

2580-10

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

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Sensitivity Analysis

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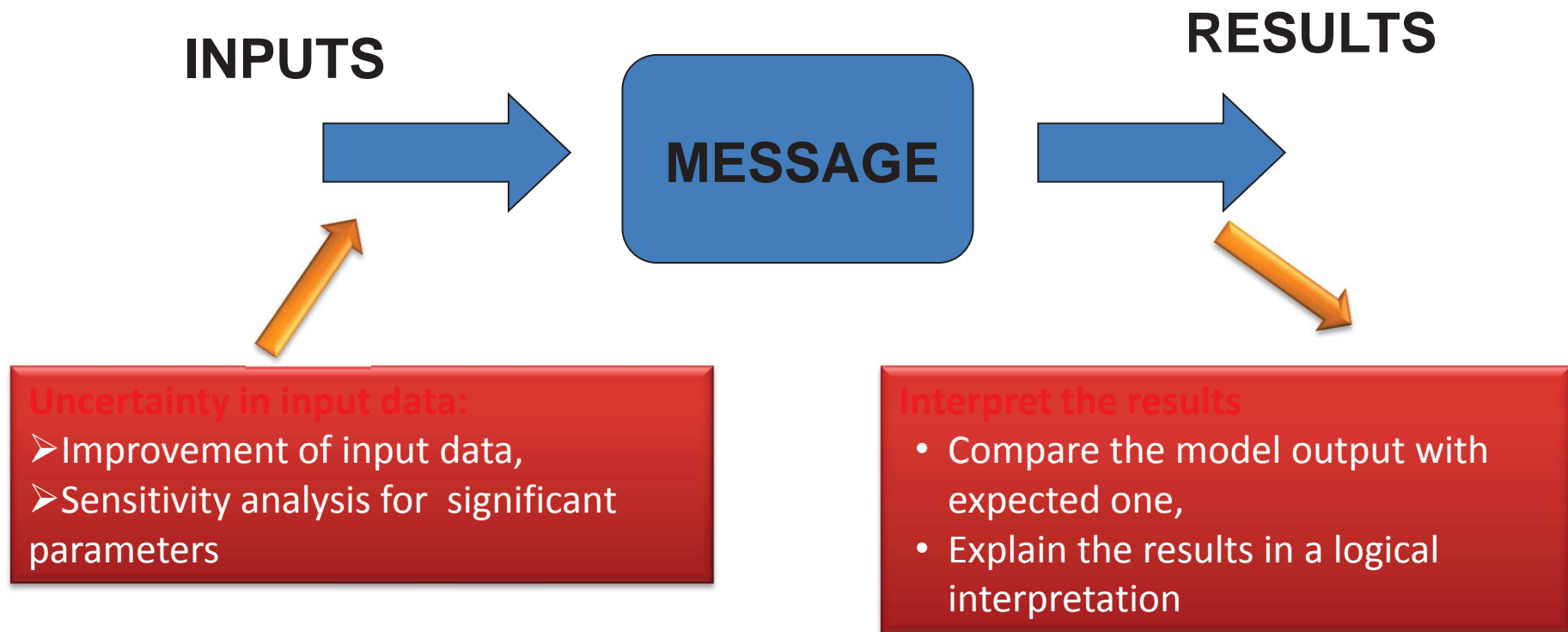
Sensitivity Analysis

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

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Successive Approach



Sensitivity analysis

- How much will the results change if input data change?

Why Sensitivity Analysis?

To provide range of validity of the reference solution

□ Uncertainties in data

- Lack of information (forcing the planner to make assumptions).
- Data are a permanent problem!

THREE CHOICES:

- Do nothing
- Invest in collecting data
- Take the best guess now, and iterate/improve later

□ Unknown future

- Uncertainty in assumptions

□ Sensitivity analysis helps to identify those coefficients which have major impacts on results.

□ Sensitivity analysis shows the stability of solution

What Sensitivity Studies to Conduct

- ❑ The general rule to conduct sensitivity analysis would be to consider all types of information for which large uncertainties are recognized
 - either because of lack of knowledge on their statistical or
 - current values or because of their future evaluation is difficult to predict.

- ❑ By general rule, the tendency would be to conduct a very large number of sensitivity analysis so as to cover all possibilities of uncertainty in data and the hypothesis made.

