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Education

Ph.D. in Industrial Engg., METU

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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 \Rightarrow **energy-economy models**

1979 : 1. World Climate Conference
 \Rightarrow **energy-environment models**

1992 : UNFCCC
 \Rightarrow **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.

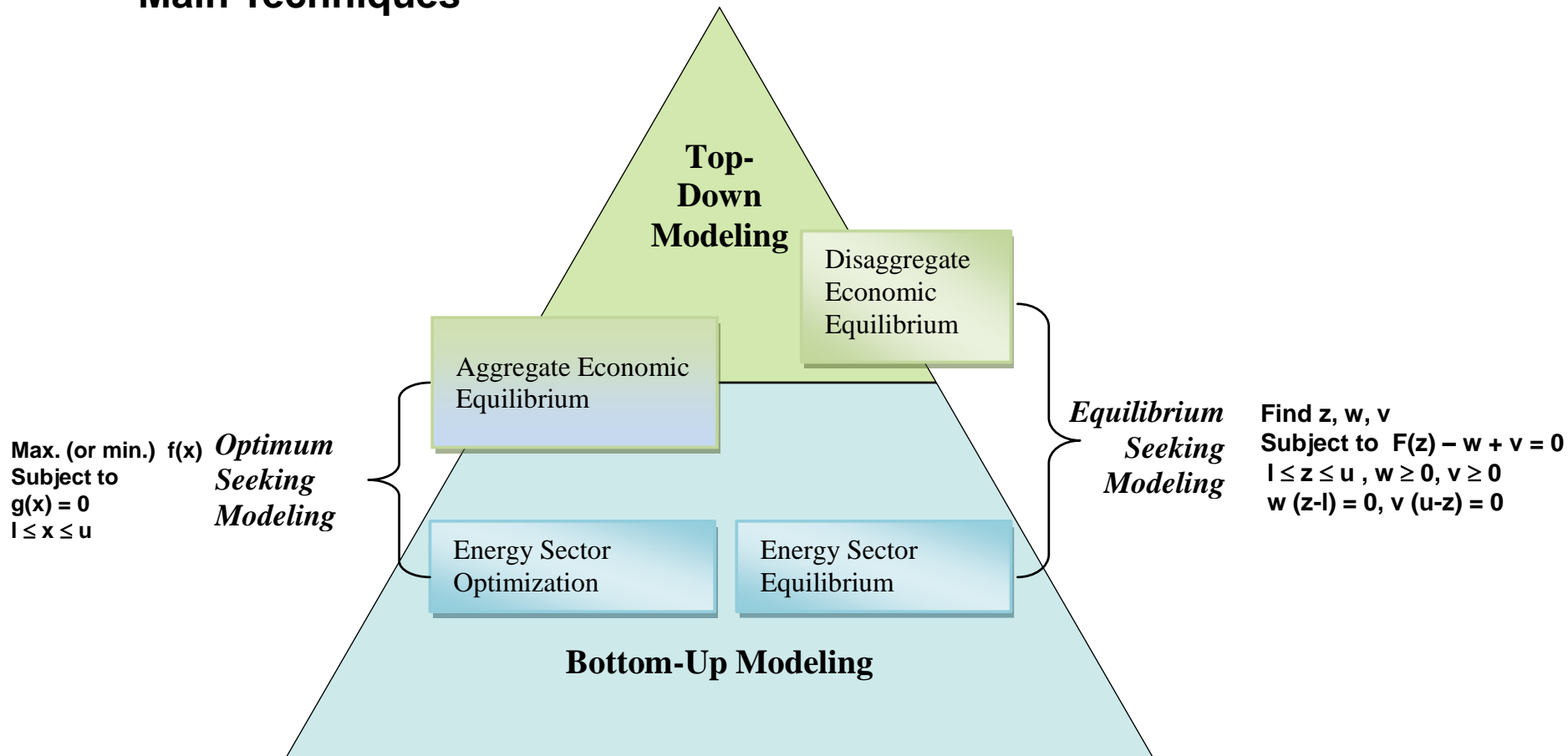
(AR4; IPCC, 2007)

