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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

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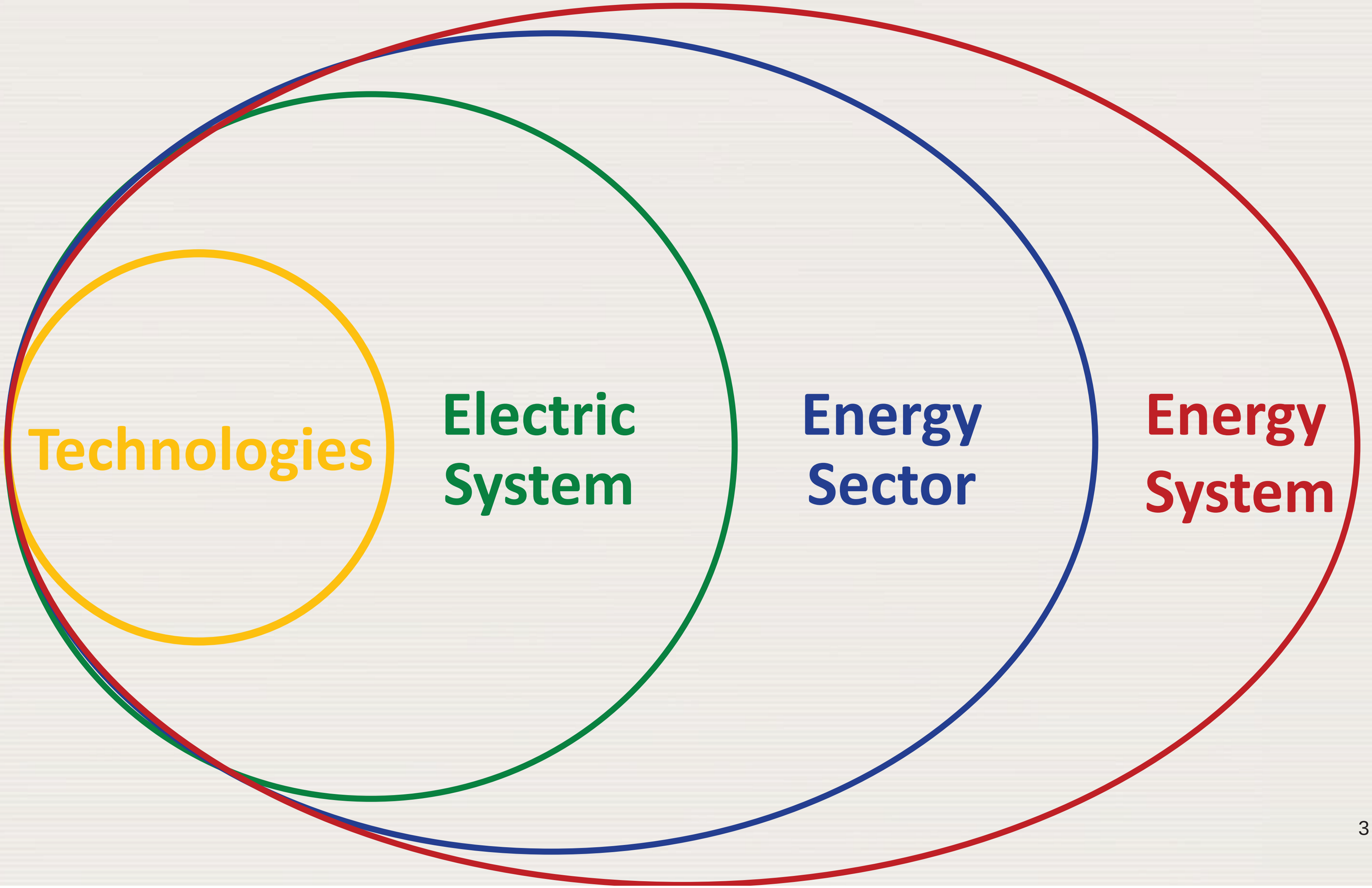
Architecture of the Energy System

Sources	coal, oil, natural gas, sunlight, uranium, wind, biomass	What nature Provides
Extraction Treatment	coal mine, hydro dam, oil rig, cleaning, separation, benefication, liquef-action, gasifi-cation	
Conversion Technologies	hydro station, thermal power plant, oil refinery, nuclear generating station, photovoltaic cell, wind converter	Energy Sector
Currencies (fuels)	electricity, gasoline, methanol, methane, hydrogen, heat	
Distribution	electricity grid, gas grid, truck, dewar, railway, district heat grid	
Service Technologies	automobile, light bulb, telephone, furnace, microwave oven, aircraft, PC	*Efficiency & Infrastructure*
Services	transportation, communication, keeping warm/cold, food, potable water, health care, security, consumer goods	What people want

