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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

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Sensitivity Analysis

Thushara De Silva
Ceylon Electricity Board
Sri Lanka

Sensitivity Analysis

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

Thushara De Silva

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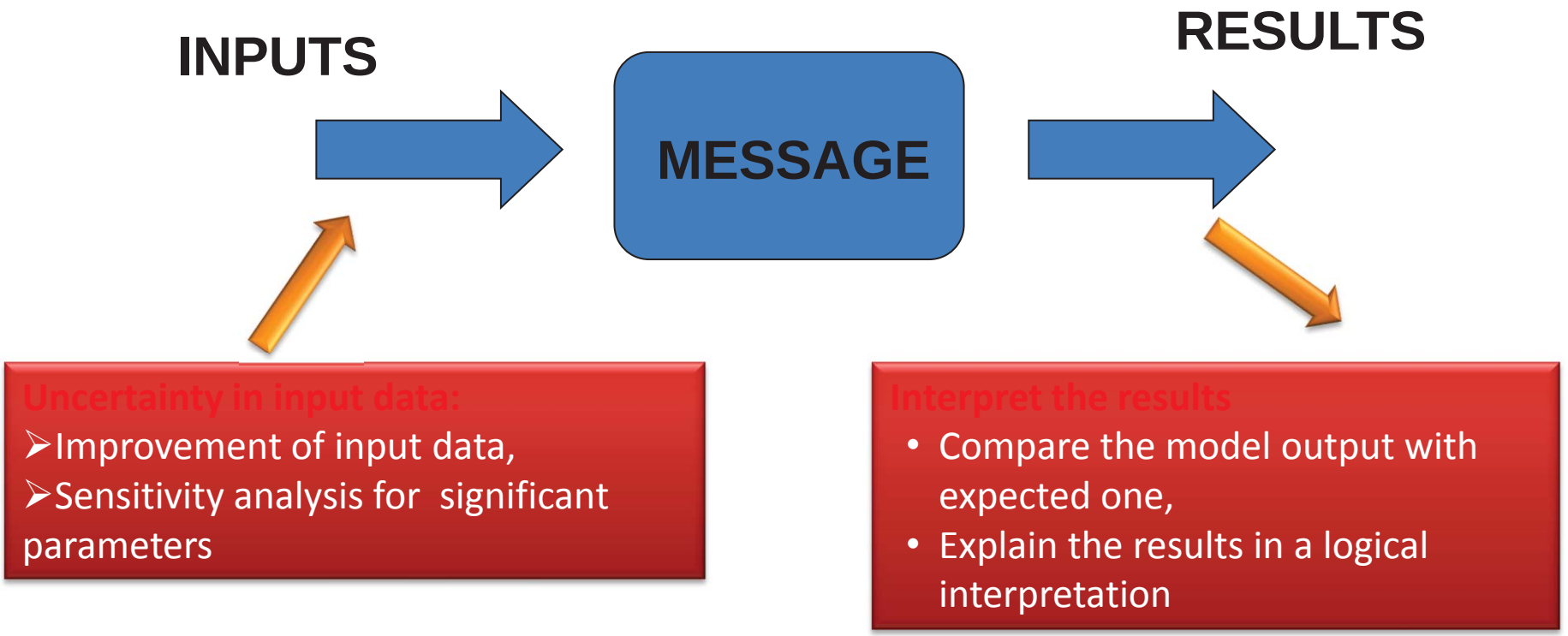
Successive Approach



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 import parameters for which the planner(s) or sometime the decision maker(s) accord the highest degree of uncertainty.

