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Education

Ph.D. in Industrial Engg., METU
Post-Doc at CEPE, ETH Zurich and LBNL, UC Berkeley

NGO Activities

President 2016, IAEE
President, Turkish Association for Energy Economics
President, Turkish Association for Electro Mobility

Research Interests

Energy and environmental policy modeling, Energy economics & management, Environmental economics, General economic equilibrium, Power system economics, Real options theory

Outline

- Evolution of Energy Modeling
- Major Approaches
- Modeling Techniques
- Energy Networks
- Modeling Energy Flow
- Optimization Modeling of Energy Consumption/Production
- State of the Art Energy Modeling:
  - MARKAL
  - TIMES
  - LEAP

Evolution of Energy Modeling

1950 : **energy sector models**

1973 : Oil crisis ⇒ **energy-economy models**

1979 : 1. World Climate Conference

⇒ **energy-environment models**

1992 : UNFCCC

⇒ **energy-economy-environment models**

Major Approaches in Energy Policy Modeling

TOP-DOWN:

Top-down models are aggregate models of the entire macroeconomy that draw on analysis of historical trends and relationships to predict the large-scale interactions between the sectors of the economy, esp. between the energy sector and the rest of the economy.

(AR3; IPCC, 2001)

Top-down studies assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

(AR4; IPCC, 2007)

Major Approaches in Energy Policy Modeling

BOTTOM-UP:

Bottom-up models incorporate detailed studies of the engineering costs of a wide range of available and forecast technologies, and describe energy consumption in great detail. (AR3; IPCC, 2001)

Bottom-up studies are based on assessment of mitigation options, emphasizing specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged.

(AR4; IPCC, 2007)

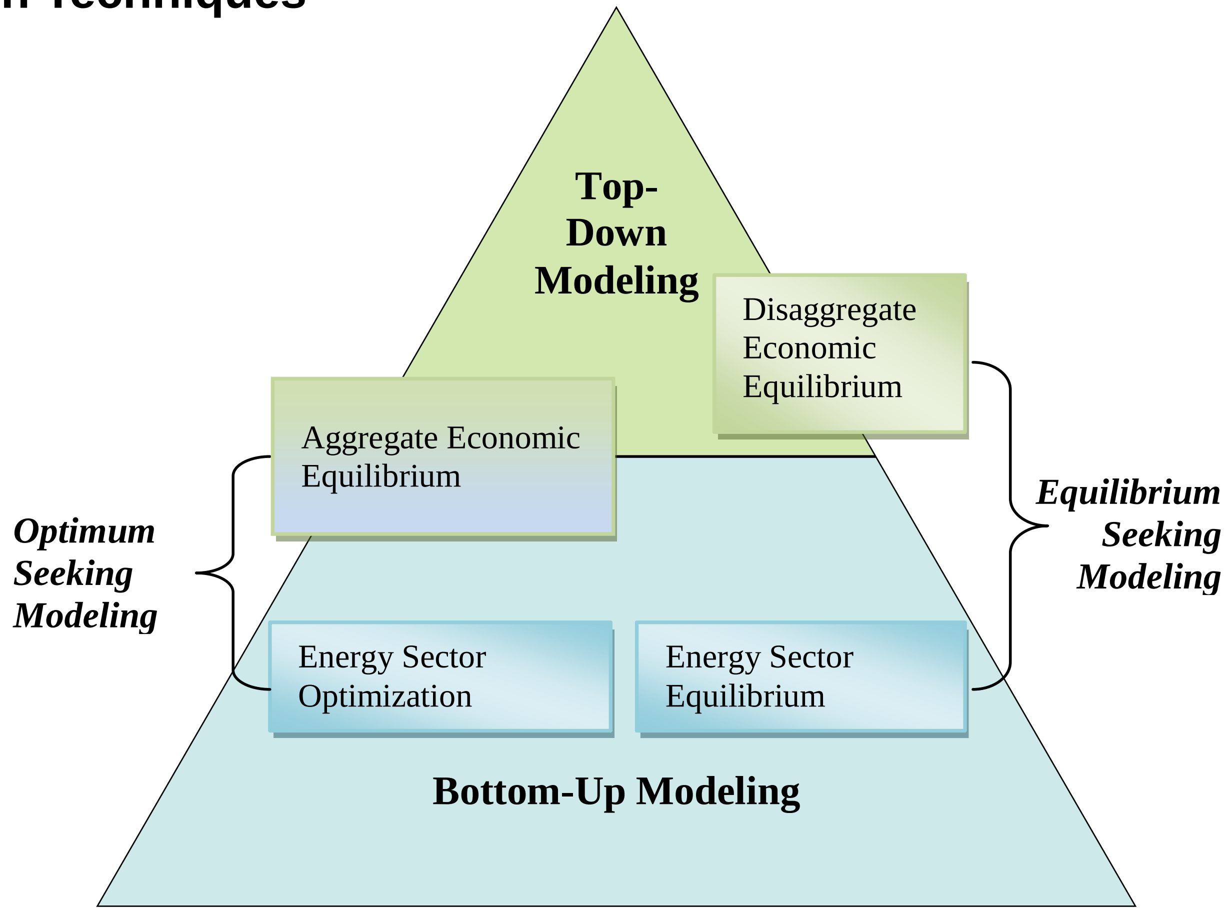
Major Approaches in Energy Policy Modeling

Bottom-up and top-down models have become more similar since the 3rd AR as top-down models have incorporated more technological mitigation options and bottom-up models have incorporated more macroeconomic and market feedbacks as well as adopting barrier analysis into their model structures.

(IPCC - 4th AR, 2007)

Main Techniques

Max. (or min.) f(x)
Subject to
g(x) = 0
$l \le x \le u$



Find z, w, v
Subject to F(z) – w + v = 0
$l \le z \le u$, $w \ge 0$, $v \ge 0$
w (z-l) = 0, v (u-z) = 0

