Paradigms of the ETSAP-TIMES Family

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Six paradigms

1. TIMES as a supply model with *exogenous* energy demands
2. TIMES as a supply model with exogenous energy *service* demands
3. TIMES as a supply-demand *equilibrium* with *endogenous* energy service demands
4. TIMES-MACRO: *integrated TD-BU* model
5. *Coupled (hybrid)* TIMES-CGE model
   - One-way coupling (from CGE to TIMES)
   - Two-way coupling

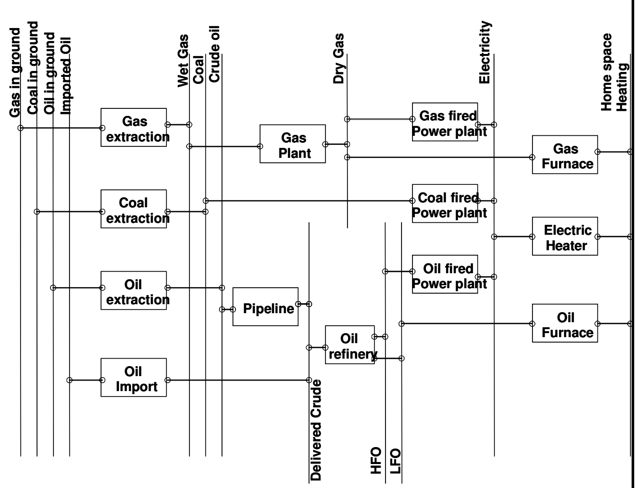
TIMES in a nutshell

- 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
- Integrated Climate Module (see Global version: TIAM)

Further details: www.etsap.org/documentation

The RES concept

- **A Reference Energy System is a network of interlinked technologies and commodities, depicting the energy system (and emissions) of a country, province, or region.**
- **A technology is anything that produces and/or consumes commodities**
- **A commodity may be an energy form, an emission, a material, or an energy service**



RES Components: Technologies

- Examples:
  - Car, Nuclear plant, Source of natural gas
- 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

RES Components: 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**

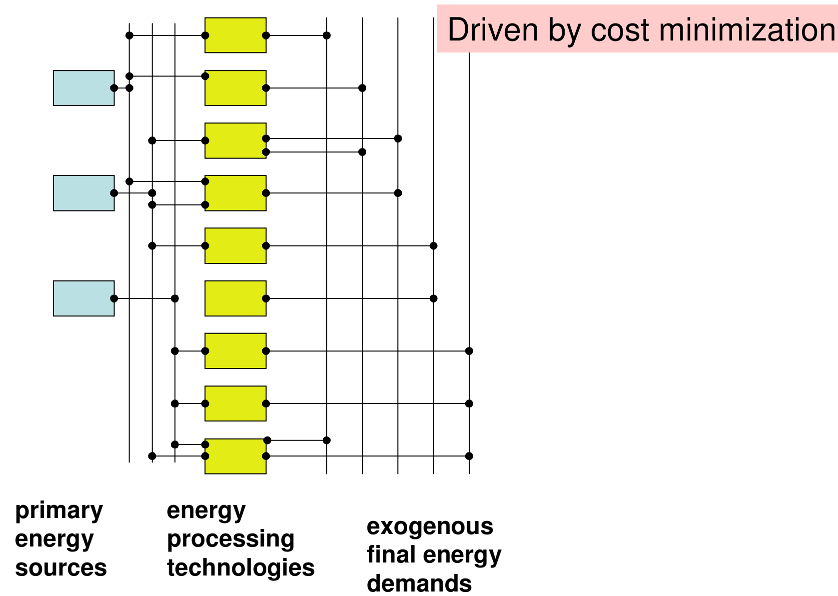
RES Components: Demands

- TIMES is normally driven by a vector of (several dozens) demands for *energy services* (except paradigm 1)
  - 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 (except in paradigm 1)

RES Components: Trades

- In multiregional TIMES models, the regions are linked by energy trade variables. The model *endogenously* determines the amount of trade of each energy form between regions, in response to different energy prices (themselves endogenous) in each region.
- Examples of trades: Coal, Crude Oil, RPP's, Nat Gas, LNG, Ethanol, Emission permits
- One could also define trade of materials (steel, pulp and paper, aluminum, ..).