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



Main Techniques

Energy Sector Optimization

Minimize $\sum_j c_j x_j$

Subject to

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

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

\vdots
 \vdots

Energy Sector Equilibrium

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

Subject to

$$e_1(p) = 0$$

\vdots

$$e_n(p) = 0$$

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

Main Techniques

Aggregate Economic Equilibrium

Maximize $U = u(C)$

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

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

$$Y = GDP + EC$$

$$E = [a] [z]$$

$$EC = [b] [z]$$

Disaggregate Economic Equilibrium

Consumers: $U_i = u(C_i)$

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

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

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



Classification of Selected Models

Energy Sector Optimization

EFOM	PERSEUS
MARKAL	PERSEUS-GWI
TIMES	

Energy Sector Equilibrium

GEMINIWATEMS	
ERB	WATEMS-GDL
ICF	

Aggr. Econ. Equilibrium

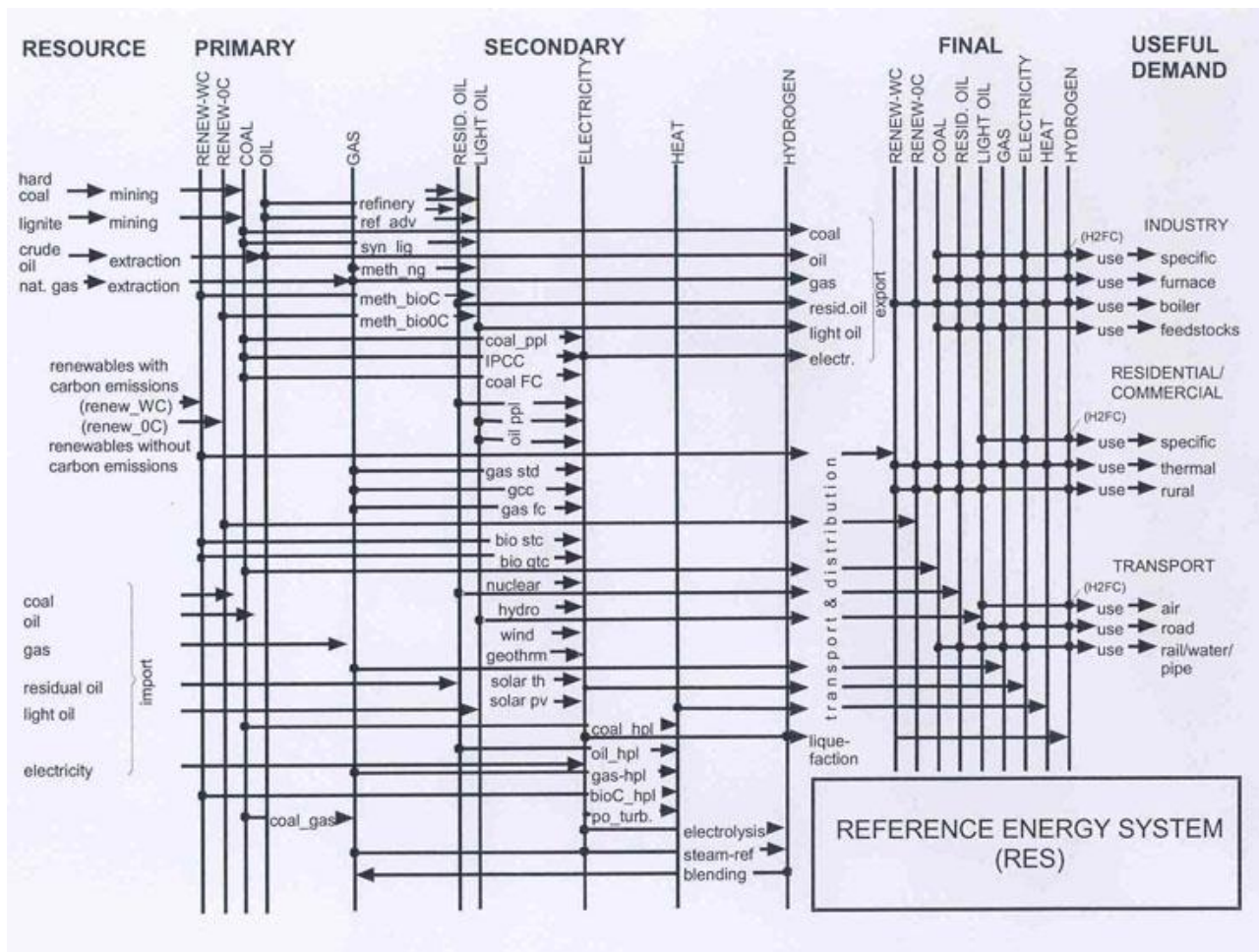
MIS	MARKAL-MACRO
RICE	GMM
IIAM	MERGE
CETA	MERGE-ETL
ENVEES	

Disaggr. Econ. Equilibrium

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

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

$$\text{Minimize } c x$$

$$\begin{aligned} \text{S.to } \quad & M x = b \\ & 0 \leq x \leq u \end{aligned}$$

Modeling Network Flow

The **MCNF** Formulation

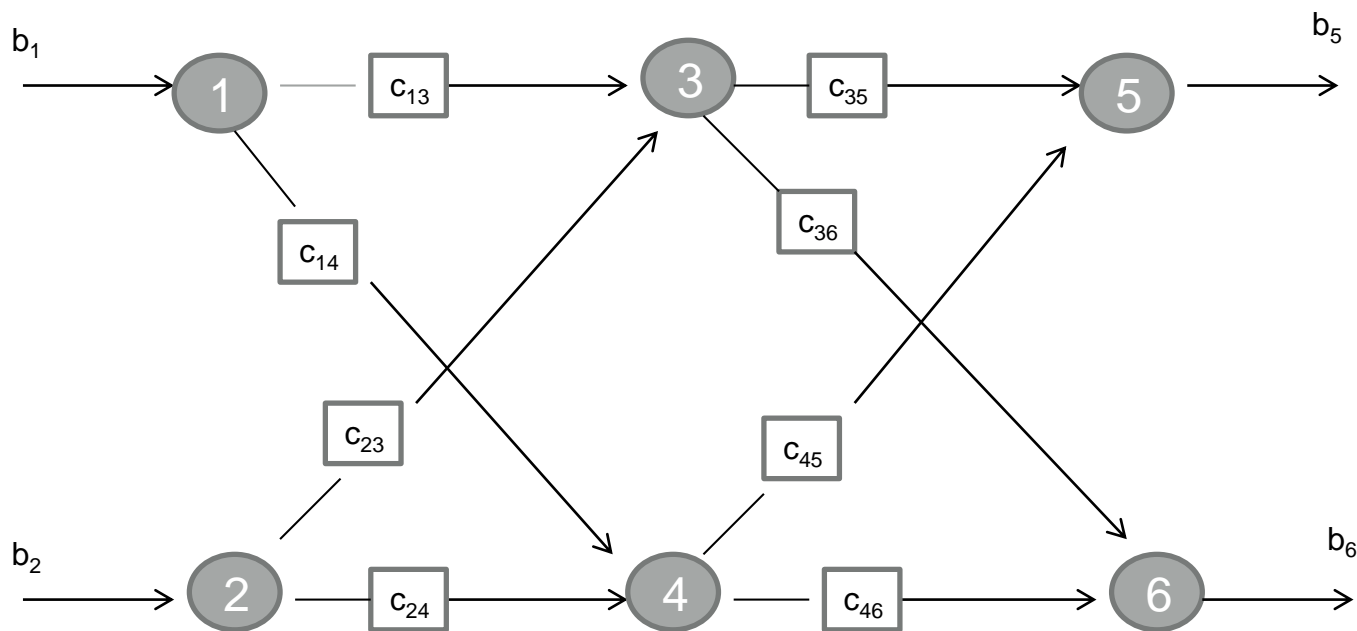
$$\text{Minimize } \sum_i \sum_{j \neq i} x_{i,j} \times c_{i,j}$$

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

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

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 pump 150 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

Minimize $c x$

S.to $M x = b$
 $0 \leq x \leq u$

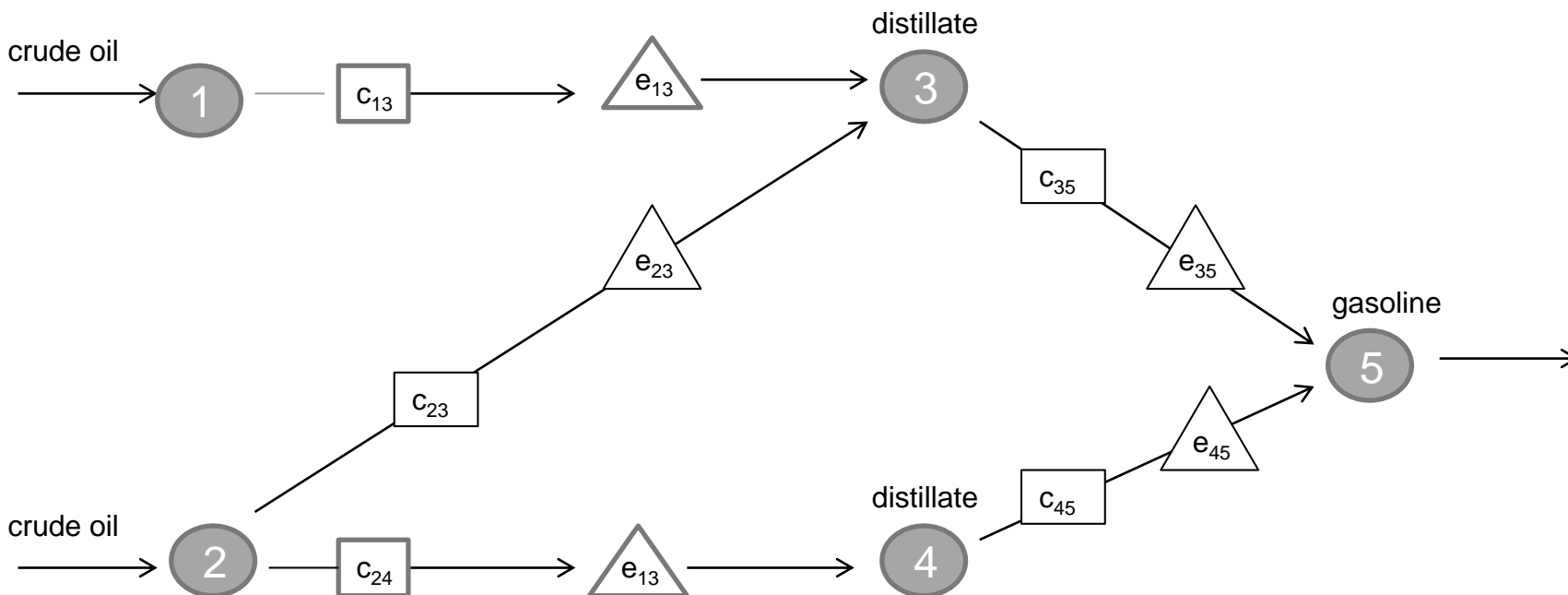
Minimize $\sum_i \sum_{j \neq i} x_{i,j} \times tc_{i,j}$