Different levels in energy planning



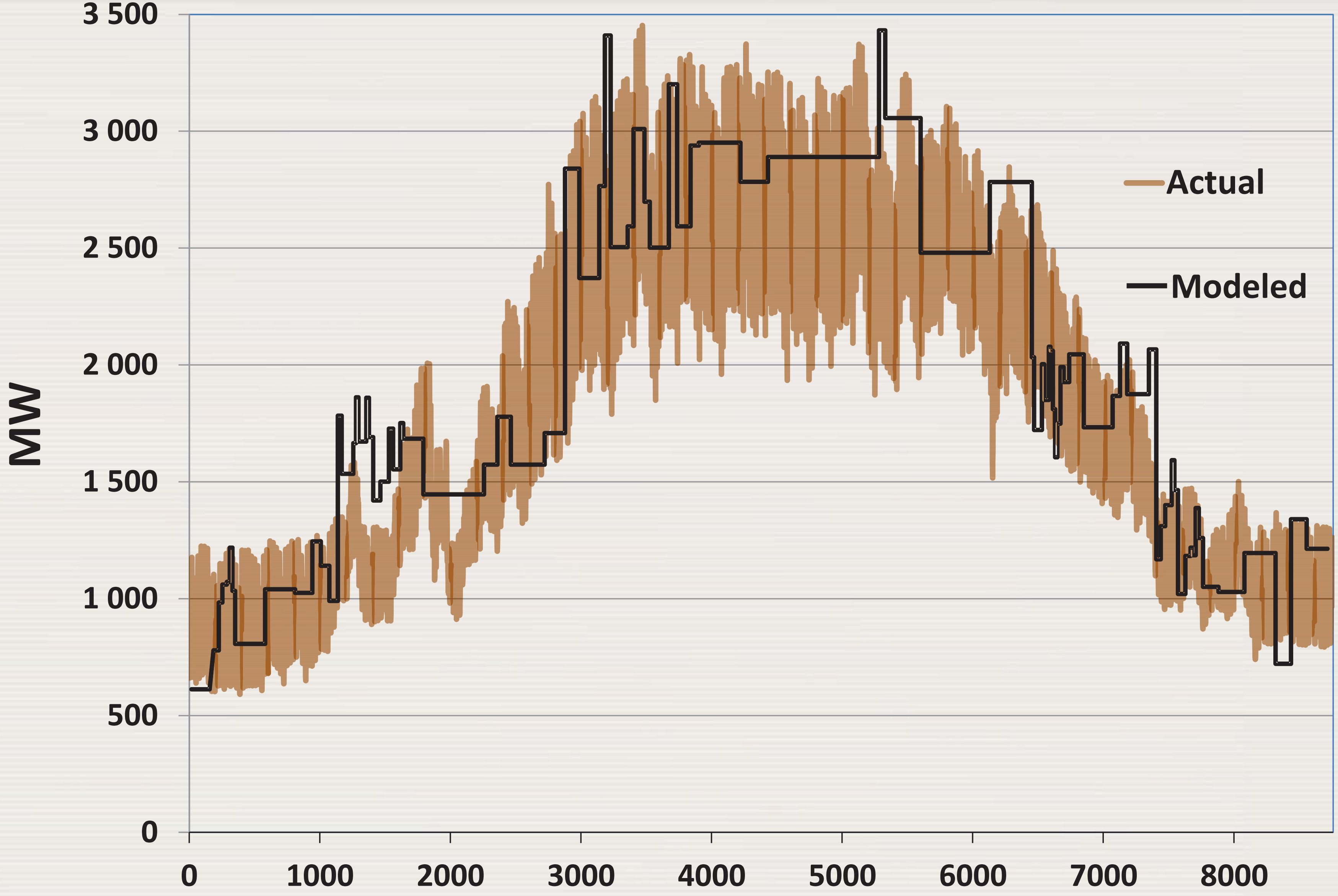
Sensitivity analysis: How stable is your solution ?