Main Techniques

Energy Sector Optimization

Minimize $\sum_j c_j x_j$

Subject to

$\sum_j (1/e_{i,j})\, x_j \leq r_i \quad i = 1,\ldots,n$

$\sum_j \eta_{k,j}\, x_j = D_k \quad k = 1,\ldots,m$

⋮

Energy Sector Equilibrium

Find $p = (p_1, \ldots, p_n)$

Subject to

$e_1(p) = 0$

⋮

$e_n(p) = 0$

$e_i(p) = D_{i,j}(p) - S_i(p)$

Main Techniques

Aggregate Economic Equilibrium

Maximize $U = u(C)$

Subject to $Y = f(E, K, L, \ldots)$

$$GDP = C + I + X - M$$

$$Y = GDP + EC$$

$$E = [a]\,[z]$$

$$EC = [b]\,[z]$$

Disaggregate Economic Equilibrium

Consumers: $U_i = u(C_i)$

Producers: $Y_i = f_i(K_i, L_i, \ldots)$

$$Y_i = \sum_j a_{ij} Y_j + C_i$$

$$GDP = \sum_i (C_i + I_i + X_i - M_i)$$

Classification of Selected Models

Energy Sector Optimization

EFOM
PERSEUS
MARKAL
PERSEUS-GWI
TIMES

Energy Sector Equilibrium

GEMINIWATEMS
ERB
WATEMS-GDL
ICF

Aggr. Econ. Equilibrium

MIS
MARKAL-MACRO
RICE
GMM
IIAM
MERGE
CETA
MERGE-ETL
ENVEES

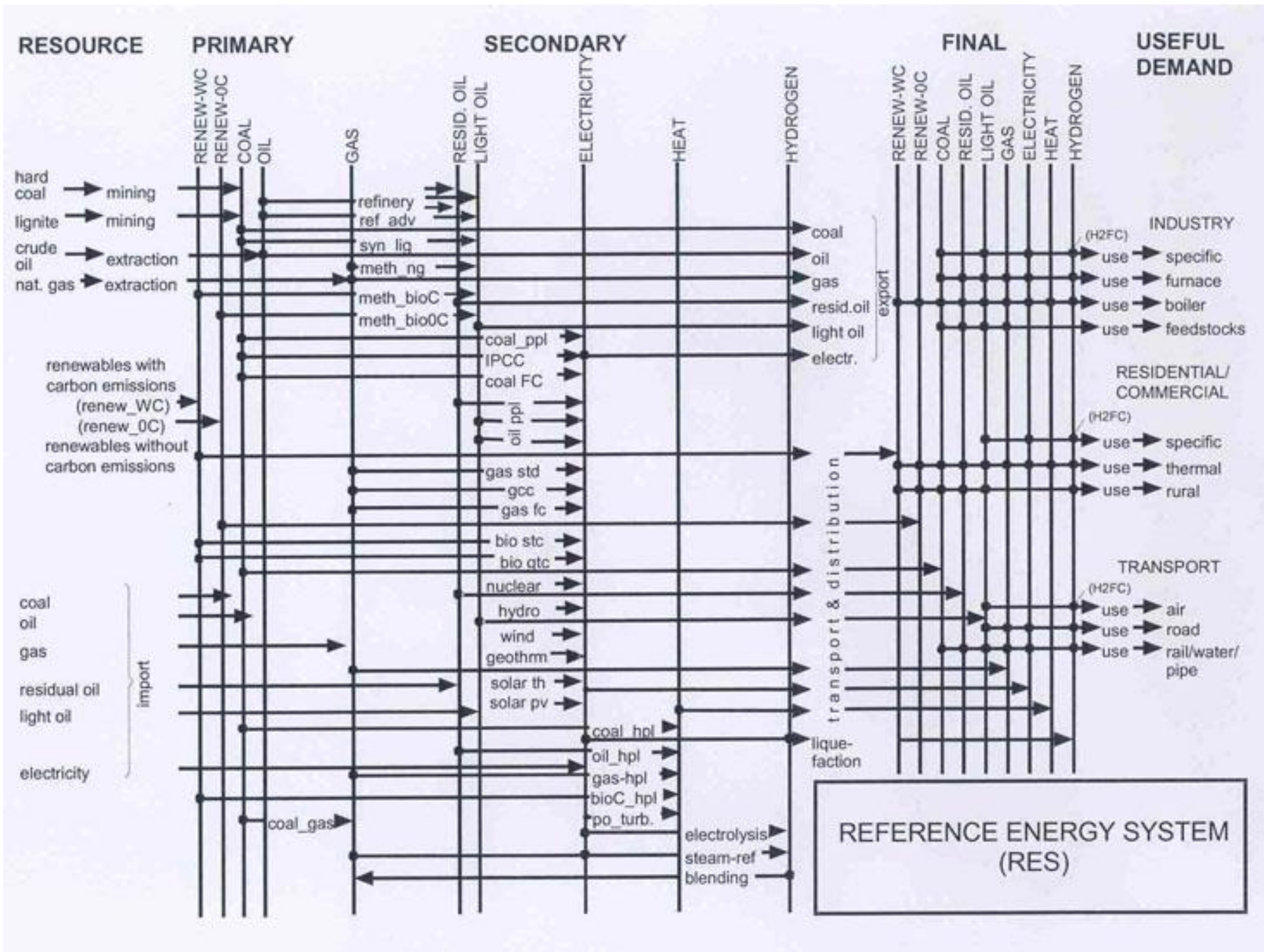
Disaggr. Econ. Equilibrium

MOBI-DK
WARM
GOULDER
DREAM
PESTES
NEWAGE
JW
GEM E-3
MULTI
SCREEN
GTAP-E
CETM

Bottom-Up Energy Systems Modeling

Energy Networks

i) Conversion of Energy from Source to Final Demand



http://www.iiasa.ac.at/Research/ECS/images/res1a.jpg

Modeling Network Flow

The **MCNF** Formulation

$$\text{Minimize} \quad c\,x$$

$$\text{S.to} \qquad M\,x = b$$

$$0 \le x \le u$$

Modeling Network Flow

The **MCNF** Formulation

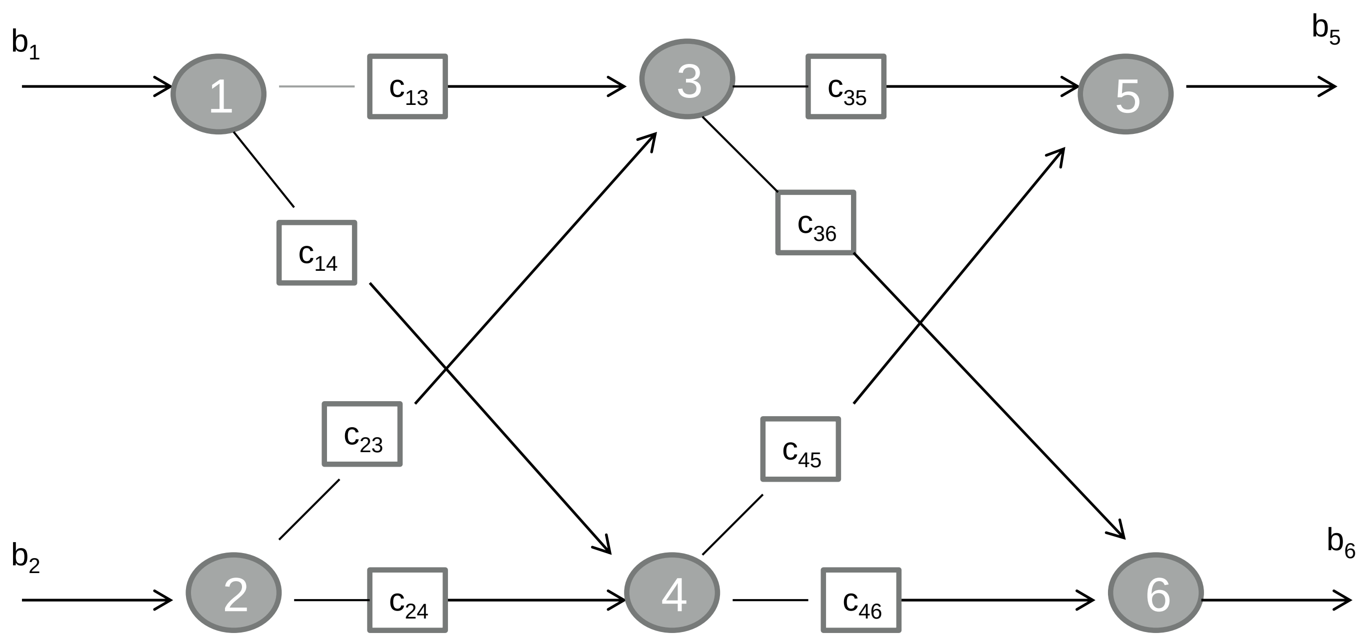
$$Minimize \sum_i \sum_{j \neq i} x_{i,j} \times c_{i,j}$$

$$\sum_j x_{i,j} - \sum_j x_{j,i} = b_i$$

$$0 \leq x_{i,j} \leq u_{i,j}$$

Modeling Network Flow

Ex.: An oil distributor pumps oil at two locations 1 and 2, then ships it through a distribution network as shown below to refineries at locations 5 and 6. The well in location 1 and 2 pump150 b/d and 200 b/d respectively. Demand in each of the consumer locations is 175 b/d. The shipment costs (in \$/b) are as follows: c_{13}=8, c_{14}=6, c_{23}=9, c_{24}=11, c_{35}=21, c_{36}=18, c_{45}=22, c_{46}=15.