$$\sum_j x_{i,j} - \sum_j x_{j,i} = b_i$$
$$0 \leq x_{i,j} \leq u_{i,j}$$

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 $c x$

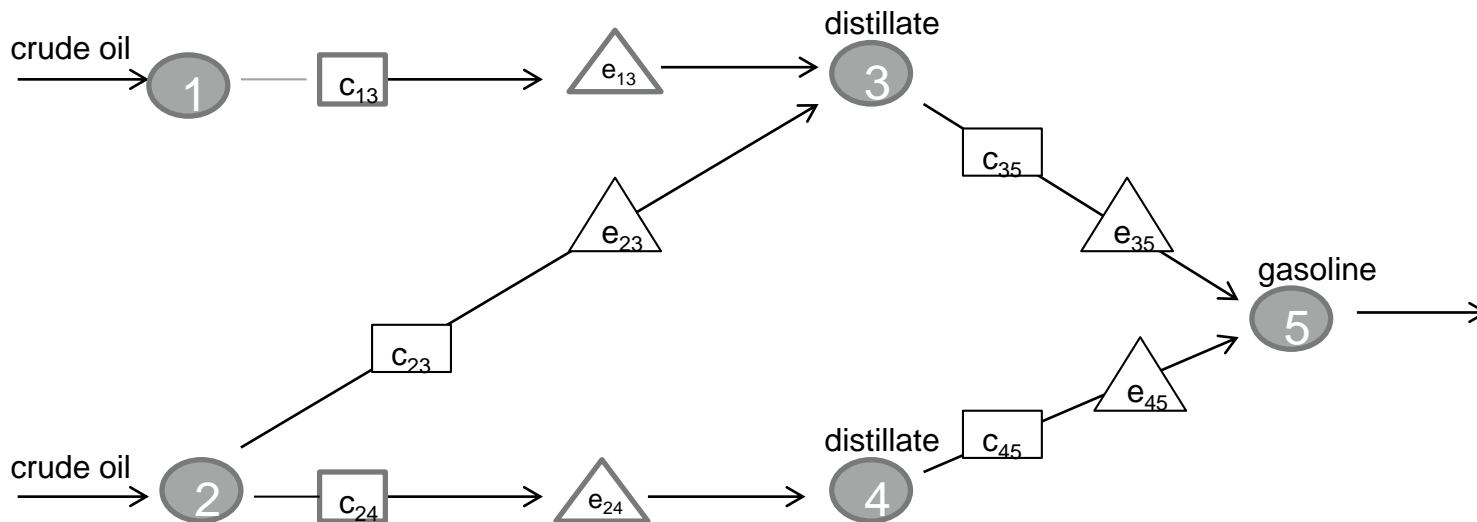
S.to $M x = b$

$x \geq 0$

Modeling Energy Production/Consumption

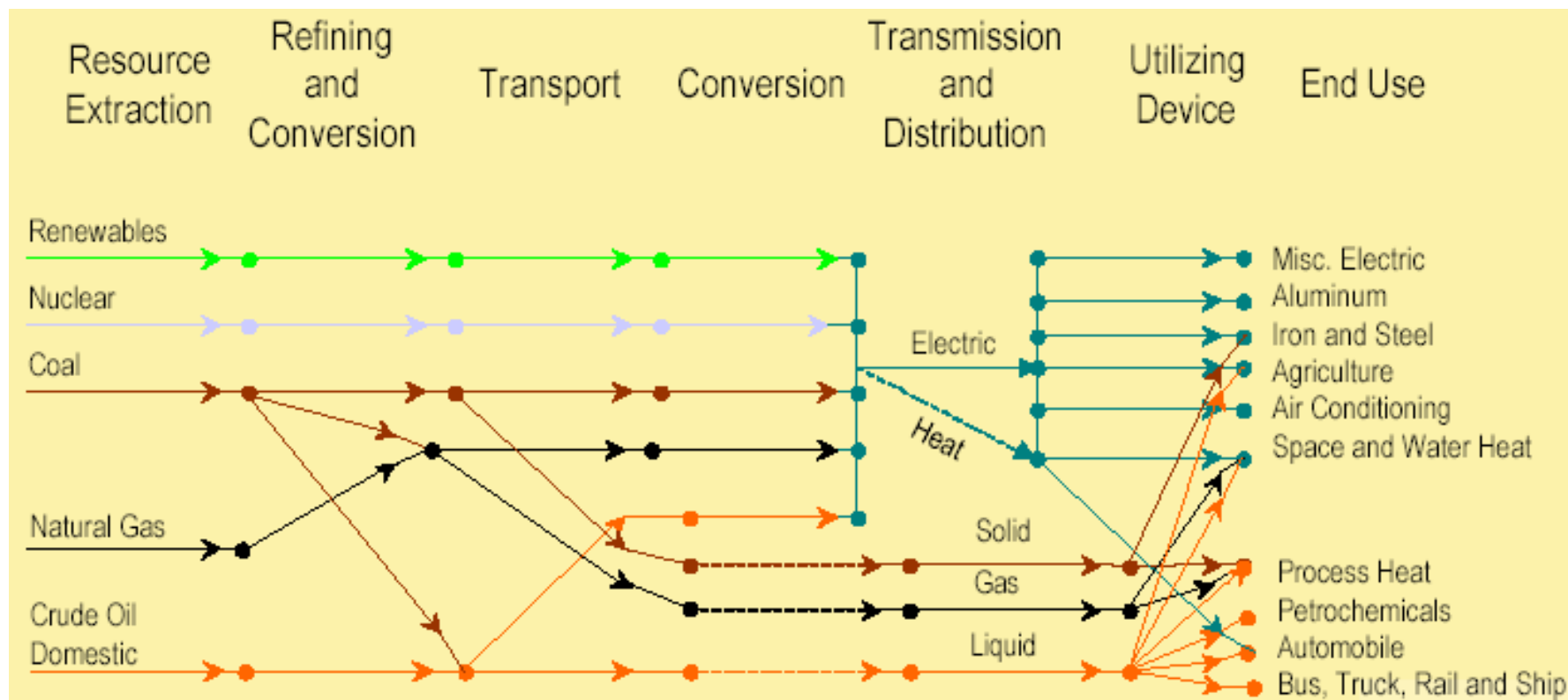
Ex.:

$$\begin{array}{l}
 \text{unit costs} \longrightarrow M = \begin{matrix} & \begin{matrix} x_{1,3} & x_{2,3} & x_{2,4} & x_{3,5} & x_{4,5} \end{matrix} \\ \begin{matrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \end{matrix} & \begin{pmatrix} -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 \\ 0.9 & 0.8 & 0 & -1 & 0 \\ 0 & 0 & 0.9 & 0 & -1 \\ 0 & 0 & 0 & 0.6 & 0.6 \end{pmatrix} \end{matrix} \\
 \begin{matrix} 4.5 \\ 6 \\ 6 \\ 19 \\ 12 \end{matrix}
 \end{array}
 \begin{array}{l}
 \begin{matrix} \text{supply \& demand} \\ \downarrow \end{matrix} \\
 \begin{matrix} \geq -200 \\ \geq -80 \\ = 0 \\ = 0 \\ \geq 120 \end{matrix}
 \end{array}
 \begin{array}{l}
 \text{Minimize } c x \\
 \\
 \text{S.to } M x \geq b \\
 x \geq 0
 \end{array}
 \end{array}$$