What Sensitivity Studies to Conduct

- ❑ However, consideration of too many sensitivity analyses will tend to:
 - Diminish the credibility of the study
 - Lead to confusion in terms of interpretation of results and recommendations

Both aspects having a negative effect on the perception by the decision maker.

- ❑ Better to concentrate in a few sensitivity analyses to study the variation of the optimal solution to the most important parameters for which the planner(s) or sometime the decision maker(s) accord the highest degree of uncertainty.

Some Examples for Sensitivity Analysis

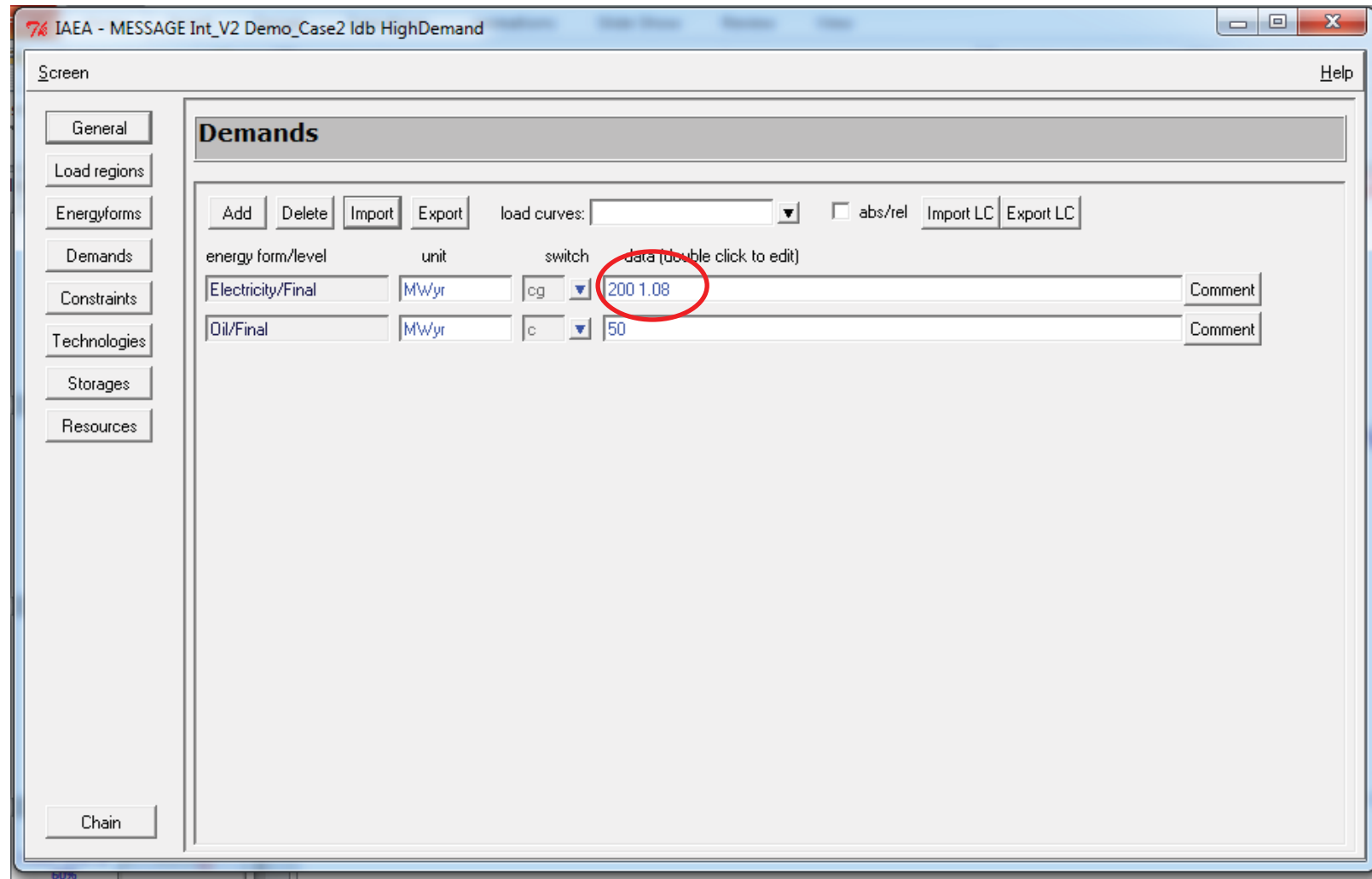
- ❑ Discount rate
- ❑ Future demand for energy/electricity
- ❑ Investment costs of new power plants and other energy facilities
- ❑ Operation and maintenance costs
- ❑ Fuel cost
- ❑ Performance of technologies (efficiency, plant factor, availability factor, etc.)
- ❑ Limits on production and construction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