Modeling Energy Production/Consumption

$$\text{Minimize} \quad c\,x$$

$$S.to \qquad M\,x = b$$

$$0 \leq x \leq u$$

$$\text{Minimize} \sum_i \sum_{j \neq i} x_{i,j} \times tc_{i,j}$$

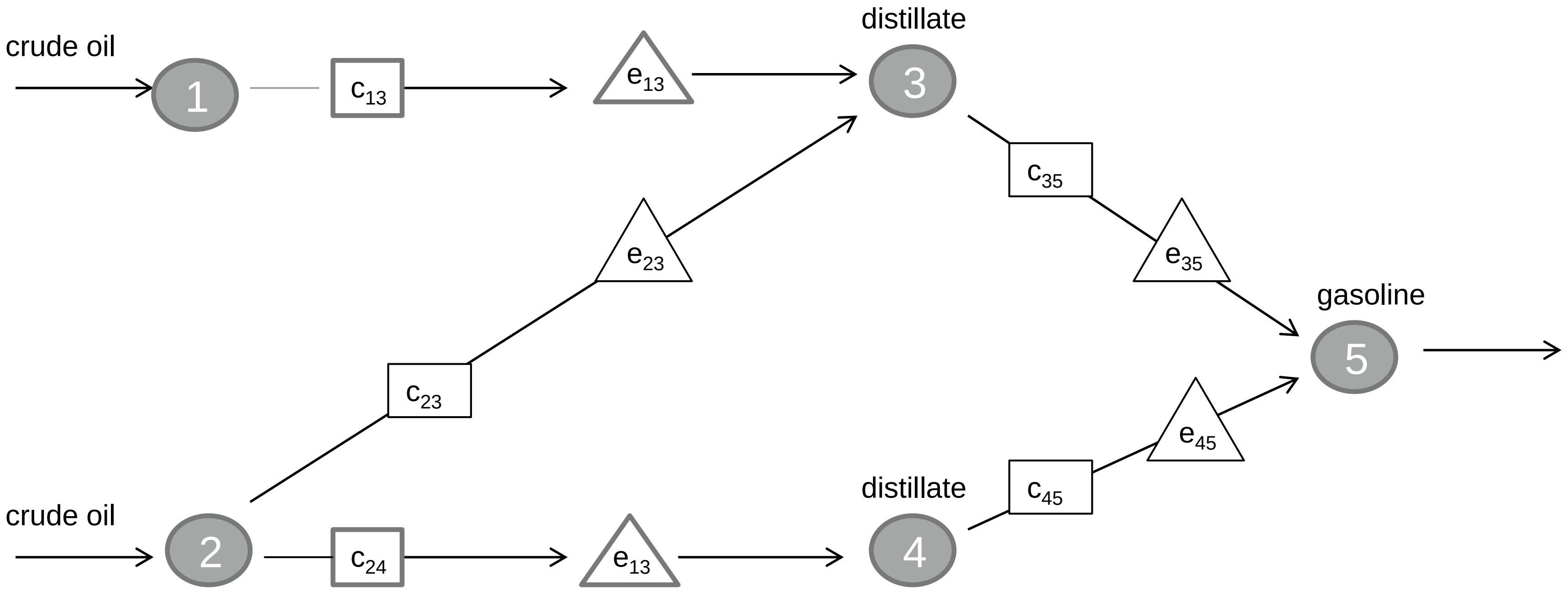
$$\sum_j x_{i,j} - \sum_j x_{j,i} = b_i$$

$$0 \leq x_{i,j} \leq u_{i,j}$$

How does the generic MCNF formulation change ?

Modeling Energy Production/Consumption

Ex.: energy network with two primary energy carriers and one final demand



c_{ij}: costs incurred in operating activity (i,j), calculated per unit of energy at node i
e_{ij}: thermal efficiency of activity (i,j), calculated as energy content of one unit of output per energy content of one unit of input

Modeling Energy Production/Consumption

How does the generic MCNF formulation change ?

$$Minimize \quad c\,x$$

$$S.to \qquad M\,x = b$$

$$x \geq 0$$

Modeling Energy Production/Consumption

Ex.:

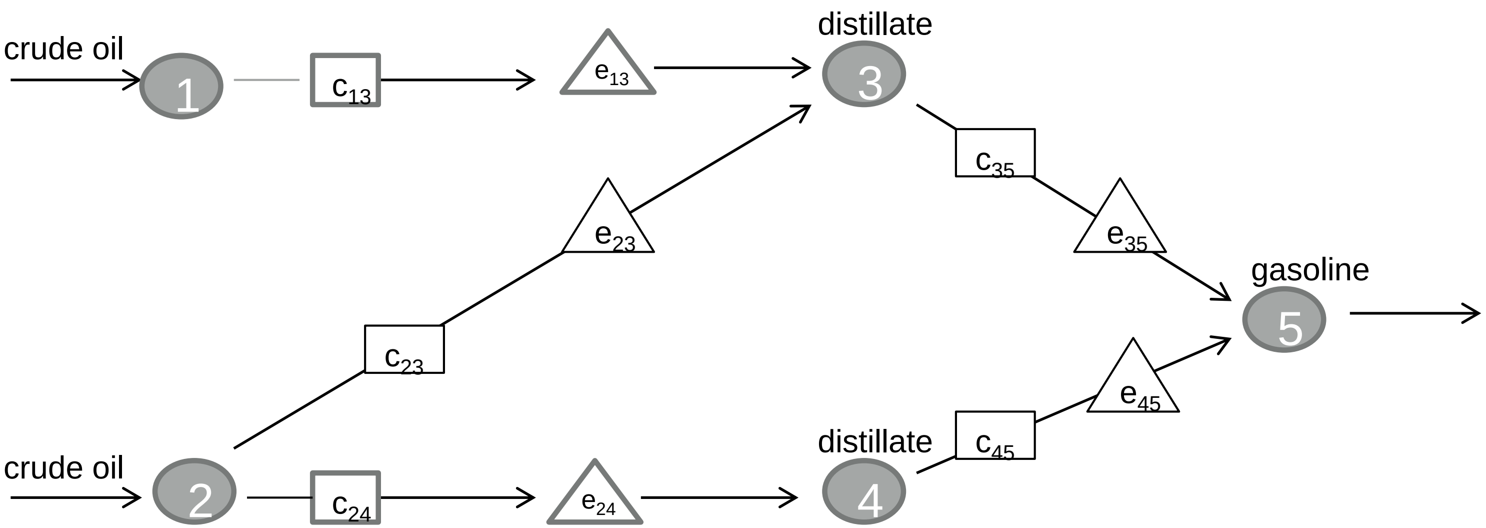
supply & demand

$$M = \begin{array}{c} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ \textit{unit costs} \rightarrow \end{array} \begin{array}{c} \begin{array}{ccccc} x_{1,3} & x_{2,3} & x_{2,4} & x_{3,5} & x_{4,5} \end{array} \\ \begin{pmatrix} -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 \\ 0.9 & 0.8 & 0 & -1 & 0 \\ 0 & 0 & 0.9 & 0 & -1 \\ 0 & 0 & 0 & 0.6 & 0.6 \end{pmatrix} \\ \begin{array}{ccccc} 4.5 & 6 & 6 & 19 & 12 \end{array} \end{array} \begin{array}{l} \\ \geq -200 \\ \geq -80 \\ = 0 \\ = 0 \\ \geq 120 \\ \\ \end{array}$$