1. Energy supply TIMES Model



Optimization Program 1

Min C*X (1)

Subject to:

A*X ≥ b (2)

E*X ≥ dem (3)

(1) Is the total NPV of system cost

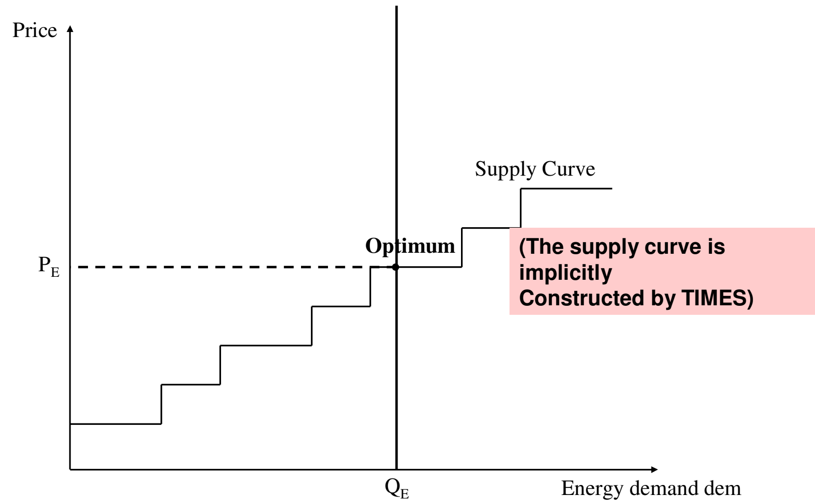
(2) Is a large set of technical and policy constraints

(3) Is a set of energy demand satisfaction constraints

X: decision variables (investment, capacity, activity)

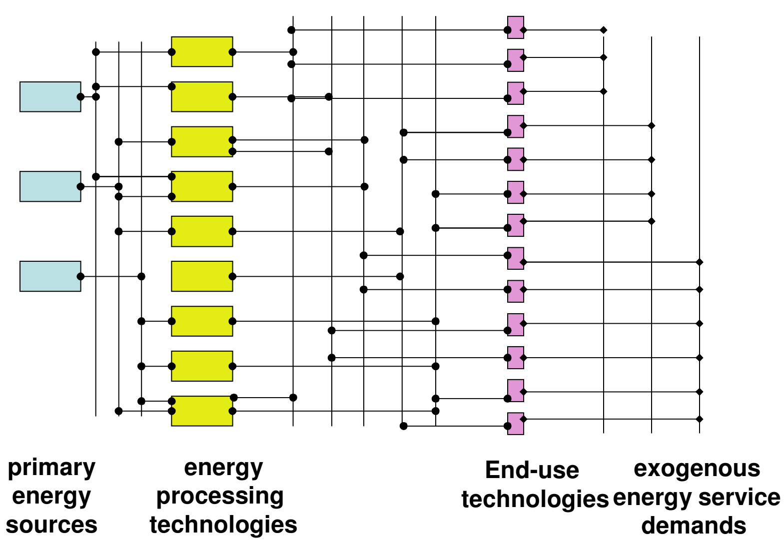
Solved by Linear Programming

Optimization Program 1



2. Energy service supply TIMES Model

Driven by cost minimization



Optimization Program 2

Min C*X (1)

Subject to:

A*X ≥ b (2)

E*X ≥ dem (3)