Some Examples for Sensitivity Analysis

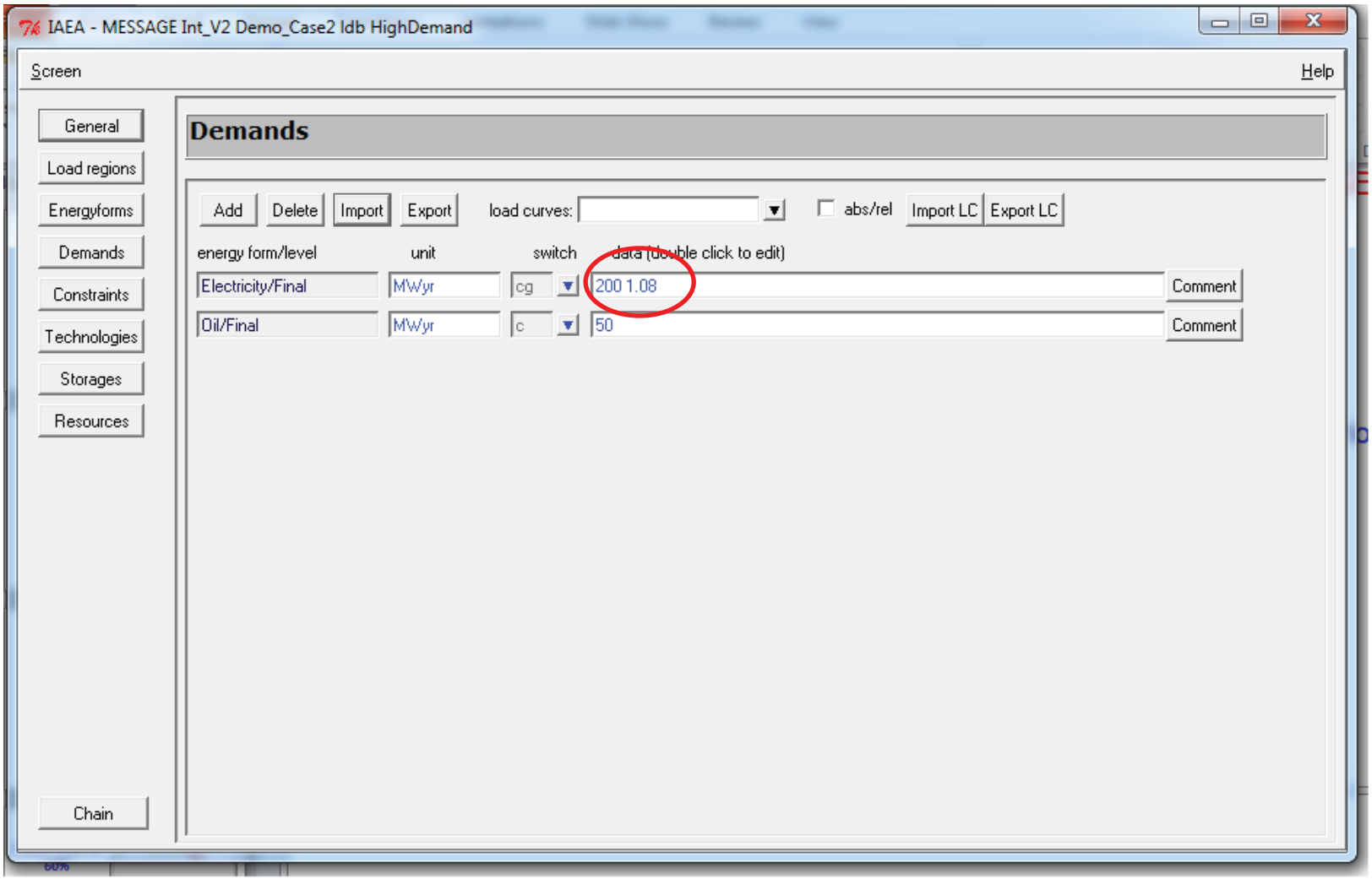
- Discount rate
- Future demand for energy/electricity
- Investment costs of new power plants and other energy facilities
- Operation and maintenance costs
- Fuel cost
- Performance of technologies (efficiency, plant factor, availability factor, etc.)
- Limits on production and construction of plants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