$$\text{Minimize} \quad c\,x$$

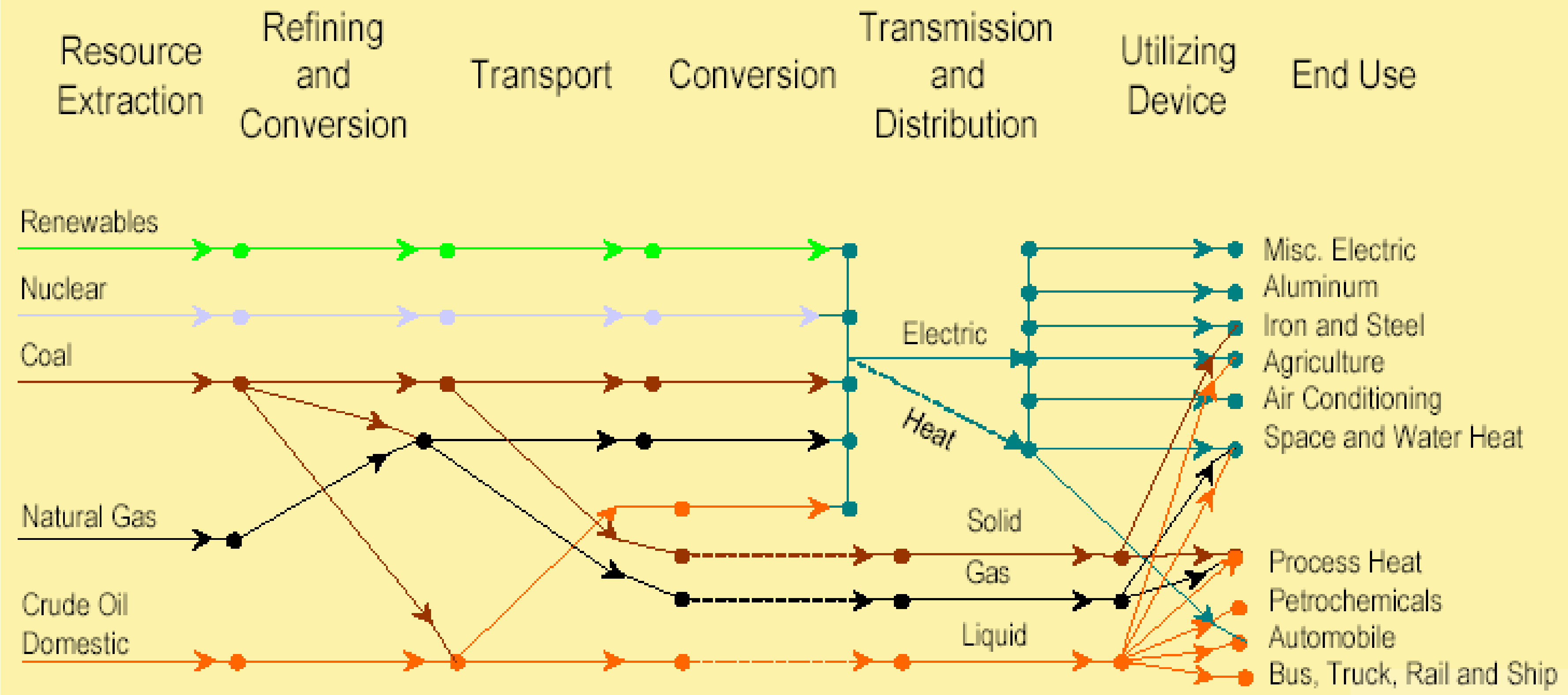
$$\text{S.to} \qquad M\,x \geq b$$

$$x \geq 0$$



The MARKAL Model

A Simplified Reference Energy System: The MARKAL Example



Source: http://www.gams.com/presentations/or01/marcal.pdf

The MARKAL Model

Main elements of the MARKAL Model

- ***Primary energy sources*** *that represent methods of acquiring various energy carriers;*
- ***Energy service demands*** *that represent the energy services which must be satisfied by the system;*
- ***Technologies*** *that either transform an energy carrier to another form or into a useful energy service;*
- ***Commodities*** *consisting of energy carriers, energy services and emissions that are either produced or consumed by the energy sources, technologies and demands.*

