Concentrated Solar Power	March 2011	ETSAP GS
E11	Photovoltaic	February 2011	ETSAP GS
E12	Nuclear Fuel Mining to Waste Management	Dec 2012, to be assagned	ETSAP GS ?
E13	Fuel Cells	Dec 2012, to be assagned	Adam Hawkes, Imperial Col.
E14	CO_2 Capture & Storage	October 2010	ETSAP GS
E15	Renewable Energy Integration	March 2012	CRES –Greece
E16	District heating systems	March 2012	Chalmers -Sweden
E17	Energy Storage (Thermal)	January 2012	FZ-Bayern - Germany
E18	Energy Storage (Electric)	January 2012	ETSAP
E19	Heat Pumps	March 2012	JHPC – Japan
E20	Electricity Transmission & Distribution	Dec 2012, to be assagned	Gerad, Canada
E21	Biomass Co-firing	In preparation – March 2012	IRENA
E22	Marine Energy Wave Devices	In preparation – Sept 2012	IRENA
E23	Marine Energy Current Devices	In preparation – Sept 2012	IRENA
E24	Energy from Waste	In preparation – Sept 2012	IRENA

Thank you

e-mail: ggian@cres.gr

http://www.iea-etsap.org