The MARKAL Model

A Simplified Reference Energy System: The MARKAL Example

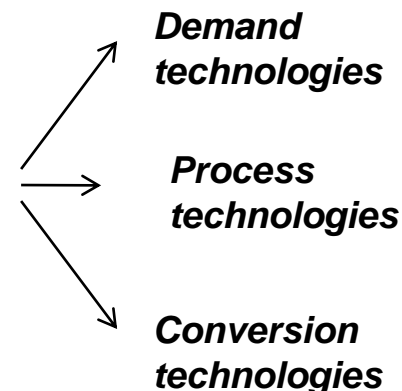


Source: <http://www.gams.com/presentations/or01/marcal.pdf>

The MARKAL Model

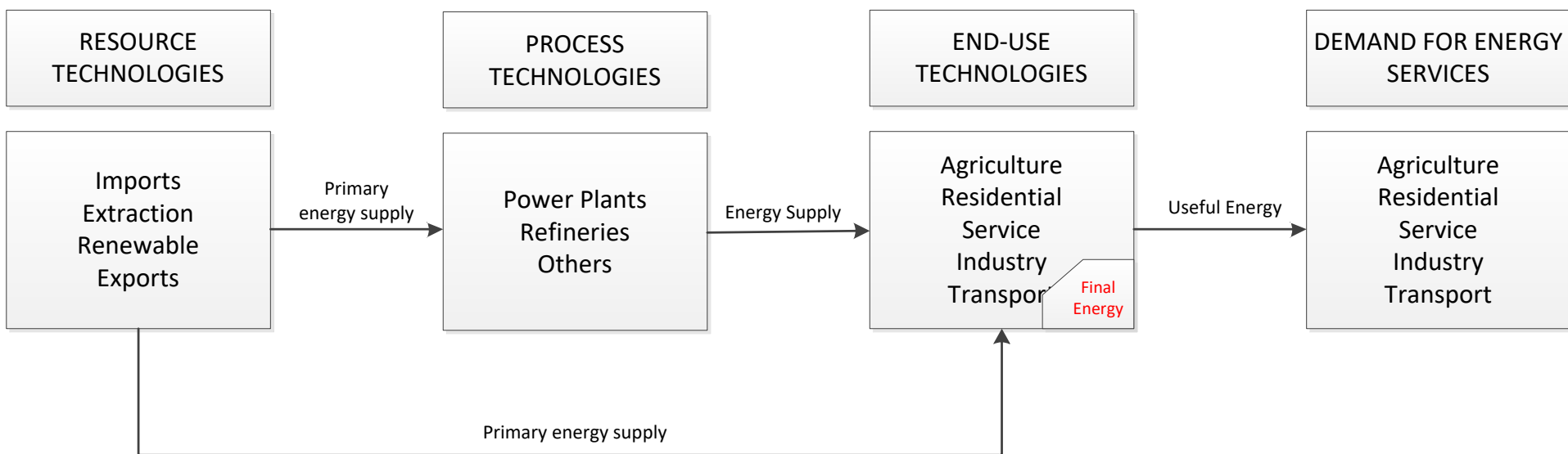
Main elements of the MARKAL Model

- **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.