Sensitivity Analysis in MESSAGE

Two options:

- ❑ Change in assumptions (either change in parameters or scenario as a whole)
- ❑ Use the sensitivity function in MESSAGE

Model High Demand Electricity 8%



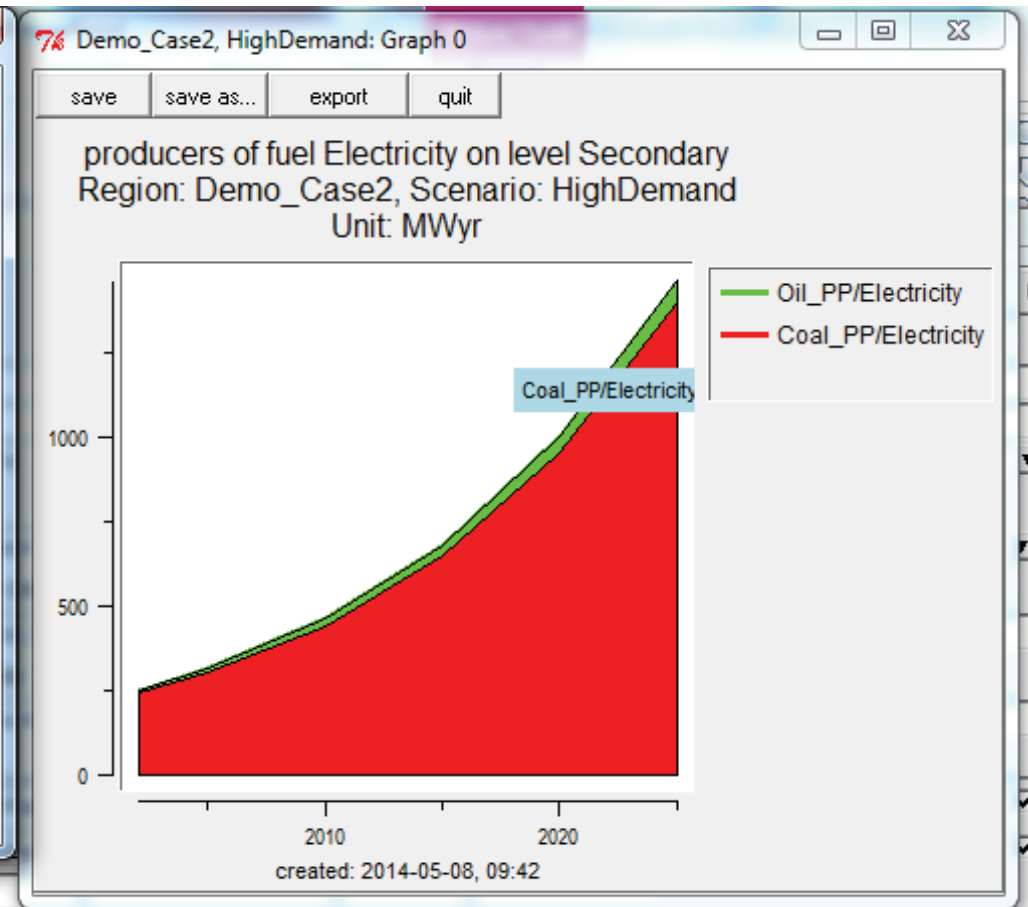
Results High Demand Electricity 8%

IAEA - MESSAGE Int_V2 Demo_Case2

graph save export quit

producers of fuel Electricity on level Secondary
Region: Demo_Case2, Scenario: HighDemand
Unit: MWyr

