From long-term global energy system research to national energy analyses and planning

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Modelling energy system transformation at IIASA

- Origin dates back to 1974
- Spatial focus: Global – world segregated into 11 regions
- Temporal focus: Long-term: 50 to 100 years plus
- Objectives:
  - Analysis of long-term demand & supply strategies under different technology & resource futures
  - Development of robust technology strategies and related investment portfolios to meet a range of policy objectives, and
  - Appreciation of uncertainty
- Several models – demand & economic development, supply, resources, impacts
- Primus inter pares: MESSAGE (Model of Energy Supply Systems And their General Environmental Impact)
Geographical resolution – the “Regions”

1 NAM North America
2 LAM Latin America & The Caribbean
3 WEU Western Europe
4 EEU Central & Eastern Europe
5 FSU Former Soviet Union
6 MEA Middle East & North Africa
7 AFR Sub-Saharan Africa
8 CPA Centrally Planned Asia & China
9 SAS South Asia
10 PAS Other Pacific Asia
11 PAO Pacific OECD
Characterization of MESSAGE

- **Linear and mixed integer programming (LP & MIP) model**
  - Continuous variables for linear processes
  - Integer or binary variables for unit commitment and decisions

- **Equations to reflect operational constraints**
  - Technical
  - Legal
  - Environmental

- **Optimization target (objective)**
  - minimize system cost
  - maximize profit
  - minimize import dependence
  - etc.
An Energy “Chain”

**PRIMARY**
- Oil
- Natural gas
- Coal
- Hydro
- Solar
- Uranium

**SECONDARY**
- Diesel
- Kerosene
- Gas
- Electricity
- Heat
- Coal

**FINAL**
- Diesel
- Kerosene
- Gas
- Electricity
- Heat
- Coal

**USEFUL**
- Low temp heat
- High temp heat
- Cold
- Light
- Mechanical energy
MESSAGE: Model for Energy Supply System Alternatives and their General Environmental Impacts

**INPUT**

- Energy system structure (including vintage of plant and equipment)
- Base year energy flows and prices
- Energy demand projections (e.g. MAED)
- Technology and resource options & their techno-economic performance profiles
- Technical and policy constraints

**OUTPUT**

- Primary and final energy mix
- Electricity generating mix
- Capacity expansion/retirement
- Emissions & waste streams
- Resource use (energy, water, land, etc.)
- Trade & import dependence
- Investment requirements
- Prices
Schematic illustration of GEA pathways

End-use transformation vs Supply transformation

- GEA Supply
- GEA Mix
- GEA Efficiency

Source: Riahi et al, 2011
Supply-side Focus
(= high demand-side flexibility)

- Rapid up-scaling of all options, including renewables and nuclear
- CCS needed as transitional technology & BioCCS for negative emissions

Source: Adapted from Riahi et al, 2011
Efficiency & Demand-side Focus
(= high flexibility for supply)

- Efficiency & intensity improvements, process and behavioral change
- ~50% renewables by 2050
- Phase-out of oil in the medium term (necessary)
- No expansion of nuclear (choice)
- Fossil CCS (optional bridging technology)
- Bio-CCS & negative emissions (long-term)

Source: Adapted from Riahi et al, 2011
Zooming from global to national

- National (sustainable) energy development objectives
  - Long-term regional/global averages provide indications at best
  - National specificity
    - National energy security
    - Indigenous resources
    - Detailed representation of the existing infrastructure (vintage, performance, reliability)
    - Variability of demand
    - Menu of technology options
    - Investment, finance, market structure and subsidies
    - Affordability & access
    - Demand side vs supply side considerations
    - Local generating costs

- MESSAGE adapted to meet national and subnational requirements
MESSAGE adopted in 1998 (replacement of WASP used since the early 1970s)

IAEA provides energy planning services to its MS
- Training of MS experts in the use of MESSAGE
- Model distribution (to governmental institutions)
- E-Learning, E-Assistance & help desk
- Note: Data & assumptions are the responsibility of MS

Objective: Capacity building in energy analysis & comprehensive energy planning

Decision support system at the national level

Essential for a national decision to introduce nuclear power
Load curves

- Variability of demand: electricity, heat, natural gas
- Intermittency of renewables
- Transmission
Example: Oil exporting country in the region

- Transformation of the national energy system
  - Associated gas on the decline
  - Subsidized energy & water not sustainable
  - Galloping electricity & water demands

- No compromise on energy security

- Use current & future oil revenues to finance transition

- Explore different futures and technology options

- Understanding future uncertainties

- Communication tool (transparency)
Model representation of load curves
## Comparative assessment of options

### How to combine these criteria?

<table>
<thead>
<tr>
<th>Criteria Alternatives</th>
<th>Investments</th>
<th>Fuel costs</th>
<th>Waste/decom</th>
<th>Reliability</th>
<th>Security</th>
<th>Environment</th>
<th>Material</th>
<th>Acceptance</th>
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<tr>
<td>Wind</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>low intermittent</td>
<td>high</td>
<td>very good</td>
<td>very high</td>
<td>high</td>
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<td>Coal (imported fuel)</td>
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<td>80</td>
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<td>low</td>
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<td>low - high</td>
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<td>IGCC (oil)</td>
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<td>base load / intermediate</td>
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<td>Nuclear</td>
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<td>0.7</td>
<td>1,800</td>
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<td>very good</td>
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<tr>
<td>Gas combined cycle turbine</td>
<td>0</td>
<td>1 - 5</td>
<td>40</td>
<td>base load / intermediate</td>
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<td>medium</td>
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<td>End-use efficiency</td>
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<td>very high</td>
<td>excellent</td>
<td>low</td>
<td>mixed</td>
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</tbody>
</table>

### How to interpret the results?

### How to compare these alternatives?
Generating capacity – Business-as-usual
Generating capacity – Transformation (TR)

- Wind
- CSP
- SolarPV
- Nuclear
- CCGT-MSF
- IGCC-MSF
- Steam-MSF
- Steam
- IGCC
- CCGT
- OCGT
- GT_plan
- CC_plan
- Pre-2006
Difference in capacities between BAU and TR
Difference in generation between BAU and TR
Fresh water supply in TR

The graph shows the projected fresh water supply in TR from 2005 to 2030. The bars represent different categories of water supply:

- **MSF_CCGT**
- **MSF_IGCC**
- **MSF_Steam**
- **Stor_out**
- **Stor_in**
- **RO**
- **Pre 2006**

The vertical axis represents the supply in million m³, and the horizontal axis represents the years from 2005 to 2030. The data indicates a steady increase in water supply over the years.
Sensitivities & solution space for nuclear power
Distribution of MESSAGE to IAEA member States

Model transferred to 102 countries by the end of 2015
MESSAGE has been the tool for

- Numerous national electrification and energy plans
- Energy policy formulation at various jurisdictional levels
- Utility capacity expansions and investment decisions
- Accounting of material (energy and non-energy) flows
- Communication of energy related GHG emissions to UNFCCC