Review of energy systems models


INOGATE Regional Seminar on Energy Planning
Chisinau, Moldova, 30 June – 1 July 2015

BUILDING PARTNERSHIPS FOR ENERGY SECURITY

www.inogate.org
What are the objectives of energy planning?

• **Main objectives of energy planning:**
  – Better energy services (economic and social development)
  – Optimal resource allocation (economic efficiency)
  – Less negative externalities (environmental protection)

• **Develop long term energy strategies (15-30 years)**
  – Long term focus (long lead times, long economic life of energy infrastructure, very capital intensive)
  – Multi-energy, multi-technology approach
  – Inclusive of demand side technologies and policies

• **A consensus building exercise, not a technical task**
  – A model is needed to make sense of the complexity of the energy system (but it’s only a tool)
  – Iterative & consultative process (transparency and communication matters)
  – Energy planning never ends / Needs frequent updating
Why use energy models?

- **Scenario analysis tool:**
  - Define consistent energy scenarios and pathways
  - Not forecasts but plausible future energy scenarios

- **Options and Policies assessment tool:**
  - Cost minimisation (the energy system should meet all current and future demand at the lowest possible cost)
  - Prioritisation of technological and policy options

- **Other important objectives or constraints:**
  - Cost of supply (electricity, gas, oil, petroleum products...)
  - Technology preferences (coal, nuclear, wind...)
  - Security of supply / diversification
  - More recently: Renewables, Energy Efficiency, GHG emissions, affordability of energy, market liberalisation, jobs...
Two main approaches to modelling

**Forecasting**

- Attempt to build forward looking scenarios
- What future developments based on current conditions, driving forces and assumptions?
- Different types of scenarios:
  - **BAU - Business-as-Usual**: continuation of current trends, unchanged policies
  - **High and low scenarios**: changes in key economic, technological or policy drivers
  - **“What-if” scenarios**: external shocks, acute economic crisis ...

**Backcasting**

- Starting point: image of the future:
  - Target (CO2 emissions, level of energy demand)
  - Desired state of the energy system (energy mix)
- What plausible development pathways for getting there?
- What will be the costs of meeting a certain policy goal?
- Exploration of policies and measures, new technologies, etc.
The 3 pillars of energy planning

- **Energy Balances (EBs)**
  - Most energy models have EBs as input data (Reference Energy System)
  - Modelling can be used to complement FEC surveys

- **Energy Efficiency Indicators (EEIs)**
  - EEIs provide checks and controls
  - EEIs used by models to calibrate relationships

- **Energy Modelling**
  - EEIs and Energy Models use similar data

Source: ITS
The Reference Energy System

*And renewables

Source: IEA/ETSAP
“Top-down” and “bottom-up” energy models

Energy Models

“Bottom-Up”
- Energy demand models
- Energy supply models

“Top-Down”
- Computational General Equilibrium models (CGE)
- Input-Output models (I-O)

Top-down and bottom-up models are complementary tools

Source: ITS from IEA, UNFCCC, World Bank
A typology of “bottom-up” energy models

“Bottom-Up”
Or
“Engineering”

End-use accounting models

- Account for physical stocks and flows in systems based primarily on engineering relationships and explicit assumptions about the future (e.g. technology improvements, market penetration rates).
- Examples: LEAP, MAED

Optimisation models

- Use mathematical (linear) programming to identify configurations of energy systems that minimise the total cost of providing services.
- Examples: MARKAL-TIMES, LEAP, MESSAGE

Simulation models

- Simulate behaviour of consumers and producers under various signals (e.g. price, income levels) and constraints (e.g. limits on rate of stock replacement).
- Examples: ENPEP-BALANCE

Source: ITS from IEA, UNFCCC, World Bank
Model selection criteria

- Can the model help answer the questions asked?
- Is it relevant for envisaged time frame (horizon and time steps) and geographical scope?
- Are the underlying model assumptions realistic for the country? (market equilibrium, optimisation)
- Data requirements: are data quality available?
- Is the expertise available at national level sufficient?
- What costs? (licensing, training, hardware, software...)
- Is the model widely applied internationally? (training available, community of modellers...)
Model inputs and results

- Energy system structure
- Base year energy flows and prices
- Energy demand and growth projections
- Technical and policy constraints