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

Modeling energy systems – Model design

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

min $c' * x$

Subject to $A * x \geq b$

$u \geq x \geq l$

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result x^*

range for c, b, l, u

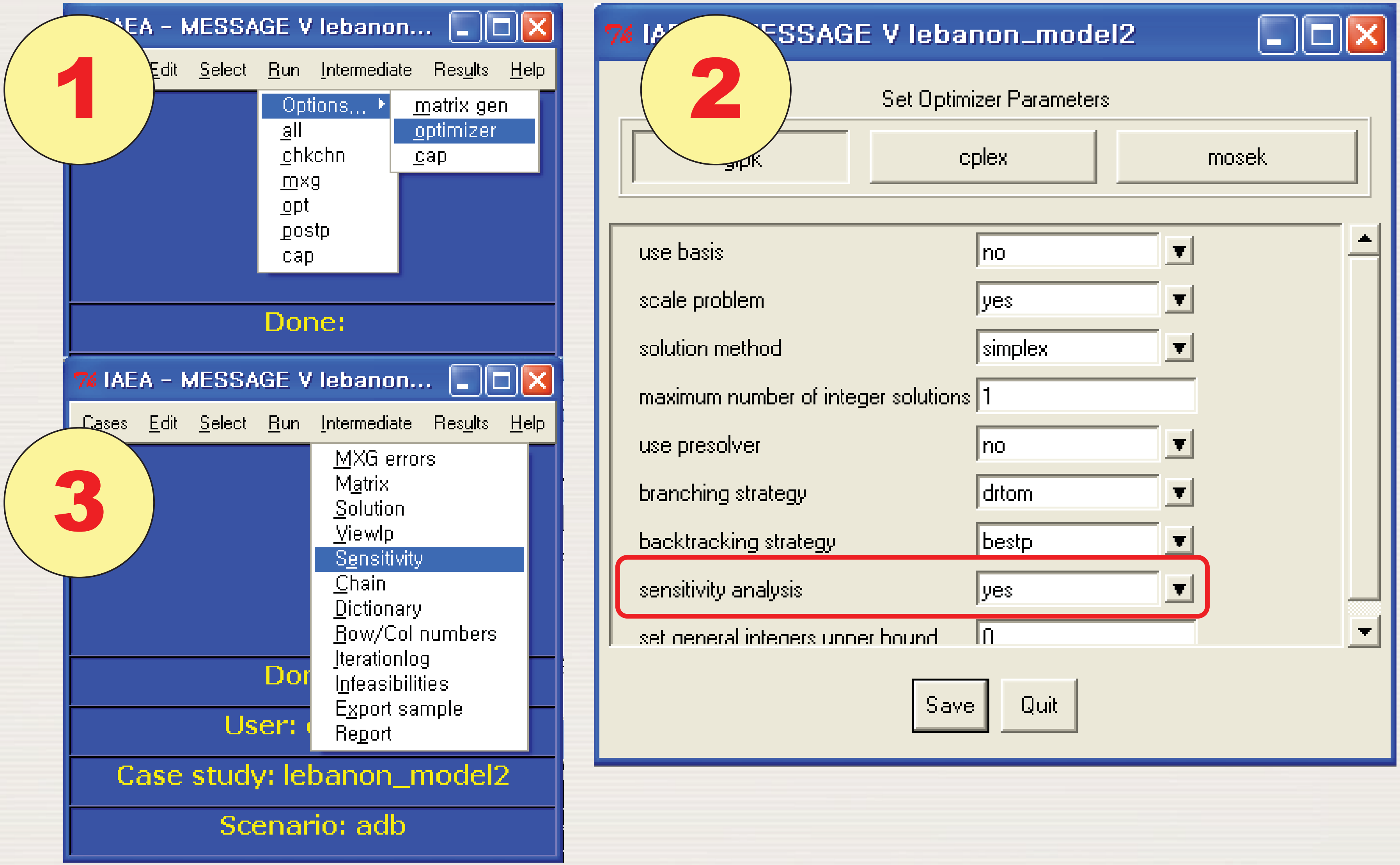
Notes on the sensitivity screen