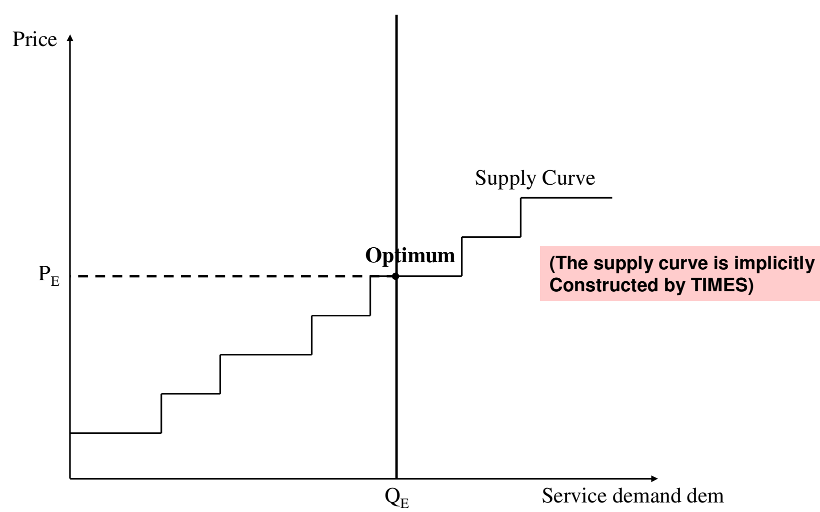
(1) Is the total NPV of system cost

(2) Is a larger set of technical and policy constraints

(3) Is a set of service demand satisfaction constraints

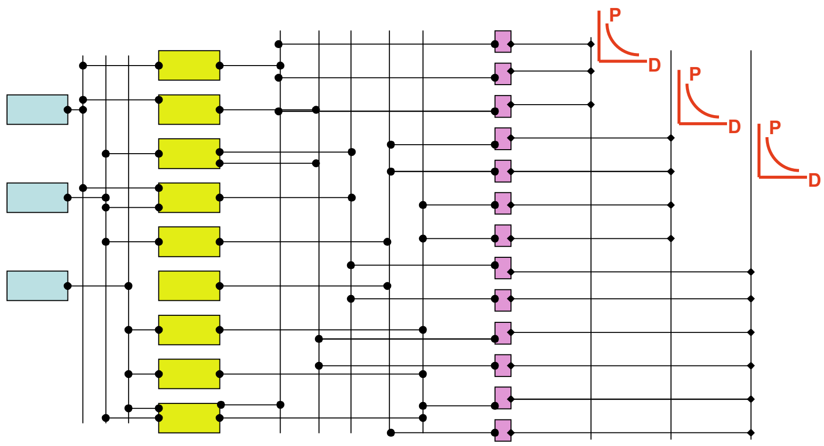
Solved by Linear Programming

Optimization Program 2



3. Energy service supply-demand Equilibrium

Driven by surplus maximization



Optimization Program 3

Min C*X (1)

Subject to:

A*X ≥ b (2)

E*X – DEM(p) ≥ 0 (3)

(1) Is the total NPV of system cost

(2) Is a **larger** set of technical and policy constraints

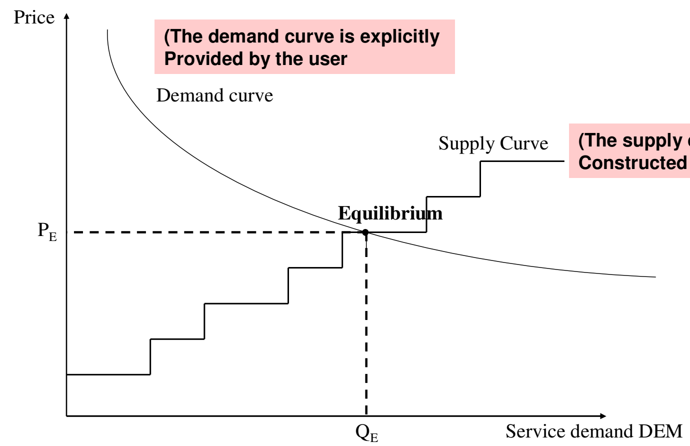
(3) Is a set of service demand satisfaction constraints, but demands are now variables and depend on prices p, which are themselves part of the solution of the optimization !