	Coal_PP Electricity	Oil_PP Electricity	Total
2002	242.22	7.78	250.00
2005	300.07	14.86	314.93
2010	440.90	21.83	462.73
2015	647.83	32.08	679.91
2020	951.87	47.14	999.00
2025	1398.60	69.26	1467.86



Model Coal Power Limit to 60%

7 IAEA - MESSAGE Int_V2 Demo_Case2 Idb CoalLimit

Screen Help

Constraints / Relations / Variables

group: relation: Copy Entries Add from ADB New Del

relations1

single entries

relation name: ident: input/output: loadcurves for: abs/rel

limit type: unit type: for_ldr:

	Unit	Switch	Time series
cost	<input type="text" value="US\$'00/kWyr"/>	<input type="checkbox"/>	<input type="text"/>
upper lim	<input type="text" value="MWyr"/>	<input checked="" type="checkbox"/>	<input type="text" value="0"/>
lower lim	<input type="text" value="MWyr"/>	<input type="checkbox"/>	<input type="text"/>
first year	<input type="text" value="2005"/>	<input type="checkbox"/>	<input type="text"/>
	interval	<input type="checkbox"/>	last year
		<input type="checkbox"/>	endval

multiple entries

penalty softlims

description

Model Coal Power Limit to 60%

$$\frac{X_{coal}}{X_{coal} + X_{oil}} \leq 0.6$$

$$X_{coal} \leq 0.6X_{coal} + 0.6X_{oil}$$

$$0.4X_{coal} - 0.6X_{oil} \leq 0$$

76 Entries in relation CoalLimit

2 Technologies in Relation CoalLimit

To add entries: select items from the lists below

other technologies:

other resources:

To delete entries: delete contents of the data field

name	type	for	ldr	tssw	data		
Coal_PP	tec	act	▼	▼	c	▼	0.4
Oil_PP	tec	act	▼	▼	c	▼	-0.6