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

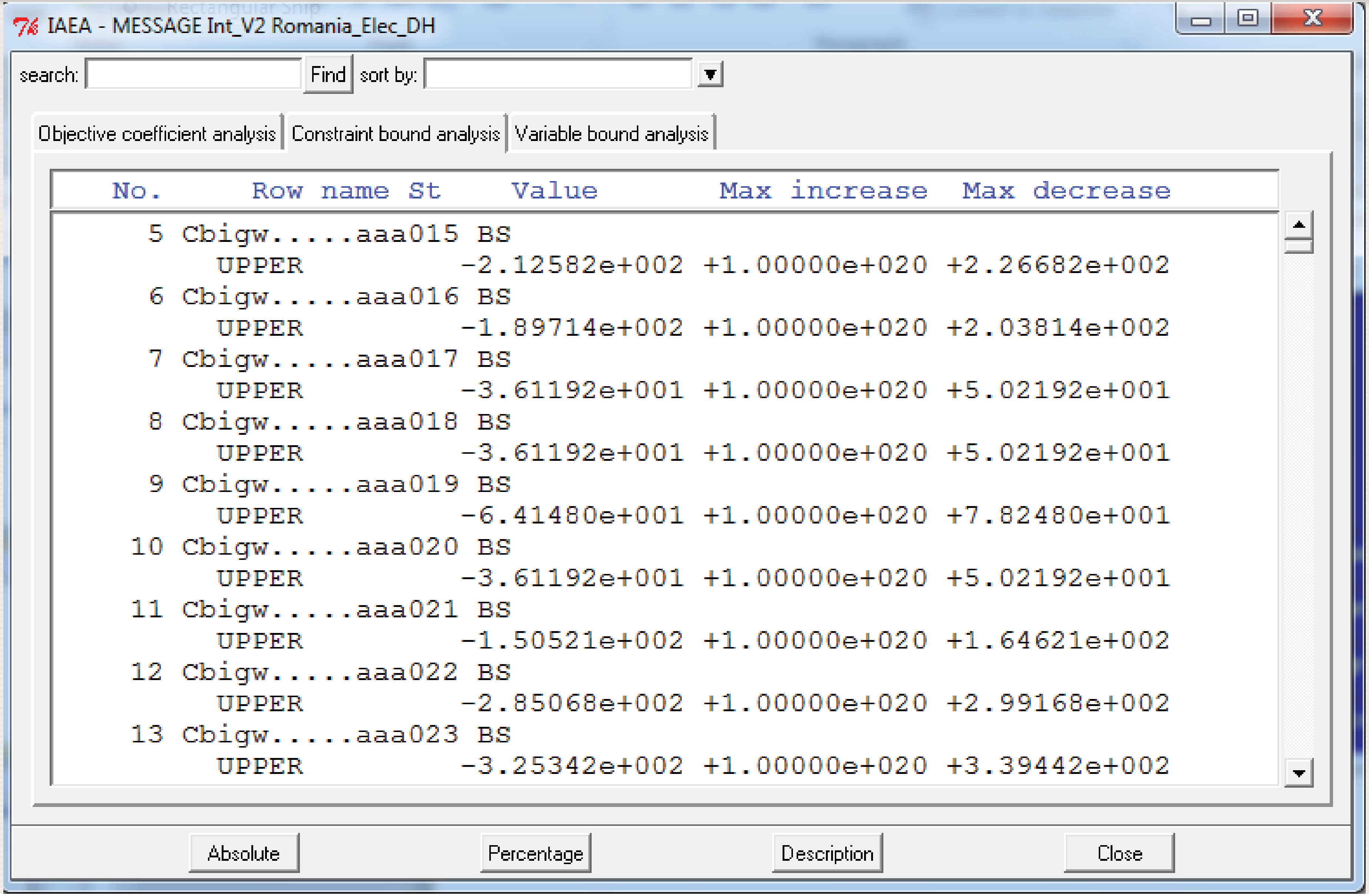
- Basis remains the same means that no other element comes into the solution, i.e. no other variable or equation reaches its upper or lower limit

<u>Important! Variations assume that all other parameter remain fixed except the one in question</u>