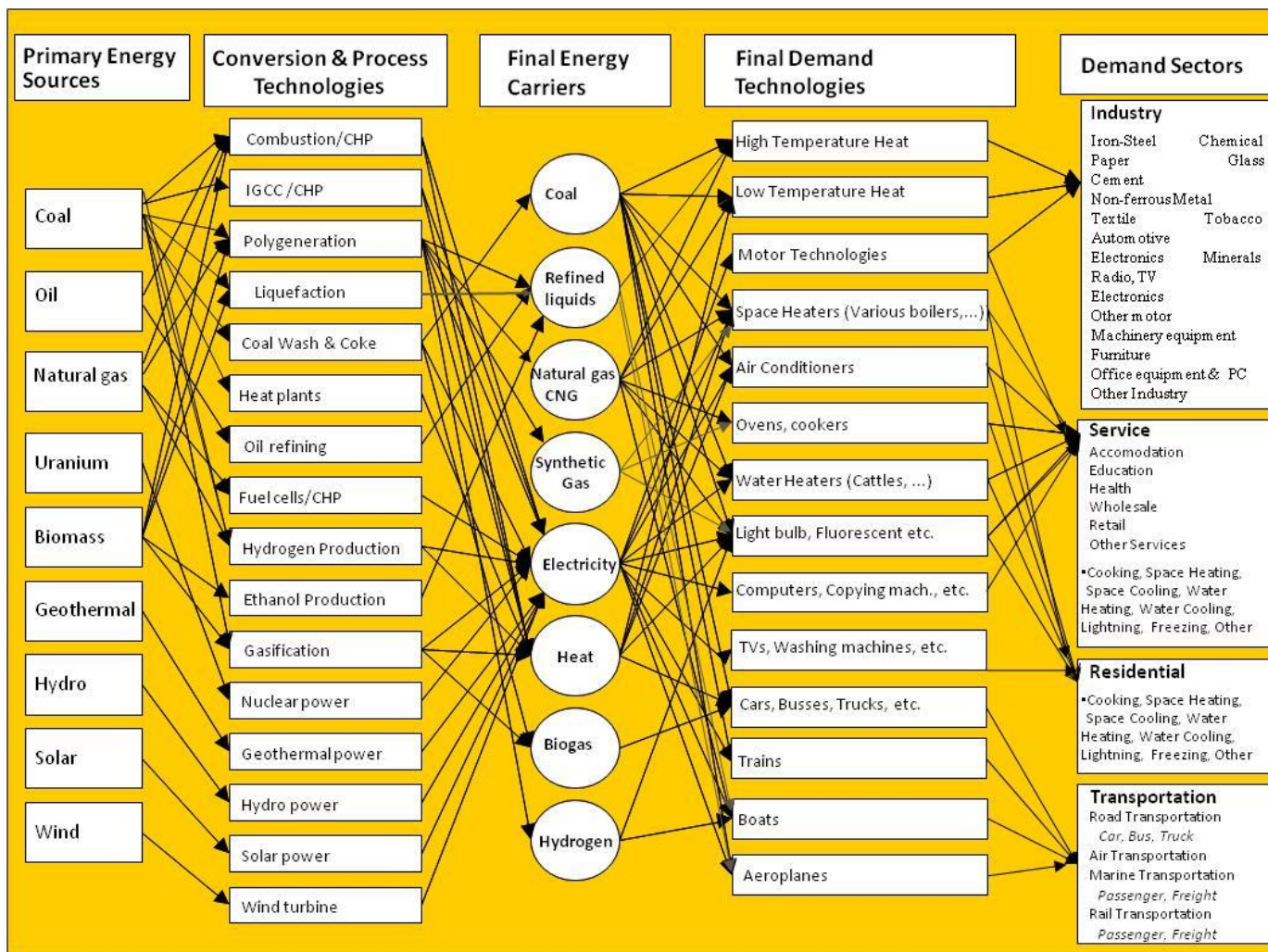
The MARKAL Model

Technology Relations in the MARKAL Model



The MARKAL Model

A Simplified Reference Energy System of the MARKAL Model

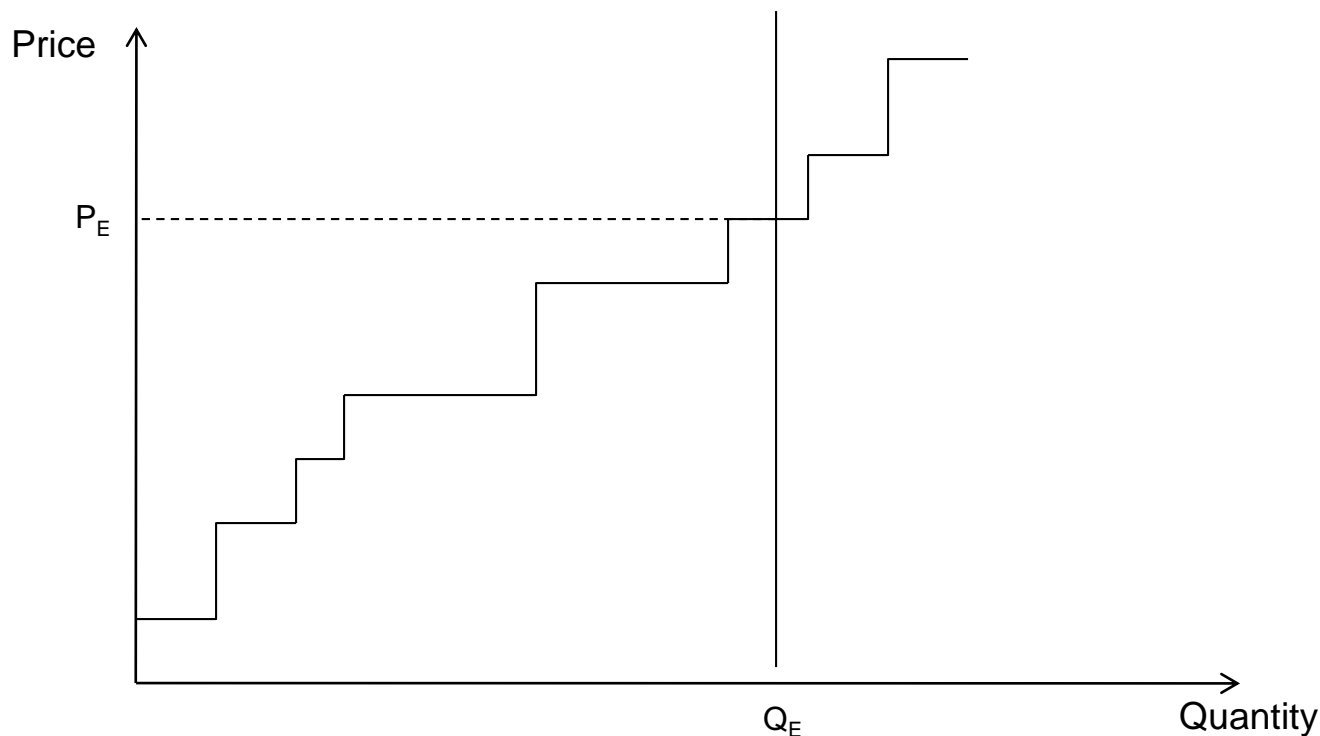


Market Equilibrium in the MARKAL Model

Objective function : Min. [discounted total system cost]

System constraints : energy balance, demands, electrical system

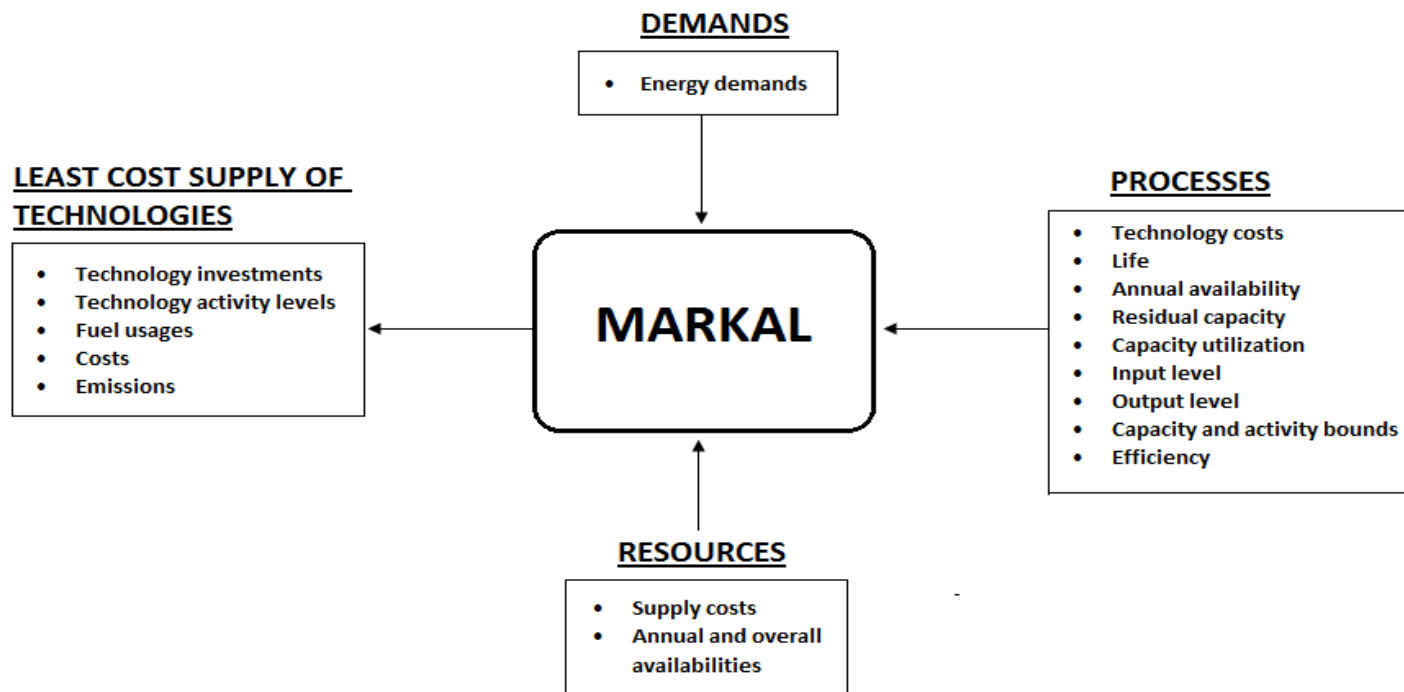
Policy constraints : emission caps, technology portfolio standards, taxes and subsidies