Save Quit

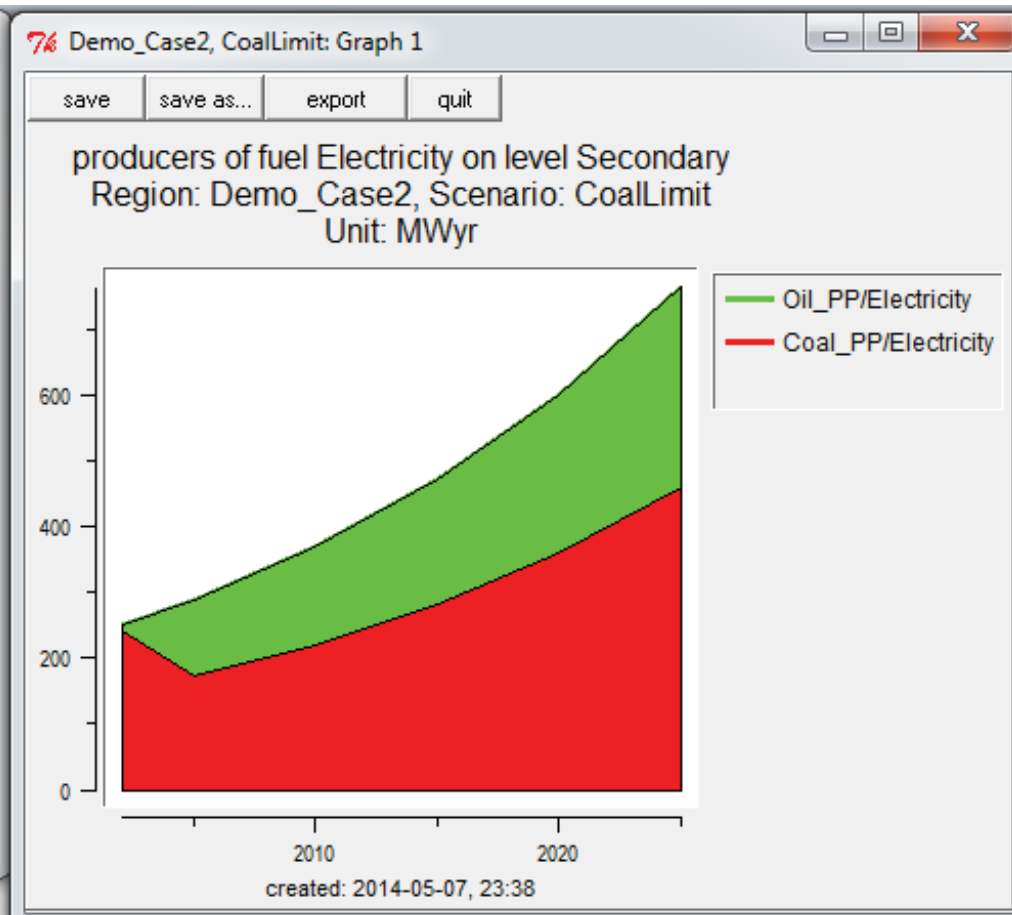
Results of Coal Power Limit 60%

7% IAEA - MESSAGE Int_V2 Demo_Case2

graph save export quit

producers of fuel Electricity on level Secondary
Region: Demo_Case2, Scenario: CoalLimit
Unit: MWyr

	Coal_PP Electricity	Oil_PP Electricity	Total
2002	242.22	7.78	250.00
2005	173.64	115.76	289.41
2010	221.62	147.75	369.36
2015	282.85	188.57	471.41
2020	360.99	240.66	601.65
2025	460.73	307.15	767.88



Comparison Objective Function

```
Problem: Demo_Case2_adb
Rows: 334
Columns: 191
Non-zeros: 2254
Status: OPTIMAL
Objective: func = 2070024.714 (MINimum)
```

No.	Row name	St	Activity	Lower bound	Upper bound
Marginal					

1	func	B	2.07002e+06		

```
Problem: Demo_Case2_CoalLimit
Rows: 339
Columns: 191
Non-zeros: 2364
Status: OPTIMAL
Objective: func = 2825973.756 (MINimum)
```

No.	Row name	St	Activity	Lower bound	Upper bound
Marginal					

1	func	B	2.82597e+06		

Comparison CO2 Emission

7% IAEA - MESSAGE Int_V2 D... graph save export quit

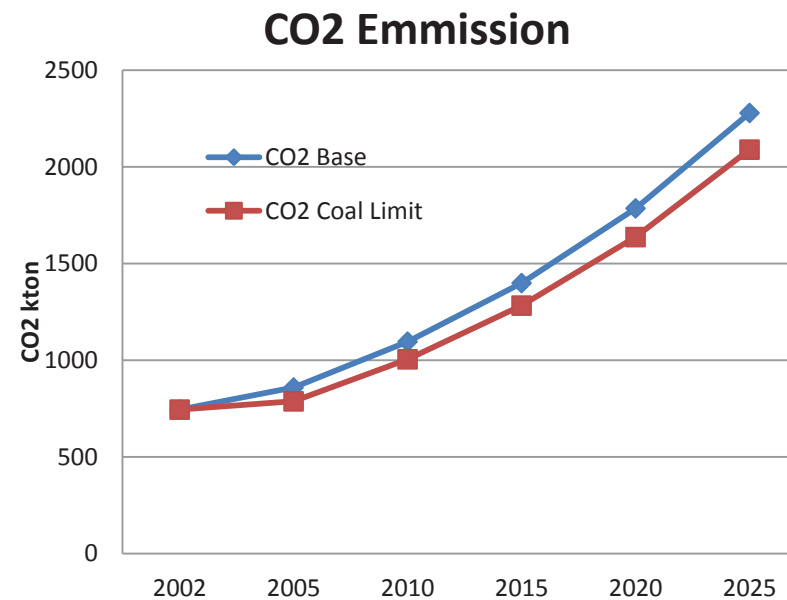
Region: Demo_Case2, Scenario: adb
Unit: MWyr

	CO2 value	Total
2002	744.55	744.55
2005	858.66	858.66
2010	1095.89	1095.89
2015	1398.67	1398.67
2020	1785.09	1785.09
2025	2278.28	2278.28

7% IAEA - MESSAGE Int_V2 Demo_Cas... graph save export quit

Region: Demo_Case2, Scenario: CoalLimit
Unit: MWyr

	CO2 value	Total
2002	744.55	744.55
2005	787.18	787.18
2010	1004.67	1004.67
2015	1282.24	1282.24
2020	1636.50	1636.50
2025	2088.64	2088.64