Sensitivity in MESSAGE Solver



Sensitivity Output Screen

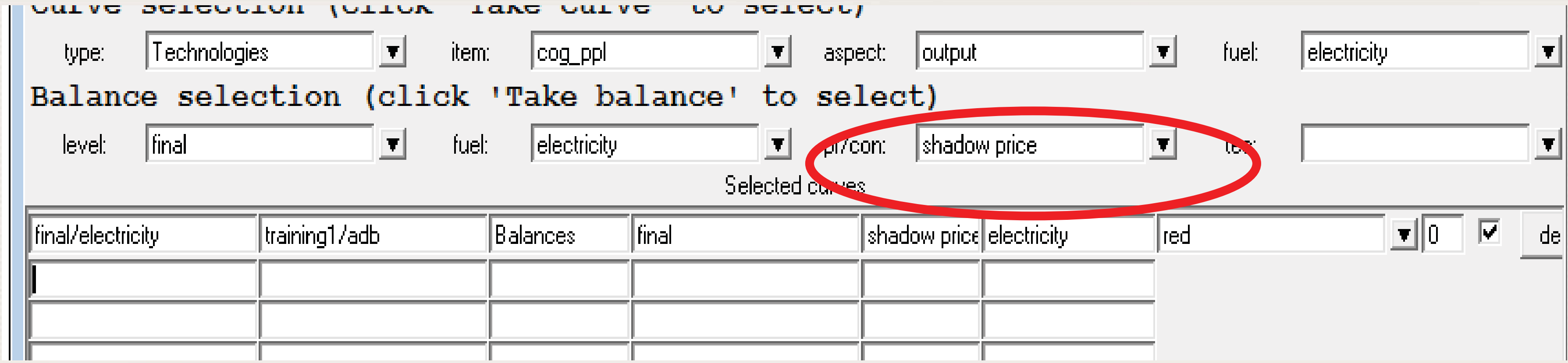


Shadow Prices

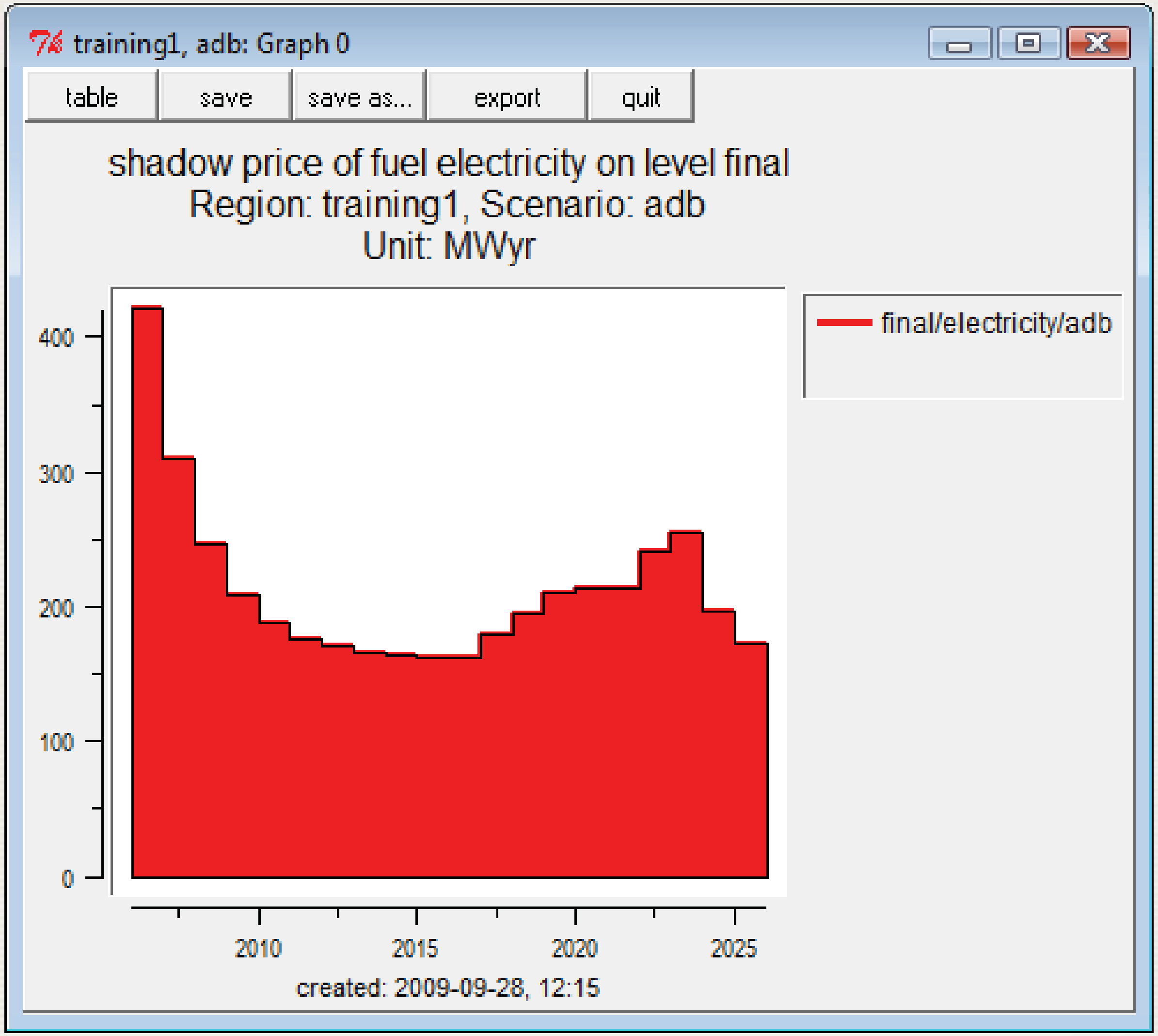
- Are important so see how expensive restrictions are
  - At the upper limit: how much would the objective function value decrease if the limit would increased by one unit
  - At the lower limit: how much would the objective function value decrease if the limit would decreased by one unit