Equilibrium for an Energy Service Demand in MARKAL-TR

The MARKAL Model

Main Components of the MARKAL Model



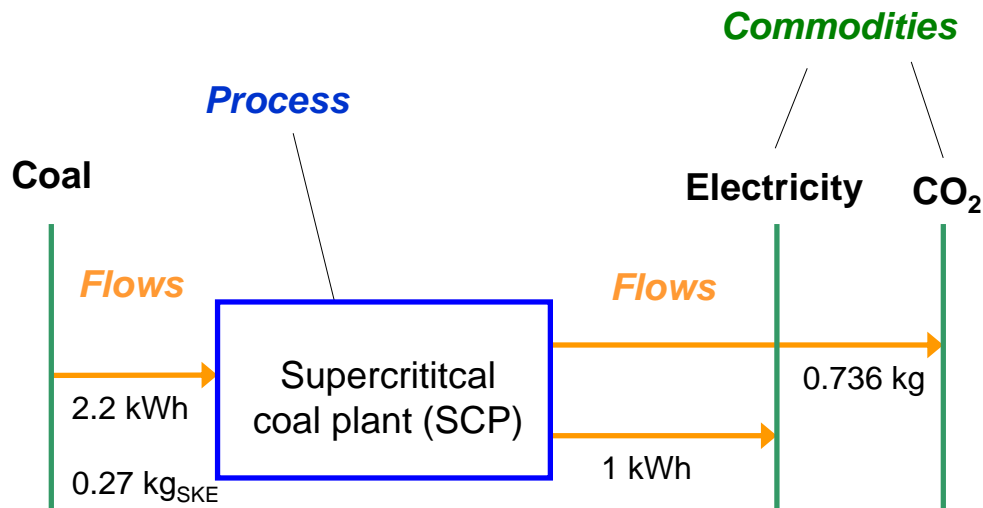


The MARKAL Model

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

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

Emission eqn

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

Activity definition

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

Utilization eqn

$$ACT_{SCP,ELC} \leq \alpha_{SCP} \cdot CAP_{SCP,ELC}$$

Input parameter

η_{SCP}

Plant efficiency

$\varepsilon_{SCP,COAL,CO2}$

CO₂ Emission factor

α_{SCP}

Annual availability

TIMES ***(The Integrated MARKAL EFOM System)***

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

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 \leq Solution for
given Input parameters

Advanced Features/Variants

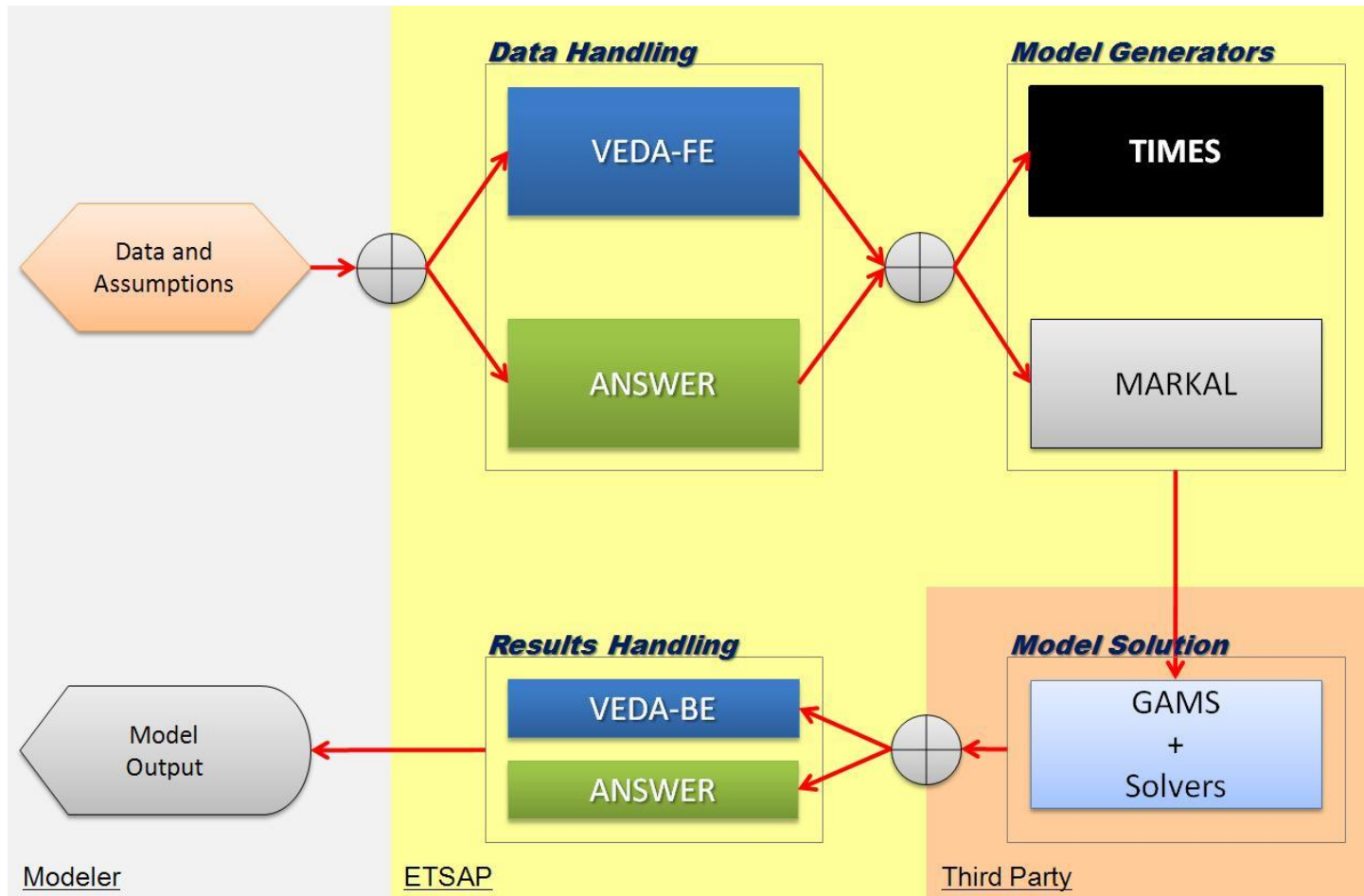
- Multi-regional
- Inter-temporal
- Power sector – discrete investment, ramping, early retirement, adv. storage, grids
- Elastic demands
- Endogenous learning
- Macroeconomic linkage
- Climate extension
- Multi-stage Stochastic programming
- Alternative objective functions
- Multi-criteria optimization

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

Menu Bar Tool Bar, showing all icons disabled apart from 'Open Database'. Note also the 'Region Management', 'Batch Management' buttons.

Utopia_Lumpy Investment - ANSWER-TIMES Energy Modelling

File Edit View Run Tools Functions Help

Region Management Batch Management

Data Management

Scenarios:

Name	Description	Created	Modified
_DELETED	Items deleted from Dat...	2008/11/12 17:13	2008/11/12 17:13
BASE	Base scenario for Utop...	2008/11/12 17:13	2008/12/20 13:48
DSC	Scenario specifying Lu...	2008/11/14 12:07	2008/12/19 21:22
MULTI	Scenario specifying M...	2008/11/12 17:17	2008/11/12 17:17

Scenarios display

Selected Scenarios:

Name	Description	Modified
BASE	Base scenario for Utopia ...	2008/12/20 13:48

Selected Scenarios display

New... Copy... Delete Edit...

Browse Data Edit Data Run Model... Batch Run...

Results Management

Cases:

Name	Description	Scenario	Created	Status
EX4-DSC	Scenario specifying...	BASE+DSC	2008/11/14 12:16	Imported...
EX4-DSC2	Scenario specifying...	BASE+DSC	2008/12/09 23:02	Imported...
EX4-DSCM	Scenario specifying...	BASE+DSC+...	2008/11/14 12:32	Imported...
EX4DSCN4	example4_dsc_no	BASE	2008/12/08 14:53	Imported...
EX4MULT3	Scenario specifying...	BASE+MULTI	2008/11/12 17:18	Imported...