Solved how ?

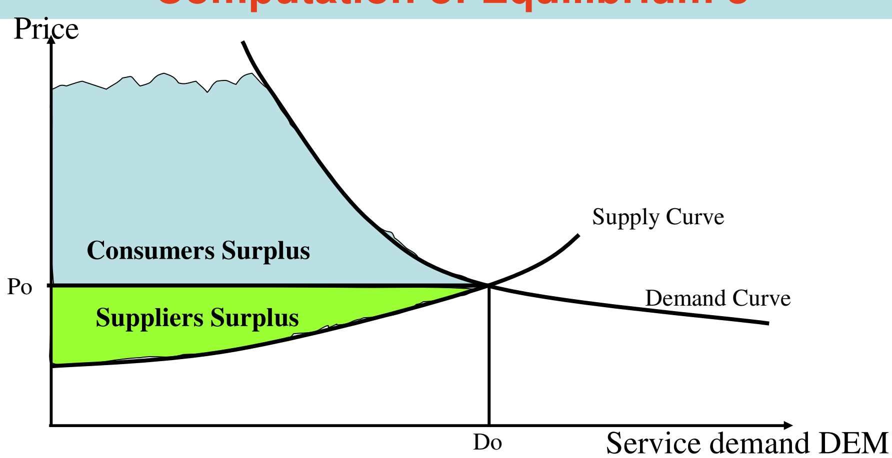
Computation of Equilibrium 3

(The demand curve is explicitly Provided by the user

(The supply curve is implicitly Constructed by TIMES)

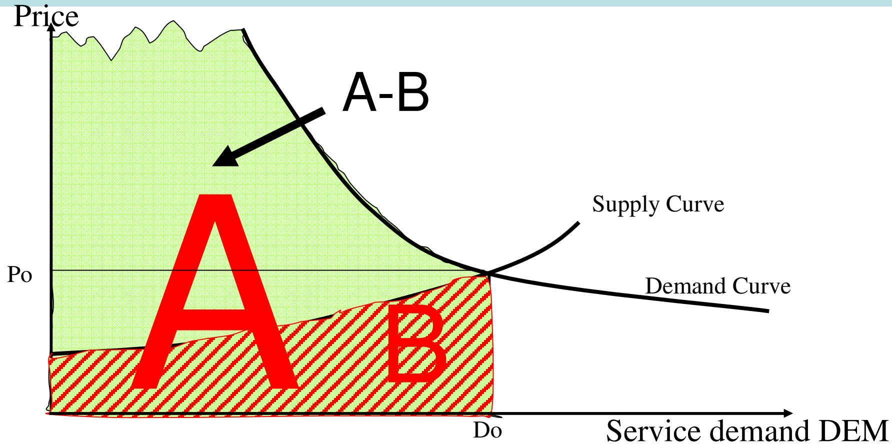


Computation of Equilibrium 3



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

Computation of Equilibrium 3



TOTAL SURPLUS IS SIMPLY: A-B

Computation of Equilibrium 3

- Remarks:
  - The implicit optimization program is transformed into a convex maximization program:

$$Max \quad \overbrace{\sum_i \beta^t \sum_t \left(p_i^0(t)\cdot\left[DEM_i^0(t)\right]^{-1/E_i} \bullet \int_a^{DEM_i(t)} q^{1/E_i}\cdot dq \right)}^{A} - \overbrace{c\cdot X}^{B}$$