Outcomes of the example

- ❑ 190kTons of CO2 Emissions of the system will be decreased by limiting the Coal power generation
- ❑ Total system cost will be increased by 755,949 \$
- ❑ Is it a economical NAMA to the country

Sensitivity Analysis in MESSAGE

Option 2

Use the sensitivity function in MESSAGE

Sensitivity analysis

- Most of the optimizers (solvers) provide information for sensitivity analysis; they calculate and report ranges on
 - objective functions coefficients (c_j 's)
 - right hand side (b_i 's)
 - Bounds (L_j and U_j)

A simple energy model in MESSAGE

Primal Objective function:

Minimise total system cost

$$z = 350 * XCL + 300 * XGS$$

$$XCL \geq 0, XGS \geq 0$$

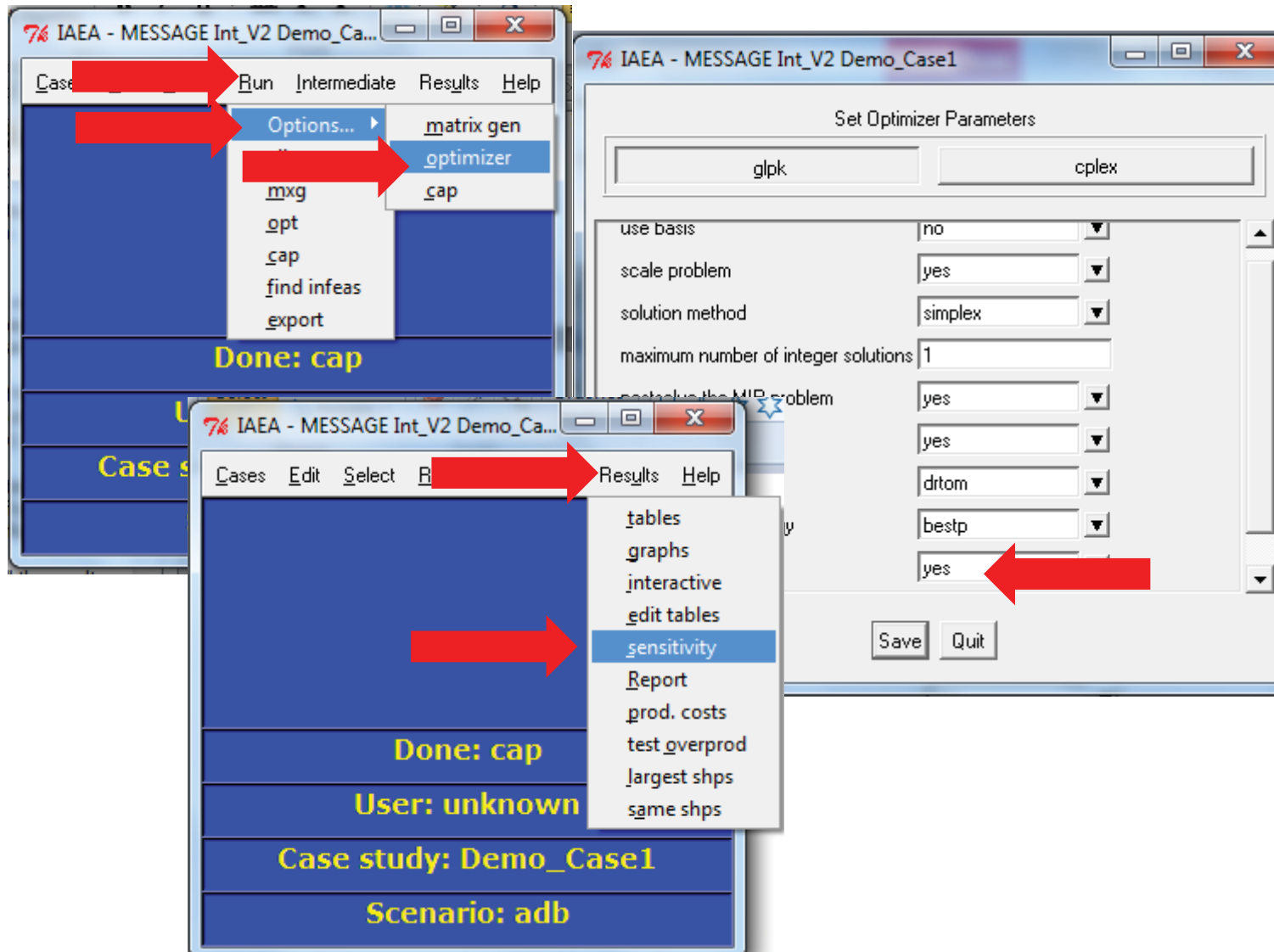
Constraint 1	Demand	$XCL + XGS \geq 250$
Constraint 2	Coal resource availability	$3 * XCL \leq 600$
Constraint 3	Gas resource availability	$2 * XGS \leq 300$