Cases display

Selected Cases:

Name	Description	Created
EX4-DSC	Scenario specifying Lump...	2008/11/14 12:16
EX4-DSC2	Scenario specifying Lump...	2008/12/09 23:02
EX4-DSCM	Scenario specifying Lump...	2008/11/14 12:32
EX4DSCN4	example4_dsc_no	2008/12/08 14:53
EX4MULT3	Scenario specifying MULT...	2008/11/12 17:18

Selected Cases display

Import... View .LST... View QC... Delete... Edit...

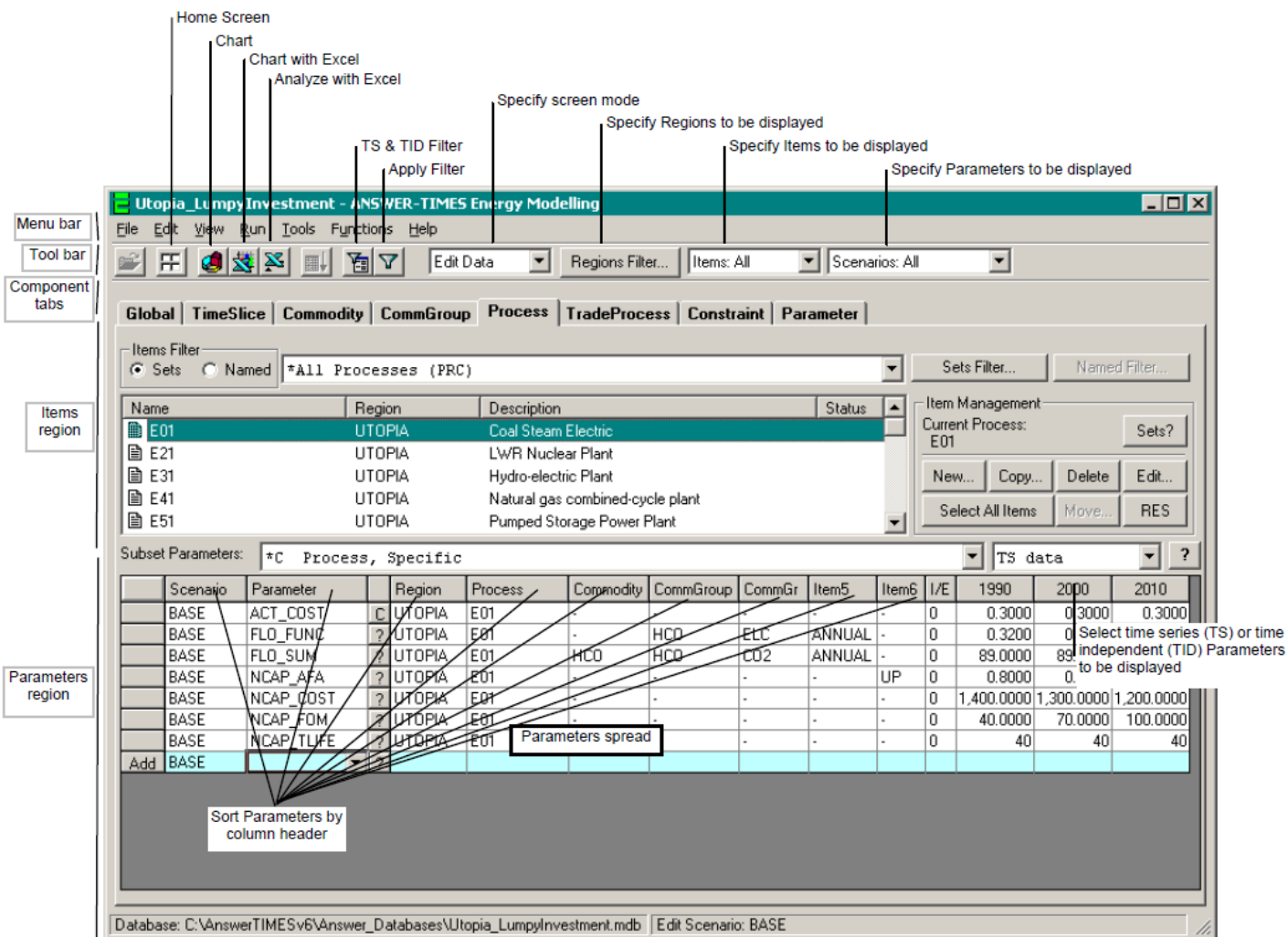
Results Results (tab) Sync. Scen.

Database: C:\AnswerTIMESv6\Answer_Databases\Utopia_Lumpy\Investment.mdb Edit Scenario:

Data Management region

Results Management region

ANSWER-TIMES: Data and Results Form



Home Screen
Chart
Chart with Excel
Analyze with Excel
Specify screen mode
Specify Regions to be displayed
Specify Items to be displayed
Specify Parameters to be displayed
TS & TID Filter
Apply Filter

Menu bar
Tool bar
Component tabs
Items region
Parameters region

Utopia_Lumpy Investment - ANSWER-TIMES Energy Modelling

File Edit View Run Tools Functions Help

Edit Data Regions Filter... Items: All Scenarios: All

Global TimeSlice Commodity CommGroup Process TradeProcess Constraint Parameter

Items Filter
Sets Named *All Processes (PRC) Sets Filter... Named Filter...

Name	Region	Description	Status
E01	UTOPIA	Coal Steam Electric	
E21	UTOPIA	LWR Nuclear Plant	
E31	UTOPIA	Hydro-electric Plant	
E41	UTOPIA	Natural gas combined-cycle plant	
E51	UTOPIA	Pumped Storage Power Plant	

Item Management
Current Process: E01
Sets?
New... Copy... Delete Edit...
Select All Items Move... RES

Subset Parameters: *C Process, Specific TS data

Scenario	Parameter	Region	Process	Commodity	CommGroup	CommGr	Item5	Item6	I/E	1990	2000	2010
BASE	ACT_COST	UTOPIA	E01	-	-	-	-	-	0	0.3000	0.3000	0.3000
BASE	FLO_FUNC	UTOPIA	E01	-	HCD	ELC	ANNUAL	-	0	0.3200	0	0
BASE	FLO_SUM	UTOPIA	E01	-	HCD	CO2	ANNUAL	-	0	89.0000	89	89
BASE	NCAP_AFA	UTOPIA	E01	-	-	-	-	UP	0	0.8000	0	0
BASE	NCAP_COST	UTOPIA	E01	-	-	-	-	-	0	1,400.0000	1,300.0000	1,200.0000
BASE	NCAP_FOM	UTOPIA	E01	-	-	-	-	-	0	40.0000	70.0000	100.0000
BASE	NCAP_TLIFE	UTOPIA	E01	-	-	-	-	-	0	40	40	40
Add	BASE											

Parameters spread

Sort Parameters by column header

Database: C:\AnswerTIMESv6\Answer_Databases\Utopia_LumpyInvestment.mdb Edit Scenario: BASE

Select time series (TS) or time independent (TID) Parameters to be displayed

ANSWER-TIMES: RES Navigation

TIMES_DemoOverview V2 - ANSWER-TIMES Energy Modelling

File Edit View Run Tools Functions Help

Regions Filter... Items: All Scenarios: All

Global TimeSlice Commodity CommGroup Process TradeProcess Constraint Stochastic Parameter