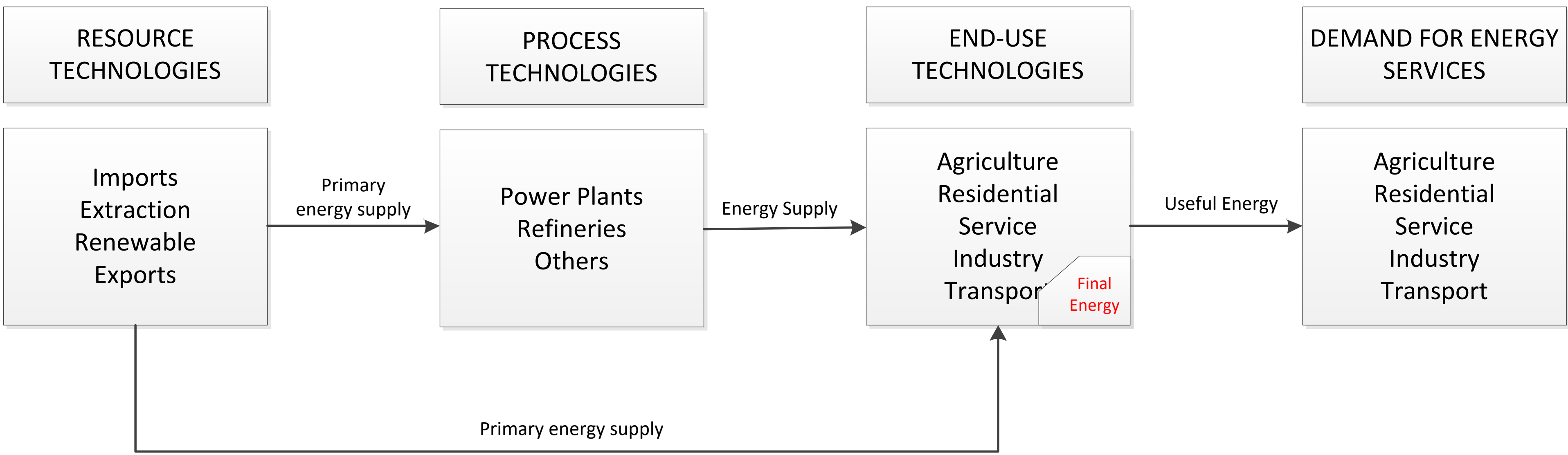
Demand technologies

Process technologies

Conversion technologies

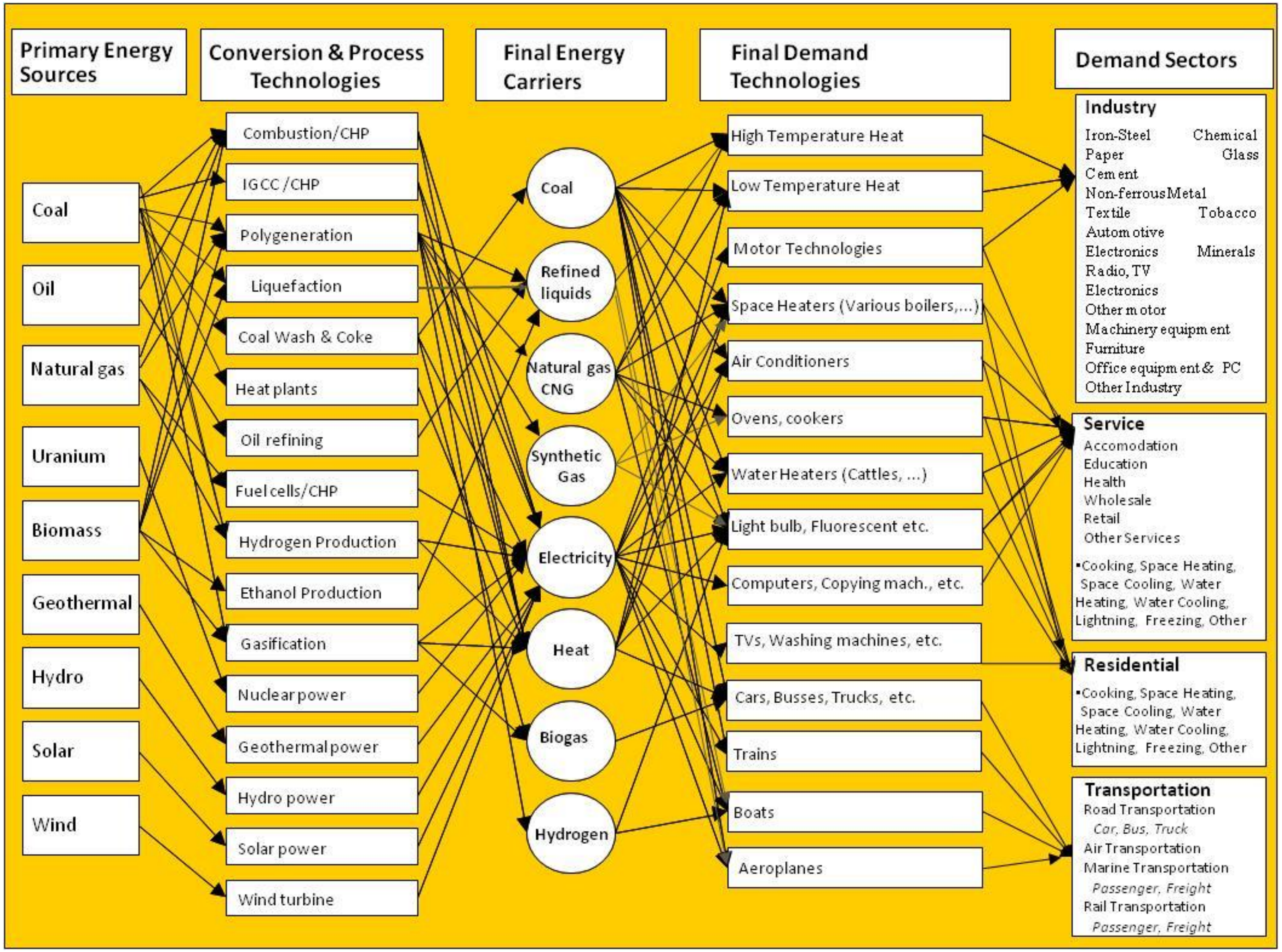
The MARKAL Model

Technology Relations in the MARKAL Model



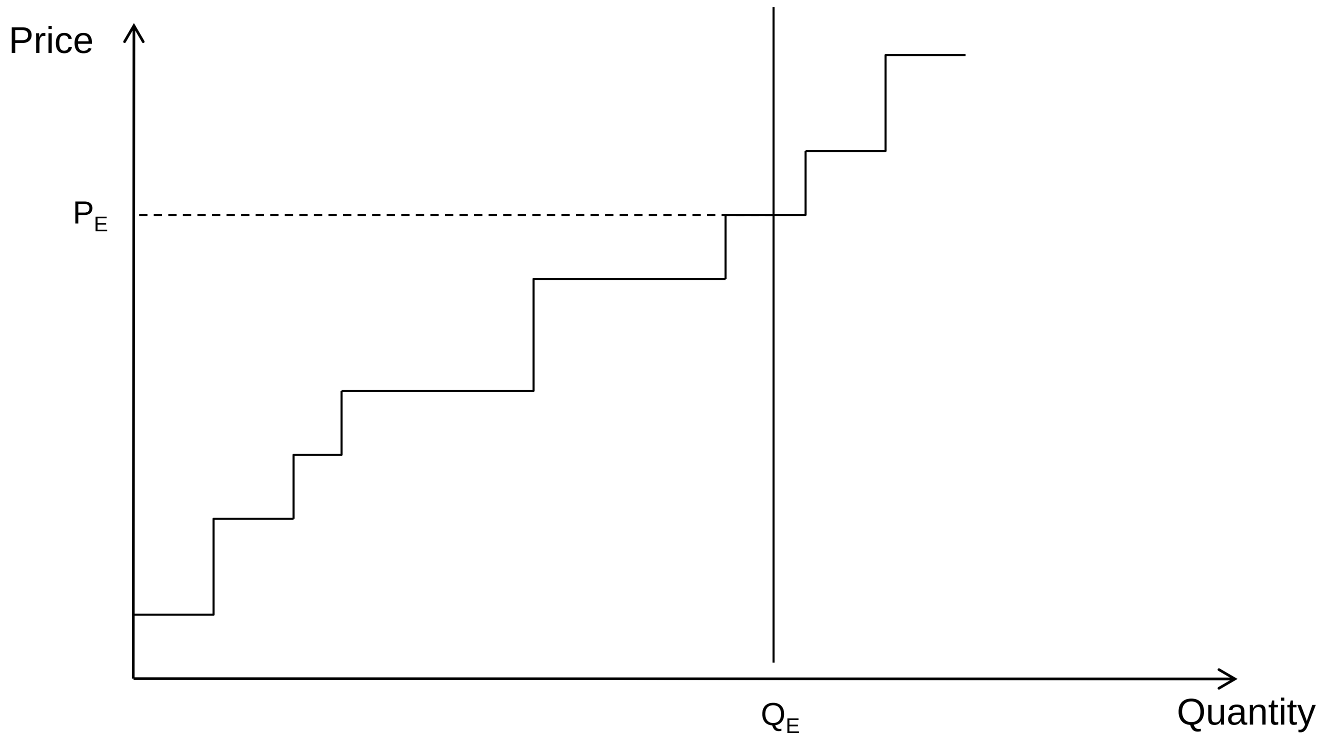
The MARKAL Model

A Simplified Reference Energy System of the MARKAL Model



Market Equilibrium in the MARKAL Model

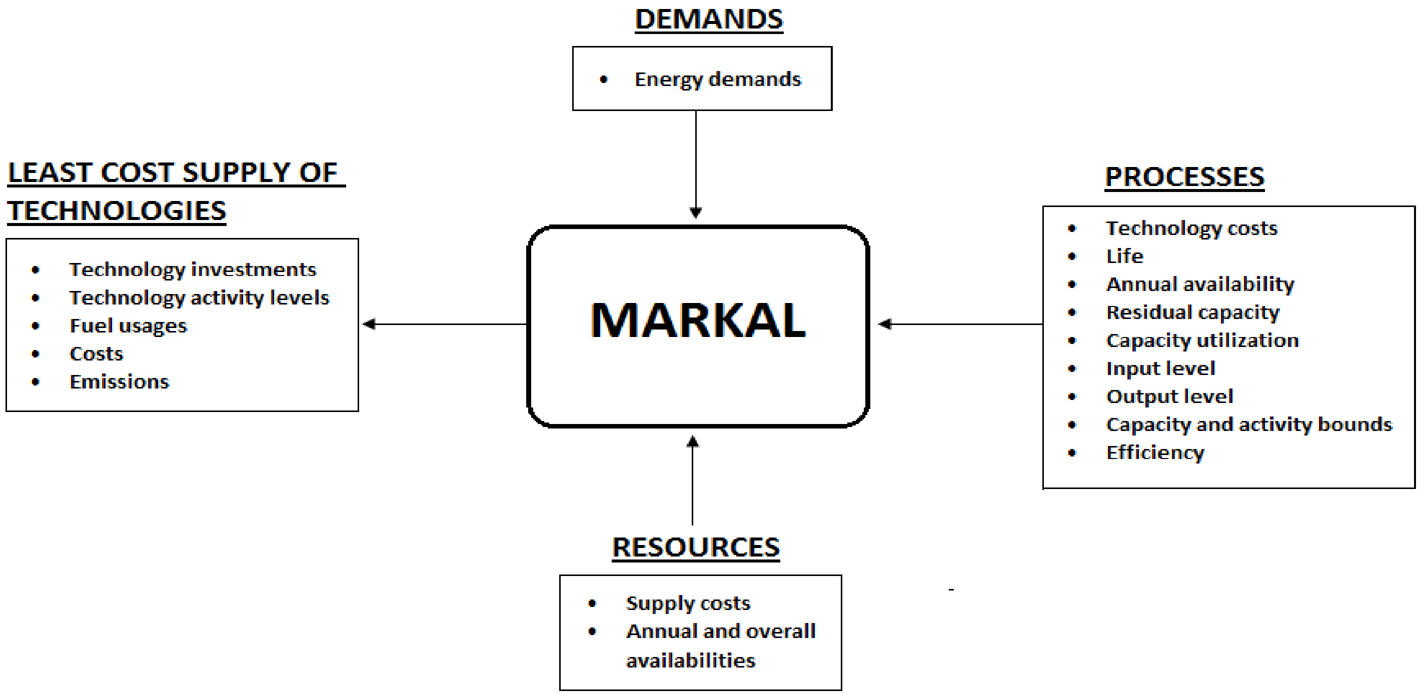
Objective function : Min. [discounted total system cost]
System constraints : energy balance, demands, electrical system
Policy constraints : emission caps, technology portfolio standards, taxes and subsidies