Principal approach

Focus on only one parameter at one time

Assume that all parameters remain fixed
except the one in question

Sensitivity analysis with MESSAGE



search: Find sort by: ▼

Objective coefficient analysis | **Constraint bound analysis** | Variable bound analysis

No.	Column name	St	Value	Max increase	Max decrease
1	fcae.....	001 B	116.55	infinity	16.65
2	lgae.....	001 B	130	25	infinity
3	s.pg.....	001 E	0	25	infinity
4	s.tc.....	001 B	0	infinity	16.65

Absolute Percentage Description

The screenshot shows a software window with a search bar at the top. Below it are three tabs: 'Objective coefficient analysis', 'Constraint bound analysis' (which is selected), and 'Variable bound analysis'. A table displays the results of the constraint bound analysis. The table has six columns: 'No.', 'Column name', 'St', 'Value', 'Max increase', and 'Max decrease'. There are four rows of data. The first row is highlighted in yellow. At the bottom of the window, there are three buttons: 'Absolute', 'Percentage', and 'Description'. Red arrows are overlaid on the image, pointing to the search bar, the 'Constraint bound analysis' tab, the table headers, the first row of data, and the 'Absolute' and 'Percentage' buttons. The Windows taskbar is visible at the very bottom of the image.

76 LP-viewer for LPDUALExample

search: Subject to in: all Next Prev Reset All dics: items:

column: oth: reg: ldr: tms: Make list Clear sel

LP input (mark name and click right mouse to get long name)

Problem:
LPDUALExample.adb

Minimize Maximum allowable reduction 16.65 We reduce by 15
 func (N): +1.16550e+02 * fcae.....001 +1.50000e+02 * fgae.....001
 Original cost coefficient 116, New coefficient 101 (116-15)

Subject to:

car1 (G): > 0. < 1.e31
 car1..... (N): > -1.e31 < 1.e31
 car1t.....001 (N): > -1.e31 < 1.e31
 car2 (G): > 0. < 1.e31
 car2..... (N): > -1.e31 < 1.e31
 car2t.....001 (N): > -1.e31 < 1.e31
 ccap (G): > 0. < 1.e31
 ccap..... (N): > -1.e31 < 1.e31
 ccapt.....001 (N): > -1.e31 < 1.e31

$$116 * fcae + 150 * fgae$$

76 LP-viewer for LPDUALExample

search: Subject to in: all Next Prev Reset All dics: Result count: 30

column: oth: reg: ldr: tms: Make list Clear sel items: Solution view: col act

LP input (mark name and click right mouse to get long name)

Problem:
LPDUALExample.adb

Minimize
 func (N): +1.01565e+02 * fcae.....001 +1.50000e+02 * fgae.....001

Subject to:

car1 (G): > 0. < 1.e31
 car1..... (N): > -1.e31 < 1.e31
 car1t.....001 (N): > -1.e31 < 1.e31
 car2 (G): > 0. < 1.e31
 car2..... (N): > -1.e31 < 1.e31
 car2t.....001 (N): > -1.e31 < 1.e31
 ccap (G): > 0. < 1.e31
 ccap..... (N): > -1.e31 < 1.e31
 ccapt.....001 (N): > -1.e31 < 1.e31
 ccur (G): +1.01565e+02 * fcae.....001 +1.50000e+02 * fgae.....001 > -1.00000e+20 < 1.e31
 ccur..... (N): +1.01565e+02 * fcae.....001 +1.50000e+02 * fgae.....001 > -1.e31 < 1.e31
 ccurt.....001 (N): +1.01565e+02 * fcae.....001 +1.50000e+02 * fgae.....001 > -1.e31 < 1.e31

