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](http://www.etsap.org/documentation)

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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

Driven by cost minimization

Optimization Program 1

Min $C^*X$ (1)

Subject to:

$A^*X \geq b$ (2)

$E^*X \geq \text{dem}$ (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

The supply curve is implicitly constructed by TIMES.

2. Energy service supply TIMES Model

Driven by cost minimization.
Optimization Program 2

Min $C^*X$ \hspace{1cm} (1)

Subject to:

$A^*X \geq b$ \hspace{1cm} (2)

$E^*X \geq \text{dem}$ \hspace{1cm} (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

![Diagram](https://example.com/diagram.png)

(The supply curve is implicitly constructed by TIMES)
3. Energy service supply-demand Equilibrium

Driven by surplus maximization

Optimization Program 3

Min C*X \hspace{1cm} (1)
Subject to:
A*X \geq b \hspace{1cm} (2)
E*X – DEM(p) \geq 0 \hspace{1cm} (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.

\[ P \]  
\[ Q \]

Equilibrium

Demand curve
Supply curve

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

Consumers Surplus
Suppliers Surplus

\[ P \]  
\[ P_0 \]
\[ Q \]  
\[ D_0 \]  
Service demand DEM

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TOTAL SURPLUS IS SIMPLY: A-B

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

\[
\begin{align*}
\text{Max} & \quad \sum_i \beta^i \sum_t \left(p^i(t) \cdot DEM^0(t)^{-1/Ei} \cdot \int_{q_{Ei}}^{DEM^0(t)} dq \right) - c \cdot X \\
\text{s.t.} & \quad E \cdot X - DEM \geq 0 \\
\text{and} & \quad A \cdot X \geq b
\end{align*}
\]

Where \( q^{1/Ei} \) is the inverse demand curve for demand category \( i \).
### Linearization of Program 3

\[
\begin{align*}
\text{Max} & \quad \sum_i \beta_i \sum_t \left( p_i^0(t) \cdot \left[ DEM_i^0(t) \right]^{-1/E_i} \cdot DEM_i(t)^{1+1/E_i} i(1 + 1/E_i) \right) - c \cdot X \\
\text{s.t.} & \quad E \cdot X - DEM \geq 0 \\
& \quad A \cdot X \geq b
\end{align*}
\]

- 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

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

\[
Y_t = C_t + INV_t + EC_t
\]

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

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

\[E_t^\rho = \left( \sum_j b_j \cdot dem_j^\rho \right)\]

TIMES-MACRO optimization program 4

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

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Y_t = C_t + INV_t + \boxed{EC_t}
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\[
Y_t = \left( a \cdot K_t^{\alpha \cdot \rho} \cdot t_t^{(1-\rho) \cdot \alpha} + \left( \sum_j b_j \cdot dem_j^\rho \right)^{1/\rho} \right)
\]

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

Choose Elasticities of demands To drivers

Compute demands

\[ D_j = K_j^* \text{DRIVER}^{\text{ELAS}_j} \]

Drivers: (GDP, Sector outputs, Households, Etc.)
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: \( DEM\_growth = ELAS*DRIVER\_growth \)

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6. Two-Way link with a CGE model

- **CGE MODEL**
  - Choose elasticities of service demands to drivers
  - **TIMES output:** Energy Mix, Energy prices, Energy investments
  - **Compute service demands:** \( DJ = KJ^{DRIVER^{ELASj}} \)
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