- Macroeconomic data
- Demographic data
- Historical energy data (e.g. energy balances)
- Energy and activity assumptions for baseline and mitigation scenario(s)
- Costs
- Non-energy data

- Supply and Demand requirements
- Technology profiles
- Constraints on imports/mining of energy
- Environmental impacts

- The intersection of supply and demand curves for all energy supply forms and all energy uses in the energy network

- Demand-driven energy system results
- Emissions by source, year and scenario
- Energy and emissions reductions related to baseline scenario(s)
- Cost-benefit analysis

- Energy/material prices
- Demand activity
- Technology and fuel mixes
- Marginal value of individual technologies to the energy system
- GHG emission levels
- Mitigation & control costs
Model inputs and results

- Energy Sector data (energy balance)
  - Scenario assumptions
    - Socio-economic
    - Technological
  - Substitute Energy uses
  - Process efficiencies
  - Hourly load characteristics

- Energy System structure (incl. vintage of plant and equipment)
  - Base year energy flows and prices
  - Energy demand projections (MAED)
  - Technology and resource options + performance profiles
  - Technical + Policy Constraints

- Final energy demand
  - Electricity demand
  - Hourly electric load
  - Load duration curves (WASP)

- Primary and final energy mix
  - Emission and waste streams
  - Environmental Impacts
  - Resource use
  - Land use
  - Import dependence
  - Investment requirements
# Key features of selected energy models

<table>
<thead>
<tr>
<th></th>
<th>LEAP</th>
<th>MARKAL-TIMES</th>
<th>MESSAGE</th>
<th>ENPEP-BALANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Developer</strong></td>
<td>Stockholm Environment Institute (SEI)</td>
<td>IEA / ETSAP</td>
<td>IAEA (Planning &amp; Economic Studies Section)/ IIASA</td>
<td>Argonne Laboratory (CEEESA)</td>
</tr>
<tr>
<td><strong>Scope</strong></td>
<td>Energy / GHG</td>
<td>Energy / GHG</td>
<td>Energy / GHG</td>
<td>Energy / GHG</td>
</tr>
<tr>
<td><strong>Geographies</strong></td>
<td>Local to global</td>
<td>Local to global</td>
<td>National to global</td>
<td>Mostly national</td>
</tr>
<tr>
<td><strong>Model Type</strong></td>
<td>Spreadsheet / Energy Accounting (econometrics and simulation possible)</td>
<td>Engineering Optimisation</td>
<td>Hybrid Energy Accounting and Optimisation</td>
<td>Non-linear iterative Equilibrium Simulation</td>
</tr>
<tr>
<td><strong>Energy Demand Representation</strong></td>
<td>Exogenous</td>
<td>Exogenous</td>
<td>Exogenous (MAED)</td>
<td>Demand curve</td>
</tr>
<tr>
<td><strong>Energy Supply Representation</strong></td>
<td>Process analysis (discrete)</td>
<td>Process analysis (discrete)</td>
<td>WASP</td>
<td>Supply curve</td>
</tr>
<tr>
<td><strong>Time steps</strong></td>
<td>User controlled</td>
<td>User controlled</td>
<td>5-10 years</td>
<td>Annual up to 75 y</td>
</tr>
<tr>
<td><strong>Consumer/producer foresight</strong></td>
<td>Not applicable</td>
<td>Perfect / Myopic</td>
<td>Myopic</td>
<td></td>
</tr>
</tbody>
</table>

Source: ITS from SEI, PROMETHEUS/FP7, UNFCCC, IEA, Ravindranath and Sathaye
# Key features of selected energy models

<table>
<thead>
<tr>
<th></th>
<th>LEAP</th>
<th>MARKAL-TIMES</th>
<th>MESSAGE</th>
<th>ENPEP -BALANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data requirements</strong></td>
<td>Low-Medium</td>
<td>Medium-High</td>
<td>Medium-High</td>
<td>Medium-High</td>
</tr>
<tr>
<td><strong>Expertise required</strong></td>
<td>Medium</td>
<td>High</td>
<td>Medium/High</td>
<td>Low/Medium</td>
</tr>
<tr>
<td><strong>Intuitive?</strong></td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Free for NGOs, government and Researchers in non-OECD countries</td>
<td>Commercial: 3,000 to 15,000 EUR (Source code + GAMS + interface)</td>
<td>Free for academic use and IAEA member countries</td>
<td>Free to all users</td>
</tr>
<tr>
<td><strong>Languages</strong></td>
<td>EN, FR, PT, ES, Chinese</td>
<td>English</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>Widely used internationally</td>
<td>Widely used internationally</td>
<td>Widely used internationally</td>
<td>Widely used internationally</td>
</tr>
</tbody>
</table>