$$101 * fcae + 150 * fgae$$

Results before and after changes

```
1 Problem: LPDUALExample_adb
2 Rows: 30
3 Columns: 4
4 Non-zeros: 22
5 Status: OPTIMAL
6 Objective: func = 80000 (MINimum)
7
8
9 No. Column name St Activity Lower bound
10 -----
11 1 fcae.....001 B 300.3 0
12 2 fgae.....001 B 300 0
13 3 s.pg.....001 B 300 0
14 4 s.tc.....001 B 300.3 0
15
16
17
18
19
20 End of output
21
```

```
1 Problem: LPDUALExample_adb
2 Rows: 30
3 Columns: 4
4 Non-zeros: 22
5 Status: OPTIMAL
6 Objective: func = 75500 (MINimum)
7
8
9 No. Column name St Activity Lower bound Upper
10 -----
11 1 fcae.....001 B 300.3 0
12 2 fgae.....001 B 300 0
13 3 s.pg.....001 B 300 0
14 4 s.tc.....001 B 300.3 0
15
16
17
18
19
20 End of output
```

Comparing the objective functions

76 LP-viewer for LPDUALExample

search: Subject td in: all Next Prev Reset All dics: R
column: oth: reg: ldr: tms: Make list Clear sel items: Sc

LP input (mark name and click right mouse to get long name)

Problem:
LPDUALExample_ada

Minimize
func (N): +1.16550e+02 * fcae.....001 +1.50000e+02 * fgae.....001

Subject to:
car1 (G): > 0. < 1.e31
car1..... (N): > -1.e31 < 1.e31
car1t.....001 (N): > -1.e31 < 1.e31
car2 (G): > 0. < 1.e31
car2..... (N): > -1.e31 < 1.e31
car2t.....001 (N): > -1.e31 < 1.e31
ccap (G): > 0. < 1.e31
ccap..... (N): > -1.e31 < 1.e31
ccapt.....001 (N): > -1.e31 < 1.e31
ccur (G): +1.16550e+02 * fcae.....001 +1.50000e+02 * fgae.....001 > -1.00000e+20 < 1.e31

$116 * fcae + 150 * fgae$

76 LP-viewer for LPDUALExample

search: Subject td in: all Next Prev Reset All dics: Result count: 30
column: oth: reg: ldr: tms: Make list Clear sel items: Solution view: col act

LP input (mark name and click right mouse to get long name)

Problem:
LPDUALExample_ada

Minimize
func (N): +9.65700e+01 * fcae.....001 +1.50000e+02 * fgae.....001

Subject to:
car1 (G): > 0. < 1.e31
car1..... (N): > -1.e31 < 1.e31
car1t.....001 (N): > -1.e31 < 1.e31
car2 (G): > 0. < 1.e31
car2..... (N): > -1.e31 < 1.e31
car2t.....001 (N): > -1.e31 < 1.e31
ccap (G): > 0. < 1.e31

$96.5 * fcae + 150 * fgae$

Results before and after changes

```

1 Problem: LPDUALExample_adb
2 Rows: 30
3 Columns: 4
4 Non-zeros: 22
5 Status: OPTIMAL
6 Objective: func = 80000 (MINimum)
7
8
9 No. Column name St Activity Lower bo
10 -----
11 1 fcae.....001 B 300.3
12 2 fgae.....001 B 300
13 3 s.pg.....001 B 300
14 4 s.tc.....001 B 300.3
15
16
17
18
19
20 End of output
21

```

```

1 Problem: LPDUALExample_adb
2 Rows: 30
3 Columns: 4
4 Non-zeros: 22
5 Status: OPTIMAL
6 Objective: func = 73002 (MINimum)
7
8
9 No. Column name St Activity Lower bound Upper bo
10 -----
11 1 fcae.....001 B 600 0
12 2 fgae.....001 B 100.4 0
13 3 s.pg.....001 B 300 0
14 4 s.tc.....001 B 600 0
15
16
17
18
19
20 End of output
21

```

Sensitivity analysis

- Range analysis provides the range, both lower and upper value of coefficients, outside this range current solution will fundamentally change.
- Limited to changing one coefficient at a time.