Joint ICTP–IAEA College on Identification and Assessment of Nationally Appropriate Mitigation Actions (NAMAs) in Energy System Development to Help Combat Climate Change

5–9 May 2014

Sensitivity Analysis and Interpretation of Model Results

H–Holger Rogner
International Institute for Applied Systems Analysis (IIASA)
Royal Institute of Technology (KTH)
Stockholm
Sensitivity Analysis and Interpretation of Model Results

H-Holger Rogner
International Institute for Applied Systems Analysis (IIASA)
Royal Institute of Technology (KTH), Stockholm
ICTP, 5 – 9 April 2014
Different levels in energy planning
Sensitivity analysis: How stable is your solution?
Why sensitivity analysis

Uncertainty in inputs and assumptions due to

- Lack of information
- Unknown or rather unknowable future
- Previously plausible assumptions no longer hold
- Testing different boundaries or resolution of detail
- Dynamic vs linear behavior
Electricity demand load curve (2009)
Why sensitivity analysis

- Explore what if questions
- Protect against surprise
- Detect methodological shortcomings
- Appreciate uncertainty and develop a better understanding for it
Typical questions faced by energy analysts and planners:

- What is the cost-optimal energy mix that meets demand by 2030?
- 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 will be consequences of introducing or phasing out nuclear power?
Sensitivity Analysis

- Future demand for energy
- Investment costs of new power plants and other energy facilities
- Operation and maintenance costs
- Fuel cost
- Performance of technologies (efficiency, plant factor, availability factor, etc.)
- Limits on production and construction of plants
- Import/export quantities and prices
- Environmental protection limits and costs
Sensitivity analysis

- Parametric sensitivity analysis
  - Assess robustness of a solution to changing assumptions (of parameters and constraints)
  - Assess which parameters are most sensitive to even small variation
  - Usually one parameter is varied – everything else is kept constant
Scenario analysis

- Assess robustness of a solution to distinctly different sets of assumptions on parameters and constraints
- Note: Emphasis on internally consistency
- Assessment of different futures
- However the primary purpose of scenario formulation is to address “What if...” type of policy question to assess implications of introducing policies by comparative assessment of scenarios
Scenario analysis

- **Parametric sensitivity analysis**
  - Assess robustness of a solution to changing assumptions (of parameters and constraints)
  - Assess which parameters are most sensitive to even small variation
  - Usually one parameter is varied – everything else is kept constant
Sensitivity analysis with MESSAGE

\[
\begin{align*}
\text{min} \quad & c' \ast x \\
\text{Subject to} \quad & A \ast x \geq b \\
& u \geq x \geq l \\
\text{result } x^* \\
\text{range for } & c, b, l, u
\end{align*}
\]
Notes on the sensitivity screen

- Parameters change in the original problem while the optimal basis remains the same
  - Objective coefficient
  - Constraint bound
  - Variable bound

- Basis remains the same means that no other element comes into the solution, i.e. no other variable or equation reaches its upper or lower limit

Important! Variations assume that all other parameter remain fixed except the one in question
<table>
<thead>
<tr>
<th>No.</th>
<th>Row name</th>
<th>St</th>
<th>Value</th>
<th>Max increase</th>
<th>Max decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Cbigw......aaa015 BS UPER</td>
<td>-2.12582e+002</td>
<td>+1.00000e+020</td>
<td>+2.26682e+002</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Cbigw......aaa016 BS UPER</td>
<td>-1.89714e+002</td>
<td>+1.00000e+020</td>
<td>+2.03814e+002</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Cbigw......aaa017 BS UPER</td>
<td>-3.61192e+001</td>
<td>+1.00000e+020</td>
<td>+5.02192e+001</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Cbigw......aaa018 BS UPER</td>
<td>-3.61192e+001</td>
<td>+1.00000e+020</td>
<td>+5.02192e+001</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Cbigw......aaa019 BS UPER</td>
<td>-6.41480e+001</td>
<td>+1.00000e+020</td>
<td>+7.82480e+001</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Cbigw......aaa020 BS UPER</td>
<td>-3.61192e+001</td>
<td>+1.00000e+020</td>
<td>+5.02192e+001</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Cbigw......aaa021 BS UPER</td>
<td>-1.50521e+002</td>
<td>+1.00000e+020</td>
<td>+1.64621e+002</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Cbigw......aaa022 BS UPER</td>
<td>-2.85068e+002</td>
<td>+1.00000e+020</td>
<td>+2.99168e+002</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Cbigw......aaa023 BS UPER</td>
<td>-3.25342e+002</td>
<td>+1.00000e+020</td>
<td>+3.39442e+002</td>
<td></td>
</tr>
</tbody>
</table>
Shadow Prices

- Are important so see how expensive restrictions are
  - At the upper limit: how much would the objective function value decrease if the limit would increased by one unit
  - At the lower limit: how much would the objective function value decrease if the limit would decreased by one unit
Shadow prices in the solution

In interactive results screen
Shadow Price for Electricity

The graph shows the shadow price of fuel electricity on level final for different years, ranging from 2010 to 2025. The unit is MWyr. The data is for Region: training1, Scenario: adb.
Which studies to conduct?

- Number of sensitivity studies should be kept as reduced as possible
- Too many sensitivity studies reduce credibility of the study and confuses interpretation of results:
  - negative perception by decision maker
- Too few sensitivity studies may lead to many questions left open to the decision maker *(What if?)*
- Studies should concentrate in a few important parameters to analyse range of validity of the optimal solution *(How robust the solution is?)*
## Comparative assessment of options

### How to interpret the results?

### How to combine these criteria?

### How to compare these alternatives?

<table>
<thead>
<tr>
<th>Criteria</th>
<th>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>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>2,200</td>
<td>0</td>
<td>15</td>
<td>low</td>
<td>high</td>
<td>very good</td>
<td>very high</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>Coal (domestic fuel)</td>
<td>1,800</td>
<td>2</td>
<td>80</td>
<td>base load/intermediate</td>
<td>very</td>
<td>high</td>
<td>low - high</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>3,500</td>
<td>0.7</td>
<td>1,000</td>
<td>base load/intermediate</td>
<td>very</td>
<td>high</td>
<td>low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas turbine (imp fuel)</td>
<td>400</td>
<td>5</td>
<td>12</td>
<td>peak</td>
<td>low</td>
<td>medium</td>
<td>low</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>Hydro</td>
<td>5,500</td>
<td>0</td>
<td>50</td>
<td>seasonal</td>
<td>high</td>
<td>good</td>
<td>high</td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>End-use efficiency</td>
<td>225</td>
<td>0</td>
<td>1</td>
<td>-</td>
<td>very high</td>
<td>excellent</td>
<td>low</td>
<td>mixed</td>
<td></td>
</tr>
</tbody>
</table>
Multi-criteria decision making

Criteria selection

Alternatives selection

Criteria weights

Groupings

Performance matrix

Scenario results

Multi scenario Tradeoff analysis

Scenario ranking

1

2

....

Grouping C1 C2 C3 C4 C5 C6 C7 C8

A

B

C

D

E

Z