Equilibrium for an Energy Service Demand in MARKAL-TR

The MARKAL Model

Main Components of the MARKAL Model

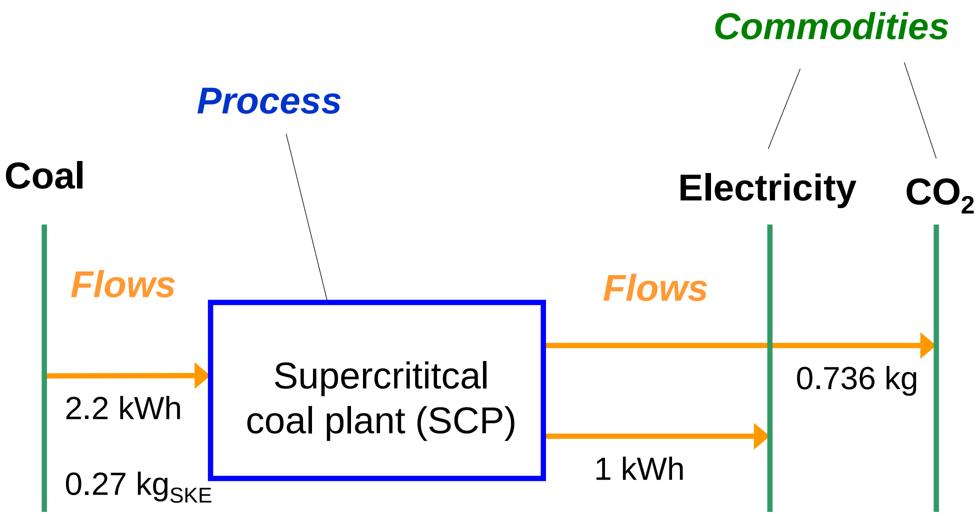


The MARKAL Model

Model constraints:

- **Capacity transfer constraint**
- **Demand balance**
- **Fuel balance other than electricity and heat**
- **Electricity balance**
- **District heat balance**
- **Load management constraints**
- **Emission and material balances**

Technology Representation



Coal PC Supercrit.	Unit	2005	2010	2020	2030
Size	MW_{el}	600	600	600	600
Construction time	Years	3	3	3	3
Lifetime	Years	35	35	35	35
Efficiency (LHV)	%	46	47	48	50
Max. availability	h/a	7500	7500	7500	7500
Spec. Investment costs (overnight)	€/kW_{el}	1175	1175	1140	1140
Fixed O&M	€/(kW a)	40.5	40.5	40.5	40.5
Var. O&M	€/MWh_{el}	2.6	2.6	2.6	2.6

Efficiency eqn $$\eta_{SPC} \cdot FLO_{SCP,COAL} = FLO_{SCP,ELC}$$

Emission eqn $$\varepsilon_{SCP,COAL,CO2} \cdot FLO_{SCP,COAL} = FLO_{SCP,CO2}$$

Activity definition $$ACT_{SCP} = FLO_{SCP,ELC}$$

Utilization eqn $$ACT_{SCP,ELC} \le \alpha_{SCP} \cdot CAP_{SCP,ELC}$$

Input parameter

η_{SPC}	*Plant efficiency*
$\varepsilon_{SCP,COAL,CO2}$	*CO2 Emission factor*
α_{SCP}	*Annual availability*

TIMES

(The Integrated MARKAL EFOM System)

Methodology

- Bottom-up technology rich model
- Perfect competition
- Perfect foresight (or myopic)
- Optimization (LP/MIP/NLP)

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

Development

- By ETSAP (Energy Technology Systems Analysis Program; www.iea-etsap.org)
- Implementation in GAMS
- Model generator & report writer
- Two software interfaces available: ANSWER-TIMES and VEDA-FE

Advanced Features/Variants

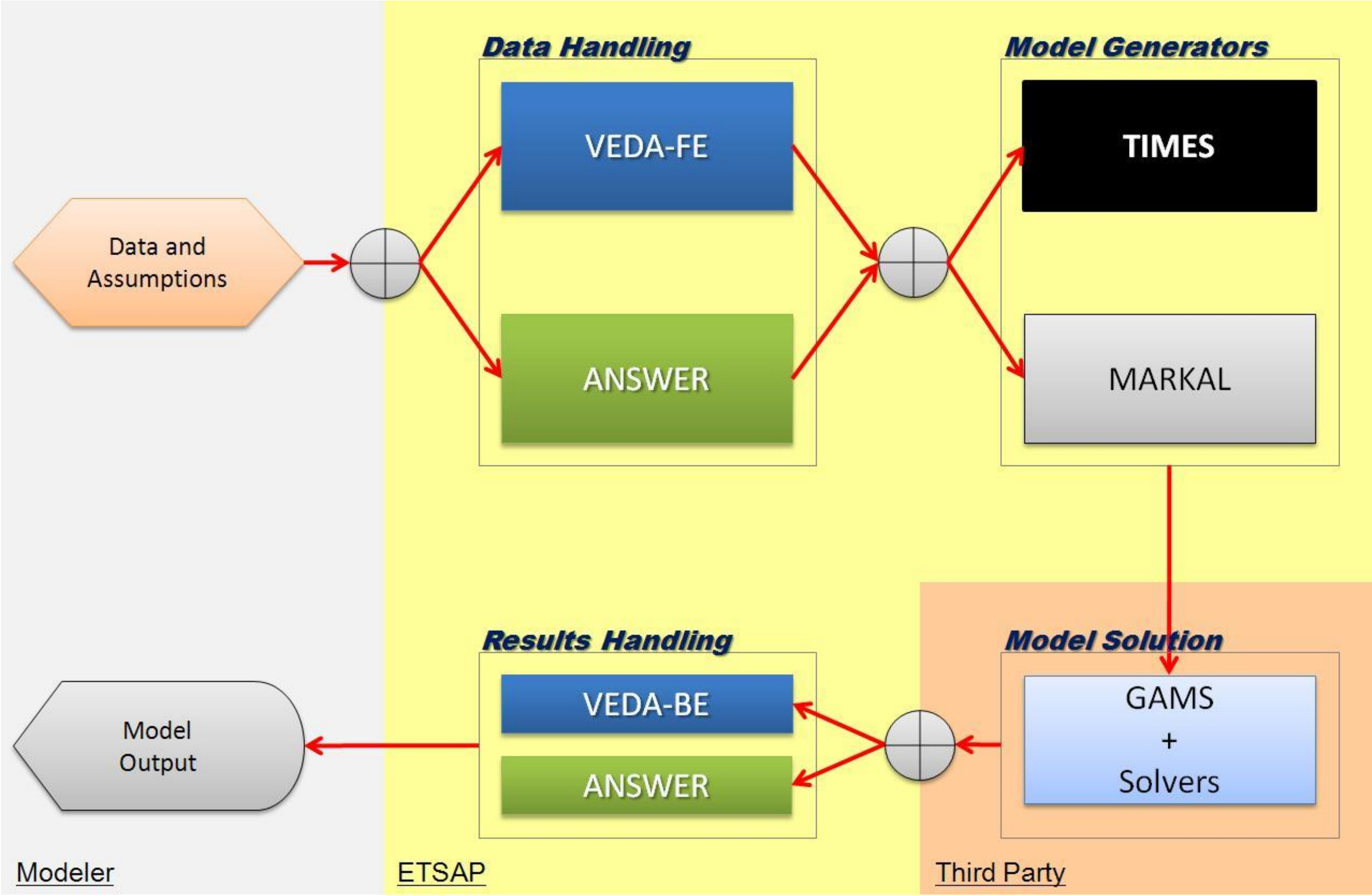
- Multi-regional
- Inter-temporal
- Power sector – discrete investment, ramping, early retirement, adv. storage, grids
- Elastic demands
- Endogenous learning
- Macroeconomic linkage
- Climate extension
- Multi-stage Stochastic programming
- Alternative objective functions
- Multi-criteria optimization

TIMES Improvements over MARKAL

Some Core Features

- Flexible period duration (unequal number of years/period permitted)
- Decoupling of model periods and data input years (so runs for any policy timing needed, without changing data)
- Flexible framework for user-defined constraints (cumulative over time or regions, inter-temporal between periods or timeslices)
- Multi-region decoupled TIMES-MACRO
- Multi-stage stochastics
- Clean code with mechanism to add new model equations/features