$$s.t. \quad E\cdot X - DEM \geq 0$$

$$and \quad A\cdot X \geq b$$

Where $q^{1/Ei}$ is the inverse demand curve for demand category i

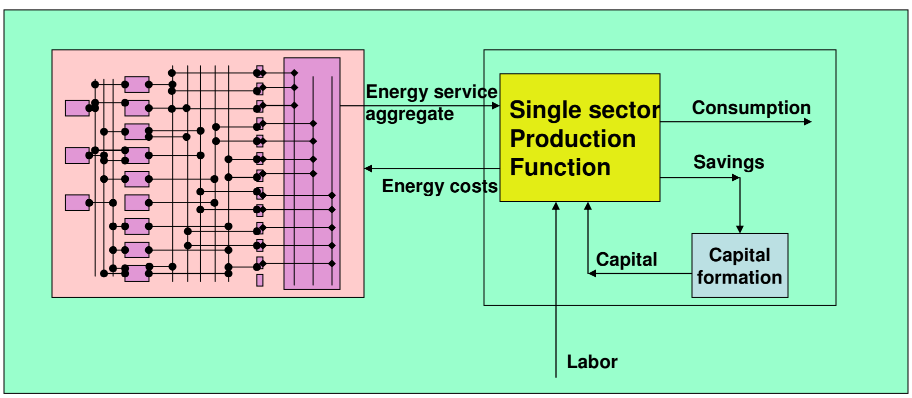
Linearization of Program 3

A - B

$$
\begin{aligned}
&Max \quad \sum_i \beta^t \sum_t \left(p_i^0(t) \cdot \left[DEM_i^0(t) \right]^{-1/E_i} \bullet DEM_i(t)^{1+1/E_i} / (1+1/E_i) \right) - c \cdot X \\
&s.t. \quad E \cdot X - DEM \geq 0 \\
&\qquad\; A \cdot X \geq b
\end{aligned}
$$

- The integral A in the objective function is easily discretized into a sum, by discretizing the DEM variables.
- The resulting maximization becomes a Linear Program:

4. Integrated MARKAL-MACRO



TIMES-MACRO (single model)
Driven by utility maximization

TIMES-MACRO optimization program 4

$$Max \sum_{t=1}^{T-1} \beta^{t-1} \cdot \ln(C_t) + B \cdot \ln(C_T)$$

$$Y_t = C_t + INV_t + EC_t$$

$$Y_t = \left(a \cdot K_t^{\alpha\cdot\rho} \cdot l_t^{(1-\rho)\cdot\alpha} + E_t^{\rho}\right)^{1/\rho}$$

$$K_{t+1} = (1-\delta_t) \cdot K_t + INV_{t+1}$$

MACRO

$$E_t^{\rho} = \left(\sum_j b_j \cdot dem_{j,t}^{\rho}\right)$$

TIMES

TIMES-MACRO optimization program 4

$$Max \sum_{t=1}^{T-1} \beta^{t-1} \cdot \ln(C_t) + B \cdot \ln(C_T)$$

$$Y_t = C_t + INV_t + EC_t$$

This is TIMES Objective function

$$Y_t = \left(a \cdot K_t^{\alpha\cdot\rho} \cdot l_t^{(1-\rho)\cdot\alpha} + \left(\sum_j b_j \cdot dem_{j,t}^{\rho}\right)\right)^{1/\rho}$$

These are the TIMES demand variables

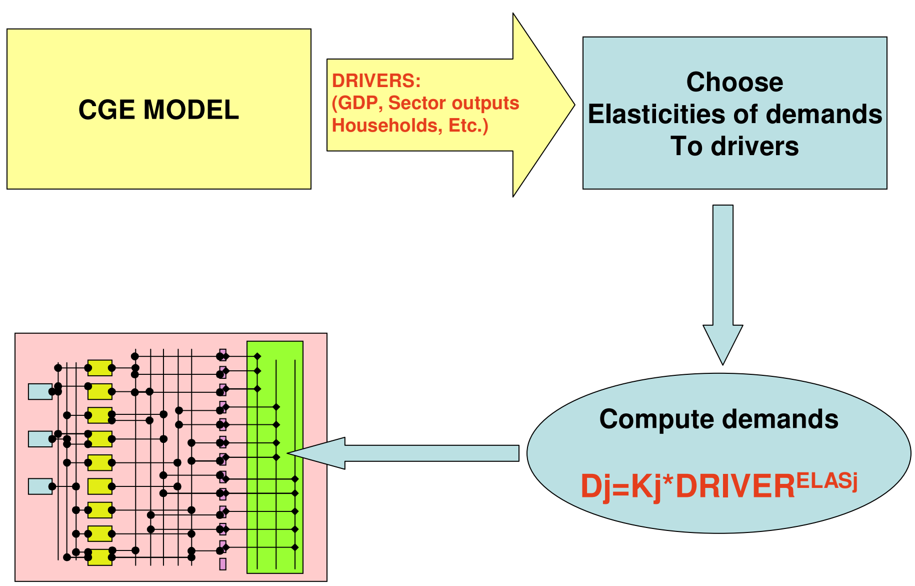
$$K_{t+1} = (1-\delta_t) \cdot K_t + INV_{t+1}$$