Items Filter: Sets Named *All Processes (PRC)

Item Management: Current Process: ECOLSCO

New... Copy... Delete Edit... Select All Items Move... RES

Reference Energy System - REGIONA region - based on Data for Selected Scenarios

Process
ECOLSCO : Coal SC plant

INPUT(S)
COL

OUTPUT(S)
ELC
ELCCO2

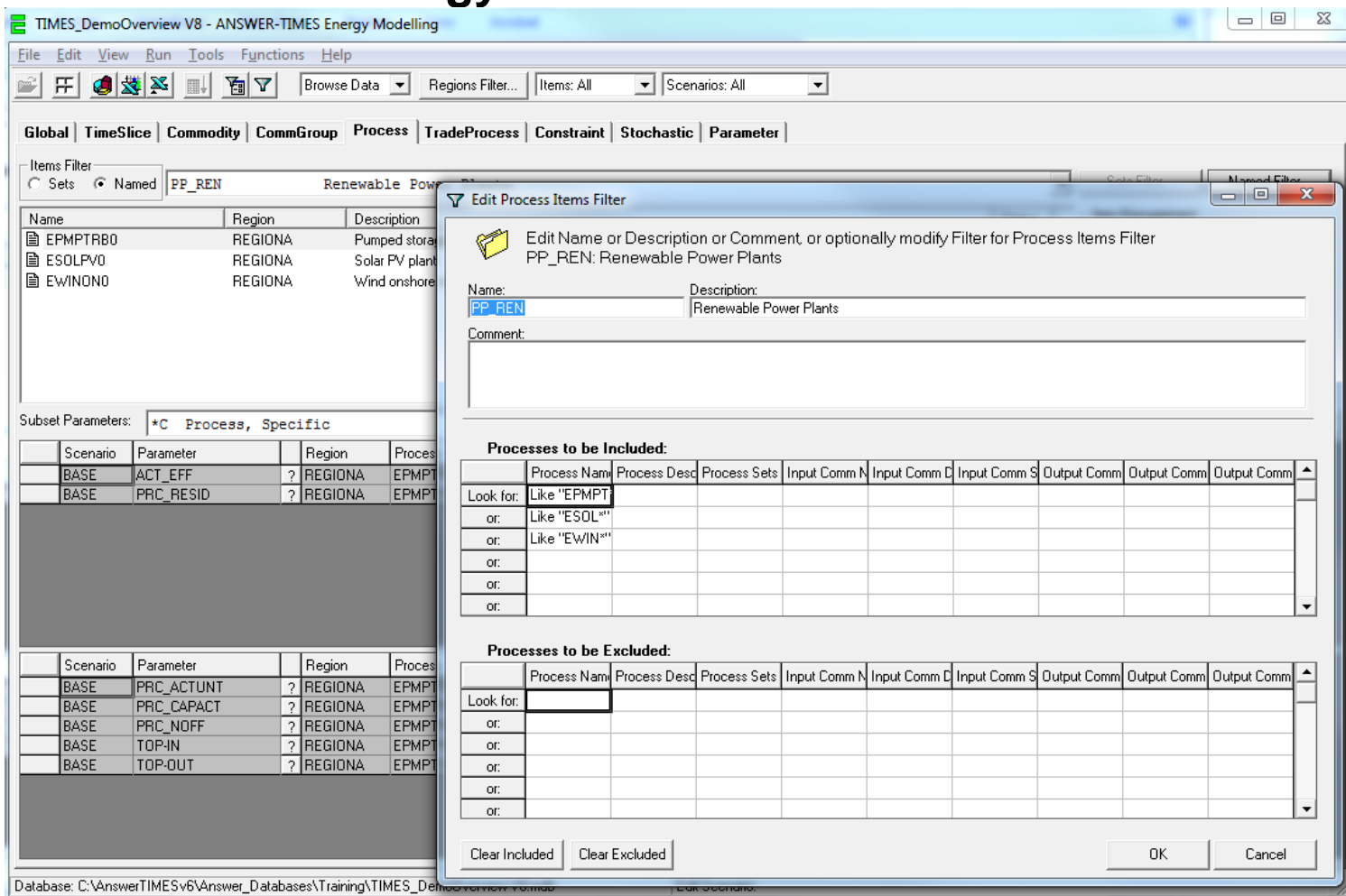
ECOLSCO : Coal SC plant

Subset Parameters: Process, Specific

Scenario	Parameter	Region	Process	Commodity	CommGroup	CommGroup	Item5	Item6	I/E	2010	2020	2030	2040	2050
BASE	ACT_EFF	?	REGIONA	ECOLSCO	-	COL	-	ANNUAL	0	0.4600				0.5000
BASE	FLO_EMIS	?	REGIONA	ECOLSCO	ELCCO2	COL	-	ANNUAL	0	95.0000				95.0000
BASE	NCAP_AFA	?	REGIONA	ECOLSCO	-	-	-	UP	0	0.9000				
BASE	NCAP_COST	?	REGIONA	ECOLSCO	-	-	-	-	0	2,100.0000				1,650.0000
BASE	NCAP_FOM	?	REGIONA	ECOLSCO	-	-	-	-	0	42.0000				32.0000
BASE	PRC_RESID	?	REGIONA	ECOLSCO	-	-	-	-	0	3.0000		0.0000		
Add	BASE	?												

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

ANSWER-TIMES: Technology Filters



The screenshot shows the 'ANSWER-TIMES Energy Modelling' software interface. The main window displays a table of process items with columns for Name, Region, and Description. The 'Items Filter' tab is active, showing a list of items including EPMPTRB0, ESOLPV0, and EWINON0. A dialog box titled 'Edit Process Items Filter' is open, allowing users to edit the filter for 'PP_REN: Renewable Power Plants'. The dialog includes fields for Name, Description, and Comment, as well as sections for 'Processes to be Included' and 'Processes to be Excluded' with associated tables for process names, descriptions, and sets.

Global | TimeSlice | Commodity | CommGroup | Process | TradeProcess | Constraint | Stochastic | Parameter

Items Filter: Sets | Named: PP_REN | Renewable Power Plants

Name	Region	Description
EPMPTRB0	REGIONA	Pumped storage
ESOLPV0	REGIONA	Solar PV plant
EWINON0	REGIONA	Wind onshore

Subset Parameters: *C Process, Specific

Scenario	Parameter	Region	Process
BASE	ACT_EFF	?	REGIONA
BASE	PRC_RESID	?	REGIONA

Edit Process Items Filter

Edit Name or Description or Comment, or optionally modify Filter for Process Items Filter
PP_REN: Renewable Power Plants

Name: PP_REN Description: Renewable Power Plants
Comment:

Processes to be Included:

Process Name	Process Desc	Process Sets	Input Comm N	Input Comm C	Input Comm S	Output Comm	Output Comm	Output Comm
Look for: Like "EPMPTRB0"								
or: Like "ESOLPV0"								
or: Like "EWINON0"								
or:								
or:								

Processes to be Excluded:

Process Name	Process Desc	Process Sets	Input Comm N	Input Comm C	Input Comm S	Output Comm	Output Comm	Output Comm
Look for:								
or:								
or:								
or:								
or:								

Clear Included Clear Excluded OK Cancel

Database: C:\AnswerTIMESv6\Answer_Databases\Training\TIMES_DemoOverview\Times6 Database: C:\AnswerTIMESv6\Answer_Databases\Training\TIMES_DemoOverview\Times6

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