IEA-ETSAP Energy Systems Analysis Tools

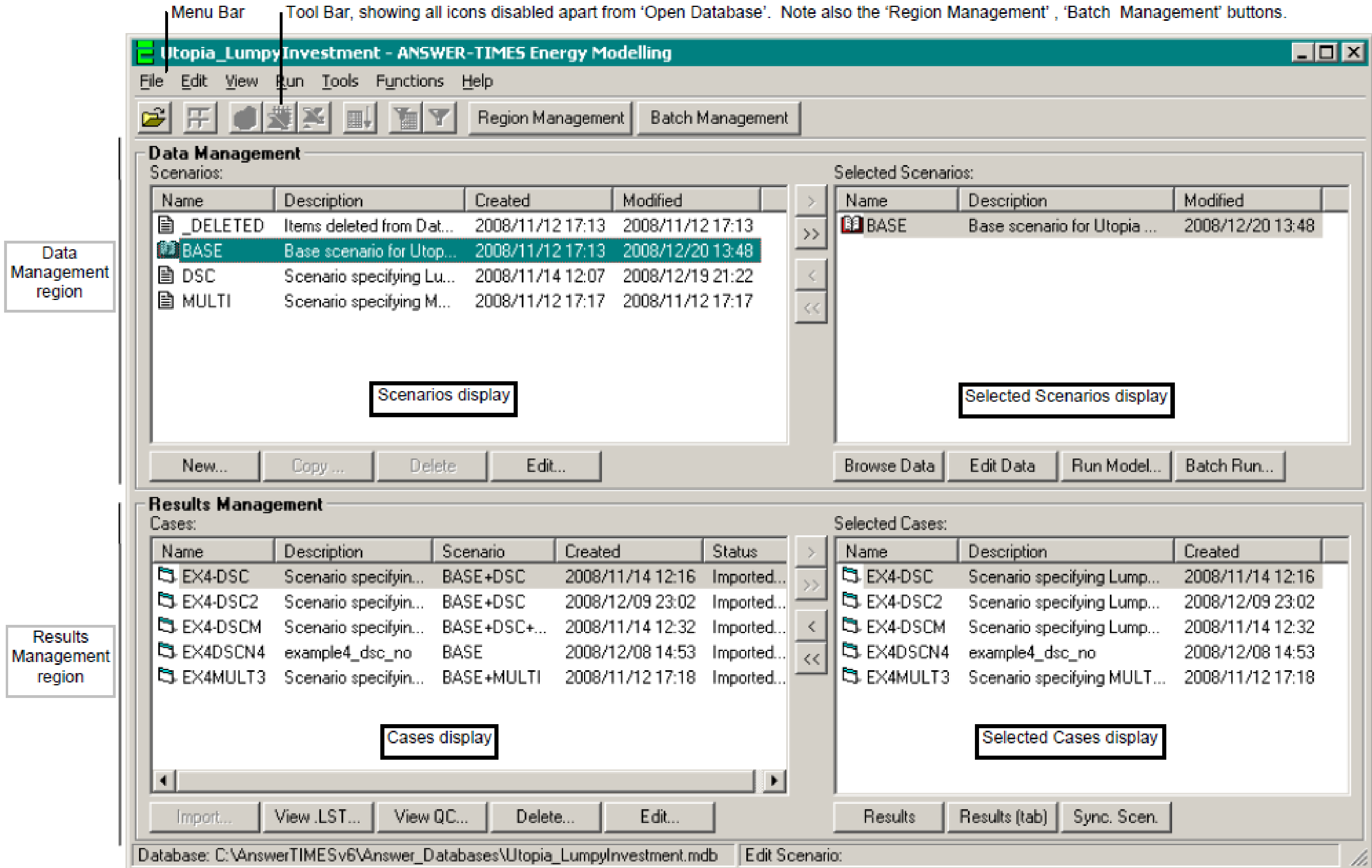


The MARKAL/TIMES Modeling Framework

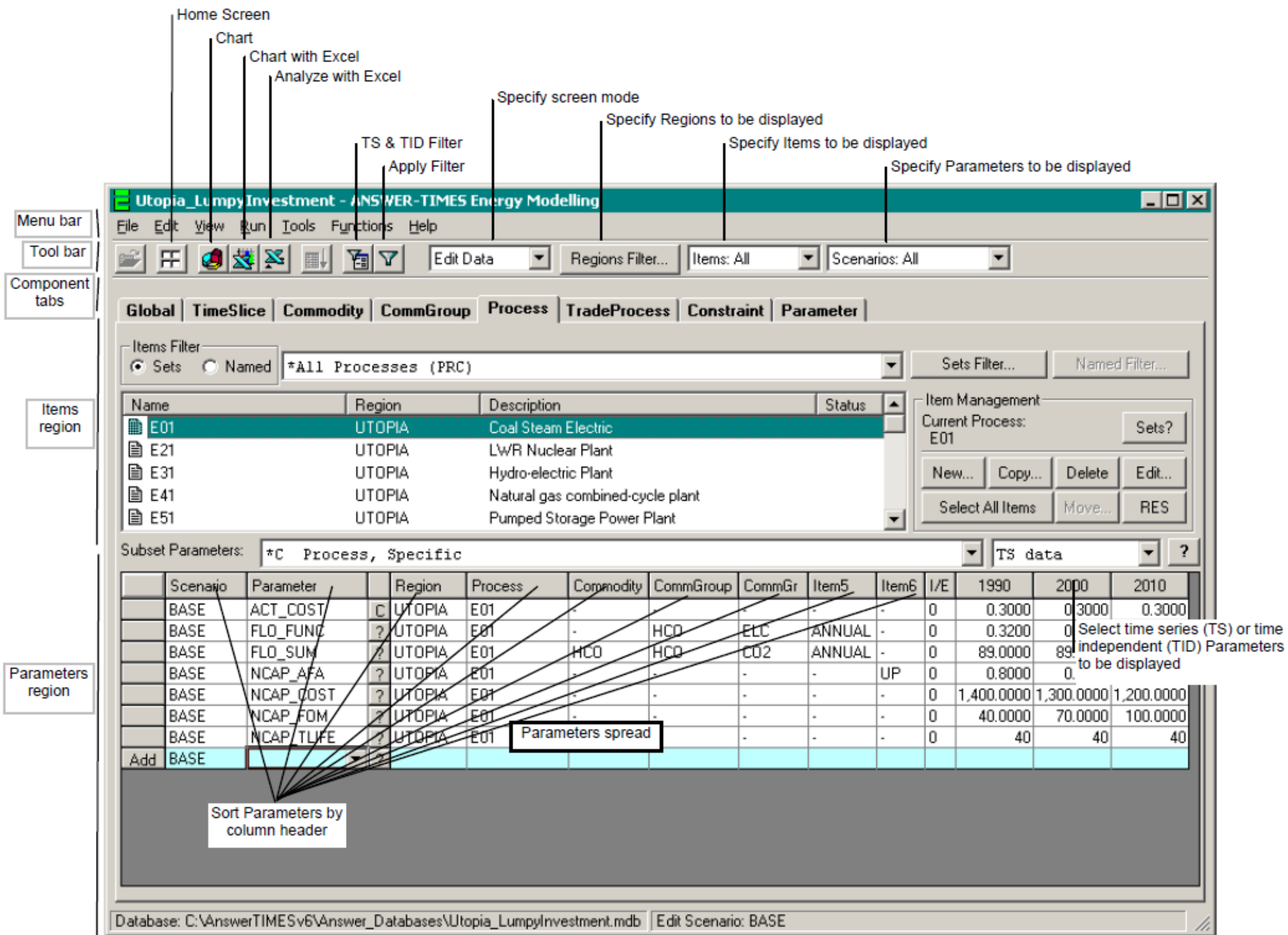
Typical questions to be analysed

- What is the cost-optimal energy mix that meets future demand?
- What is the impact of escalating fossil fuel prices?
- What are the environmental impacts?
- How does the cost-optimal energy mix change with more stringent environmental regulation?
- What will be the consequence of market restructuring?
- What needs to be done to increase the share of cleaner technologies?
- What are the consequences of introducing specific technologies?