+ TIMES EQUATIONS

Comments

- TIMES with elastic demands captures the **main feedback** from the economy, namely: the changing demands when energy prices change
- TIMES-MACRO, in addition to that, insures that **capital** is available to satisfy the energy investments as well as other investments in the economy
- All these models are of course applicable to multiple regions linked by trade.

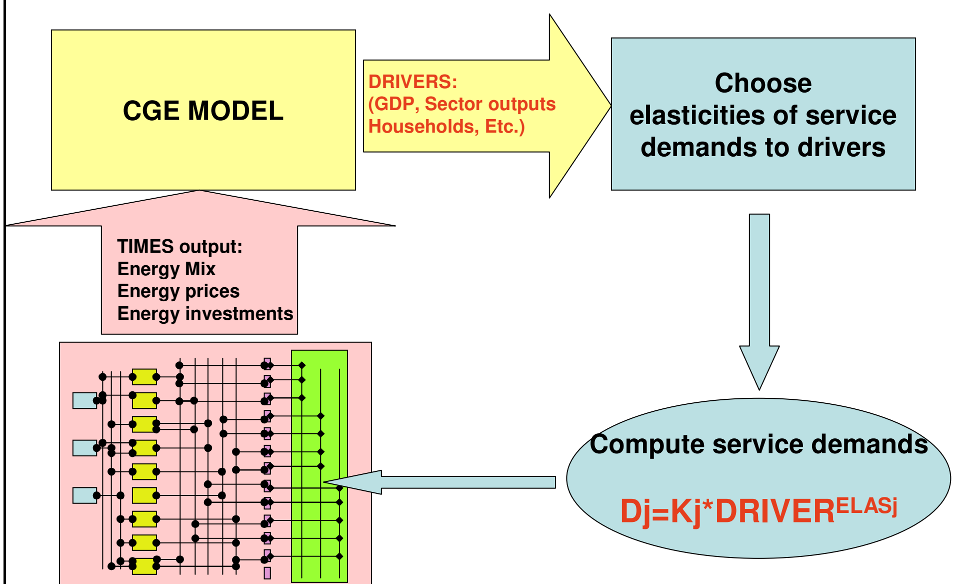
5. One-Way link from a CGE model



One-way link from CGE to TIMES 5

- DRIVERS:
  - Population, Households,
  - GDP, GDP/POP
  - Sector outputs (one per type of industry, plus agriculture)
- To each TIMES demand, we associate one driver.
  - example: car travel has driver GDPP
- To each demand, we define an elasticity of the demand to the driver
  - Ex. Car travel in USA: elas =1
  - Ex. Car travel in China: elas =1.2
- Calculate demand: $DEM = DRIVER^{ELAS}$
  - Same as : *DEM_growth=ELAS*DRIVER_growth*

6. Two-Way link with a CGE model



Conclusion

- Very flexible modeling tool
- Suitable for detailed energy/emission policy analysis
- Continuous new developments, maintenance
- Powerful interfaces
- ETSAP: large community of users, forum for exchanging experiences and tools
- Many applications in many countries