Source: ITS from SEI, PROMETHEUS/FP7, UNFCCC, IEA, Ravindranath and Sathaye
# Main energy models: Key features

<table>
<thead>
<tr>
<th>Pros</th>
<th>LEAP</th>
<th>MARKAL-TIMES</th>
<th>MESSAGE</th>
<th>ENPEP-BALANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Simplicity &amp; Flexibility</td>
<td>• Highly detailed representation of technologies</td>
<td>• Detailed representation of technologies</td>
<td>• Explicit dynamic balancing of energy S&amp;D</td>
</tr>
<tr>
<td></td>
<td>• Transparency</td>
<td>• RES cost optimisation</td>
<td>• Well adapted to M&amp;LT</td>
<td>• Separate electricity demand</td>
</tr>
<tr>
<td></td>
<td>• Scenario reporting</td>
<td>• Captures interdependencies</td>
<td>• Cost optimisation of portfolios of options</td>
<td>• Can incorporate non competitive market factors</td>
</tr>
<tr>
<td></td>
<td>• Computation of costs possible</td>
<td>Technology options /impact on S&amp;D</td>
<td>• Limited training requirements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Data requirements limited</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cons</td>
<td>• Does not generate easily least-costs solutions (problem if many technology options available)</td>
<td>• Steep learning curve</td>
<td>• Optimal behaviour assumption</td>
<td>• Market-based /decentralised simulation approach (clearing prices &amp; quantities) not always suitable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Data requirements &amp; preparation work</td>
<td></td>
<td>• Data requirements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Incorporation of non competitive market factors difficult</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Optimal behaviour assumption</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: ITS from SEI, PROMETHEUS/FP7, UNFCCC, IEA, Ravindranath and Sathaye
Energy systems models use in INOGATE PCs

- ENPEP
- MESSAGE
- Own software

- Model (name?)
- Own software

- Markal-Times
- Own software

- LEAP
- MARKAL-TIMES,
- ENPEP suite (inc. MAED, WASP)

- Markal-Times
- Own software

- LEAP
- MARKAL-TIMES,
- ENPEP suite (inc. MAED, WASP)
- SIMPACTS
- MESSAGE
- GEMIS
- RETScreen
- GT MAX
- PSS/E

- MAED
- Own software

- N/A

Source: ITS online survey June 2015
A few recommendations...

- Choose the model very carefully based on data, expertise, funds
- Sophisticated models are not necessarily the best choice
- Starting simple is OK: You can always upgrade later – several models can also co-exist
- Modellers’ role is crucial but they shouldn’t be in the driving seat
- Set up a permanent team responsible for energy (and climate) modelling
- Identify the right organisation that can invest for the long-term
  - Universities or Research Centres good candidates
  - Consultants can be helpful (but capacity building?)
  - Initial and ongoing training of analysts is crucial (staff turnover an issue)
- Earmark funds for a sustainable modelling capacity (man-days, licensing, training...)
- Find other applications during interim years: climate mitigation, input for more detailed gas or electricity modelling, modelling of specific energy policies and measures, research...
"Models should be as simple as possible, but not more so”
Attributed to A. Einstein

"It is better to be vaguely right than exactly wrong”
Carveth Read, British philosopher and logician

"Statisticians, like artists, have the bad habit of falling in love with their models”
George Box, US-British statistician
Спасибо!
Thank you!

Nicolas Brizard
Key Expert – Energy Statistics
INO Gates Technical Secretariat
n.brizard@inogate.org

INO Gates Technical Secretariat and Integrated Programme in support of the Baku Initiative and the Eastern Partnership energy objectives
Welcome to the INOGATE e-newsletter!

www.inogate.org
References

Useful links

• LEAP:
  – http://www.energycommunity.org
  – http://www.sei-international.org

• MARKAL-TIMES: http://www.iea-etsap.org/web/Markal.asp

• IAEA (ENPEP, MAED, WASP, MESSAGE):