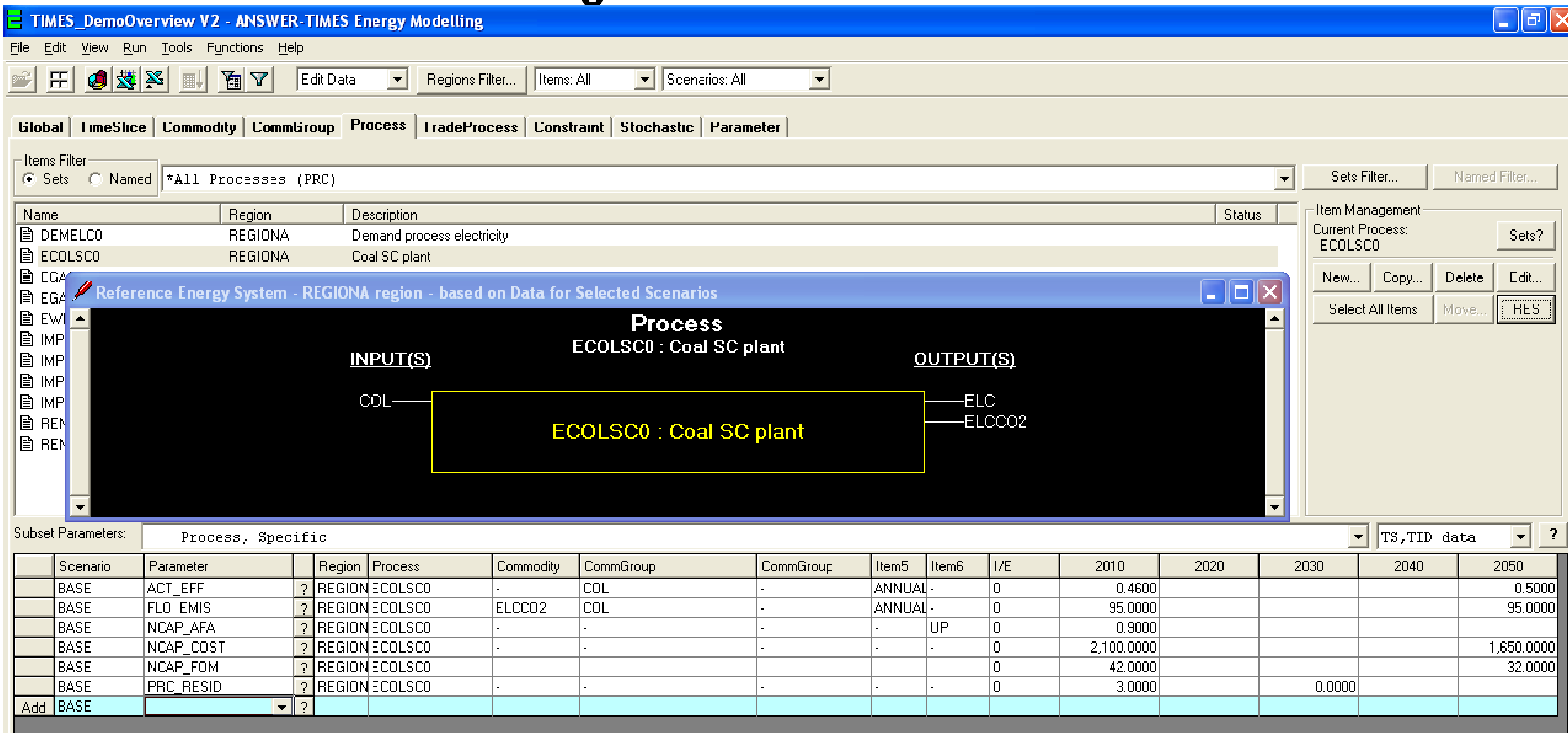
ANSWER-TIMES: Model Management System



ANSWER-TIMES: Data and Results Form

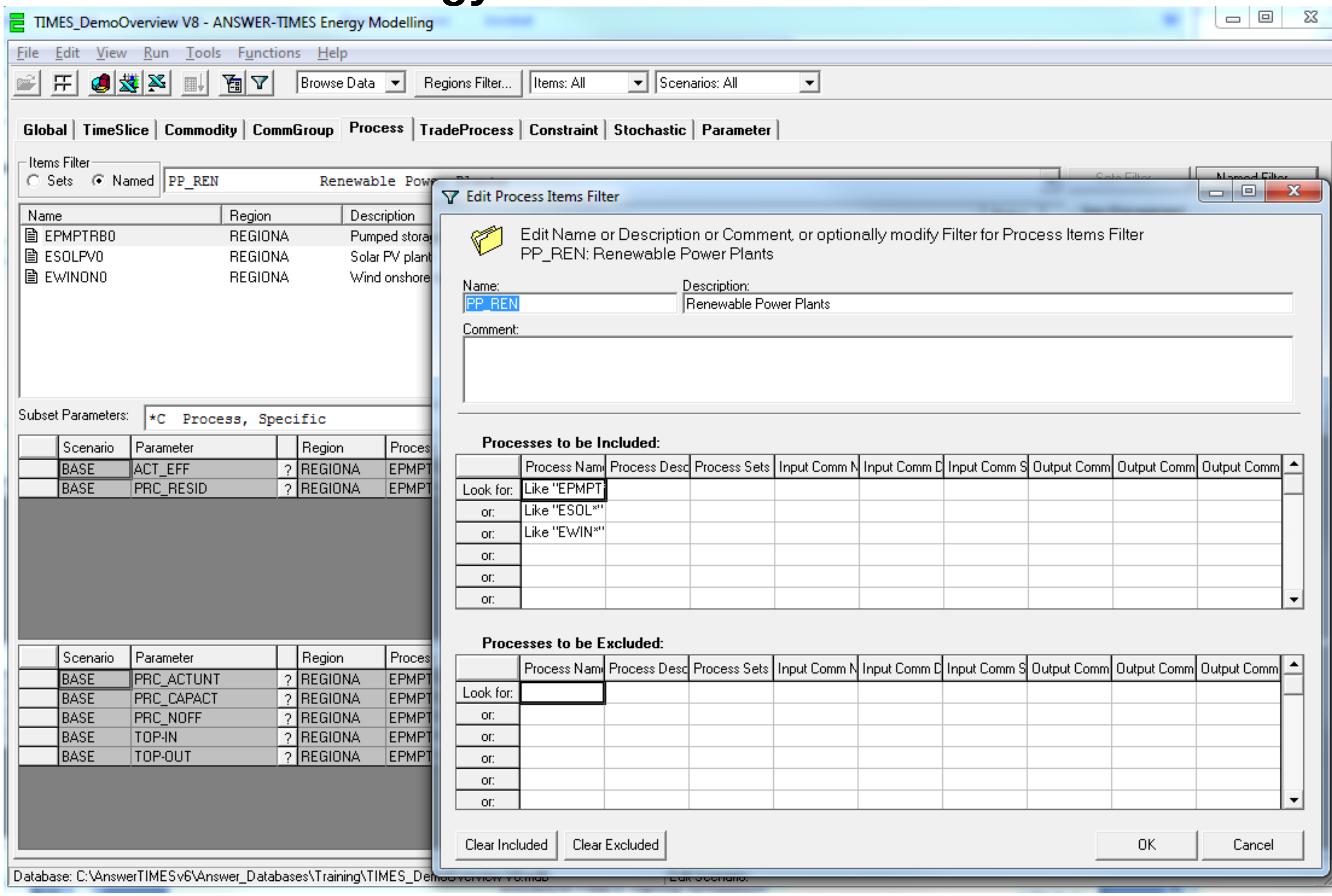


ANSWER-TIMES: RES Navigation



- Click on commodity flow/process box to cascade through the RES
- Related component data window displayed

ANSWER-TIMES: Technology Filters



- With good naming conventions technologies can be grouped to be foster organized access to subsets and for User Constraints