Shadow prices in the solution

- In interactive results screen



Shadow Price for Electricity



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 combine these criteria?

How to compare these alternatives?

Criteria / Alternatives	stments	Fuel costs	Waste/ decom	Reliability	Secutiy	Environment	Material	Acceptance
Wind	,200	0	15	low	high	very good	very high	high
Coal (domestic fuel)	,800			base load /	very		igh	low - high
Nuclear	,500						igh	low
Gas turbine (imp fuel)	400	5	12	peak	low	medium	low	high
Hydro	,500	0	50	seasonal	high	good	high	medium
End-use efficiency	225	0	1	-	very high	excellent	low	mixed

How to interpret the results?

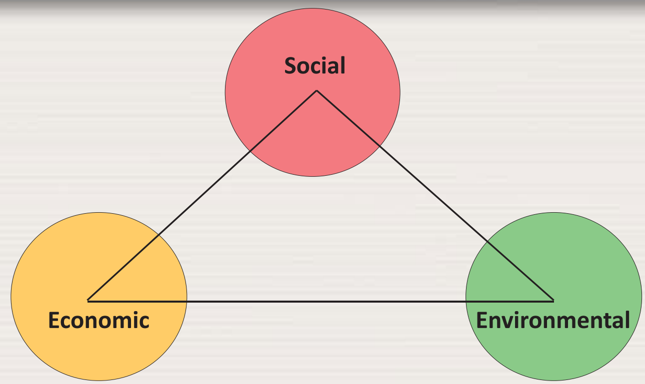
Multi-criteria decision making

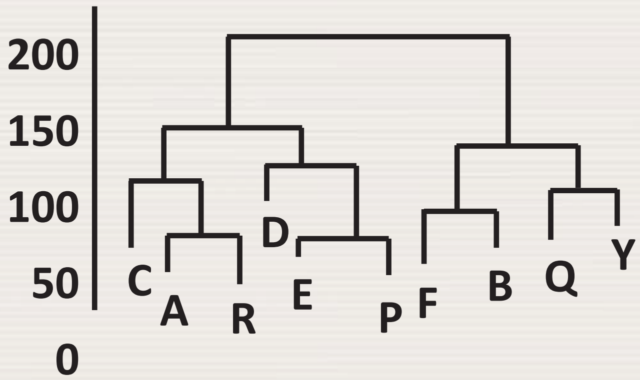
Criteria selection

Alternatives selection

Criteria weights

Groupings





Scenario ranking

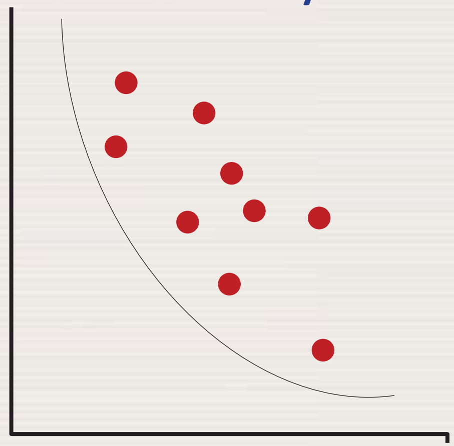
1

2

....

Scenario results

Multi scenario
Tradeoff analysis



Performance matrix

Grouping	C1	C2	C3	C4	C5	C6	C7	C8
A								
B								
C								
D								
E								
Z								