Sensitivity Analysis in MESSAGE

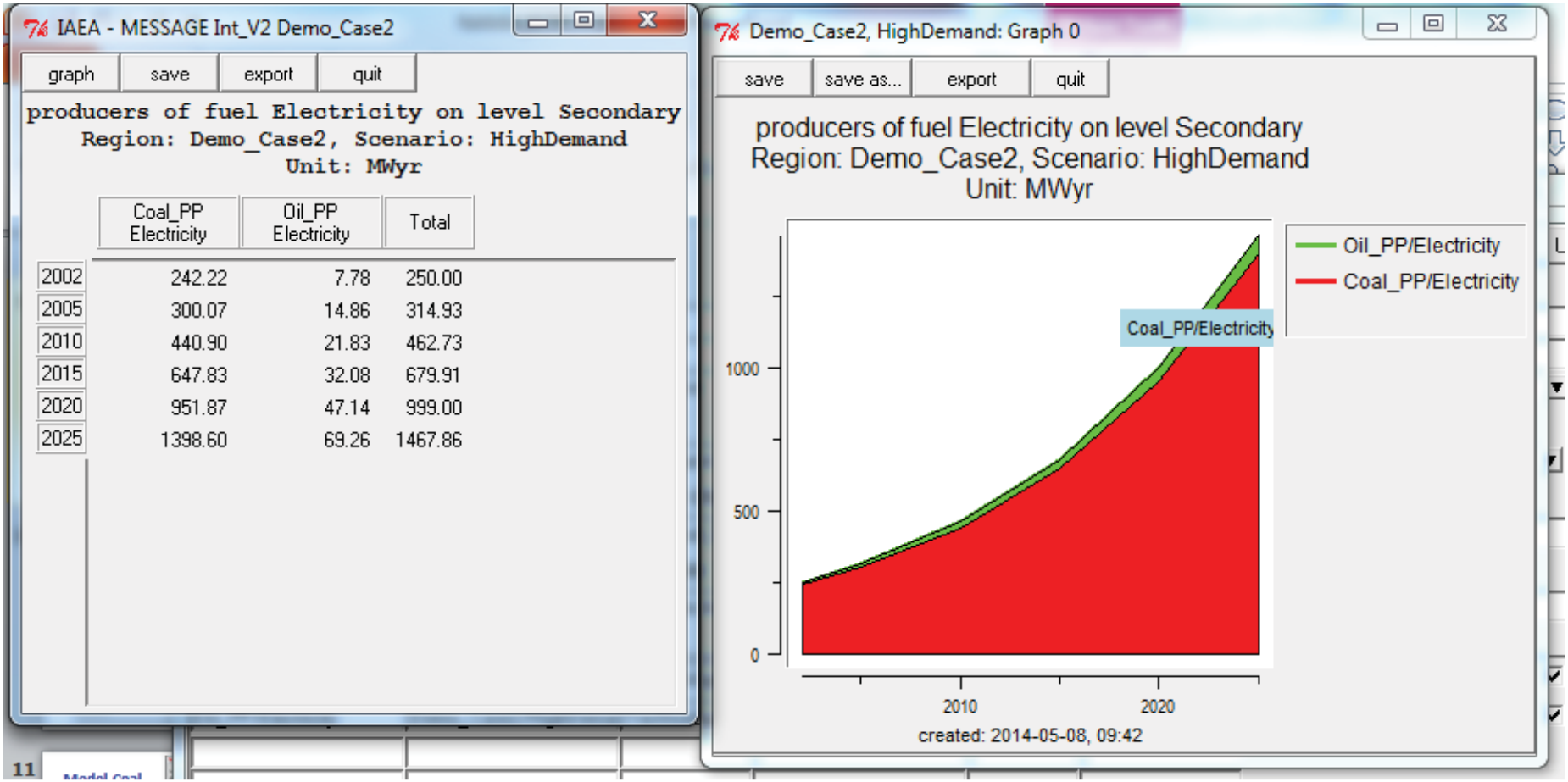
Two options:

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

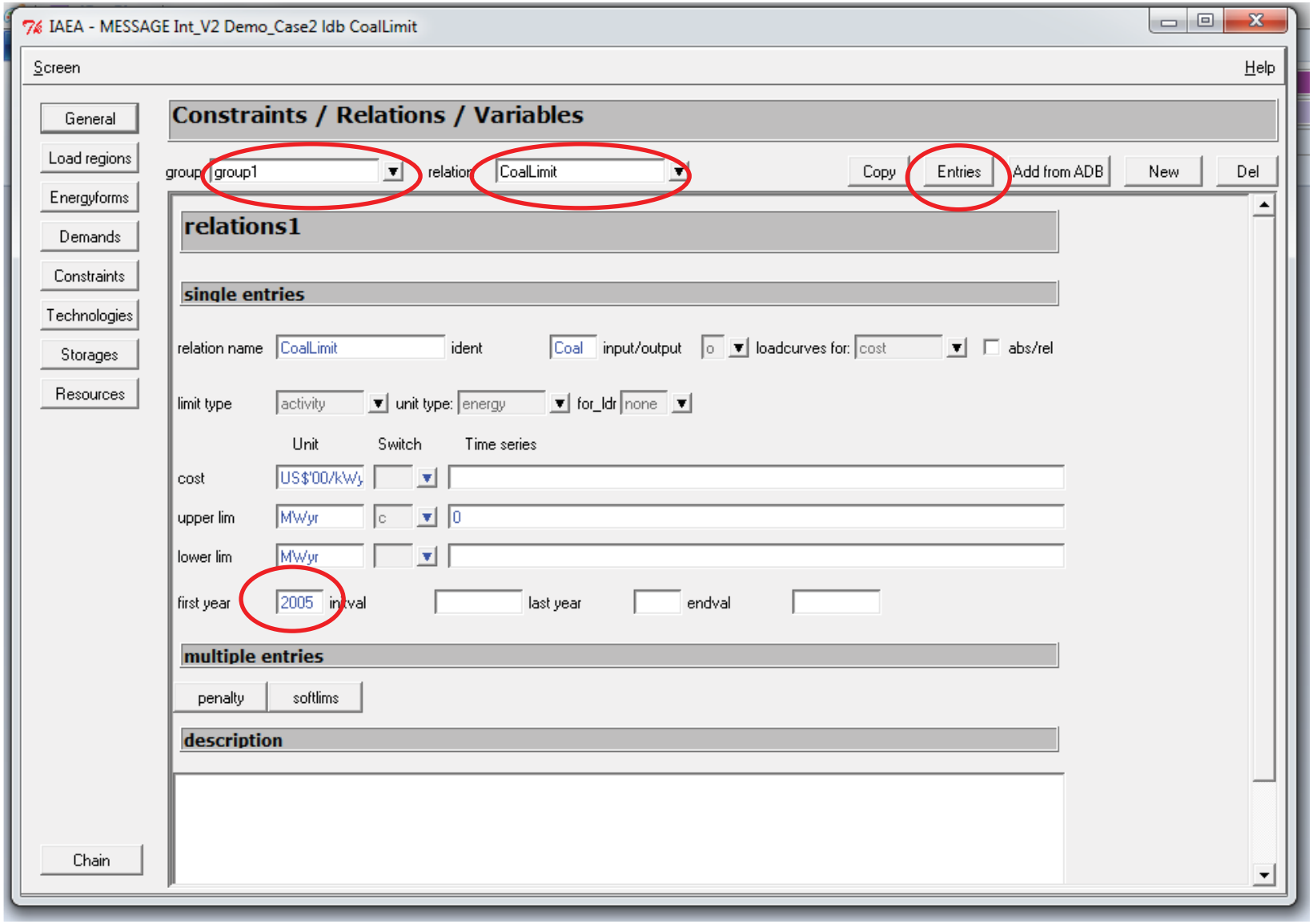
Model High Demand Electricity 8%



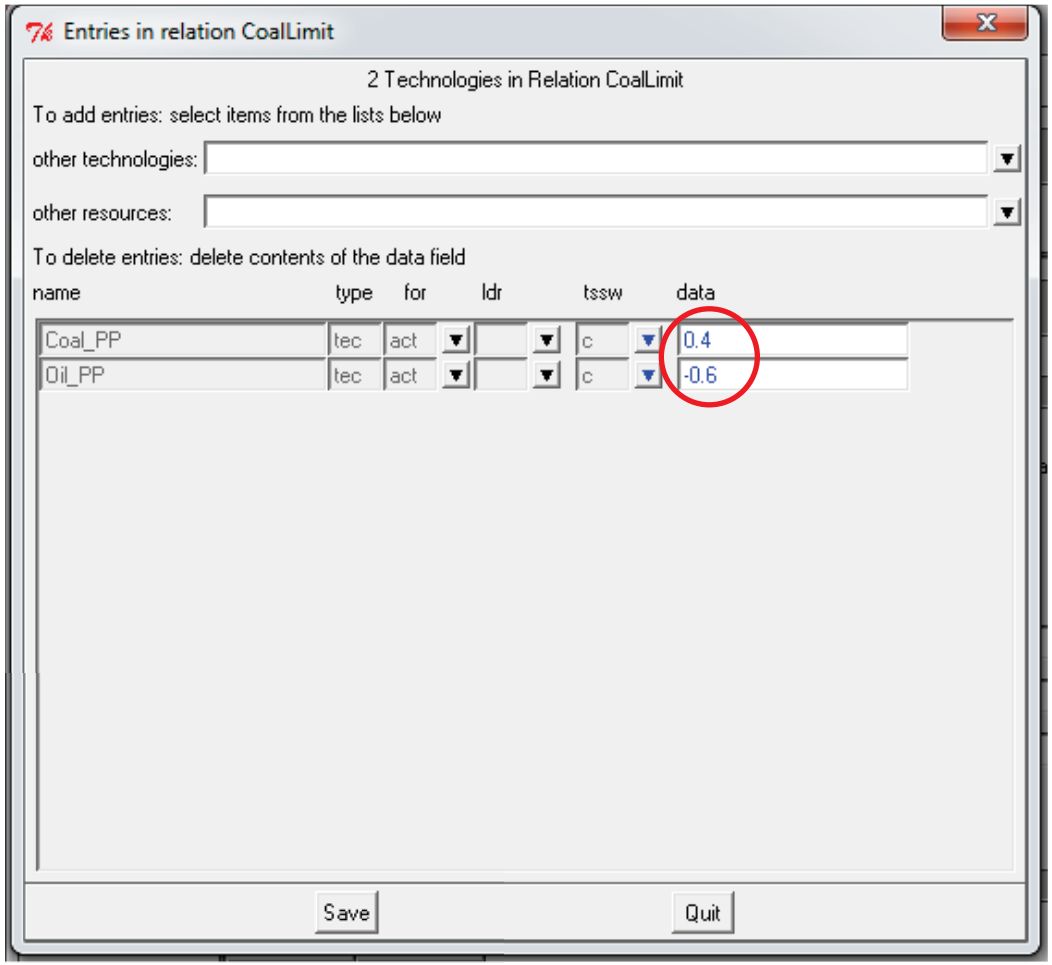
Results High Demand Electricity 8%



Model Coal Power Limit to 60%



Model Coal Power Limit to 60%

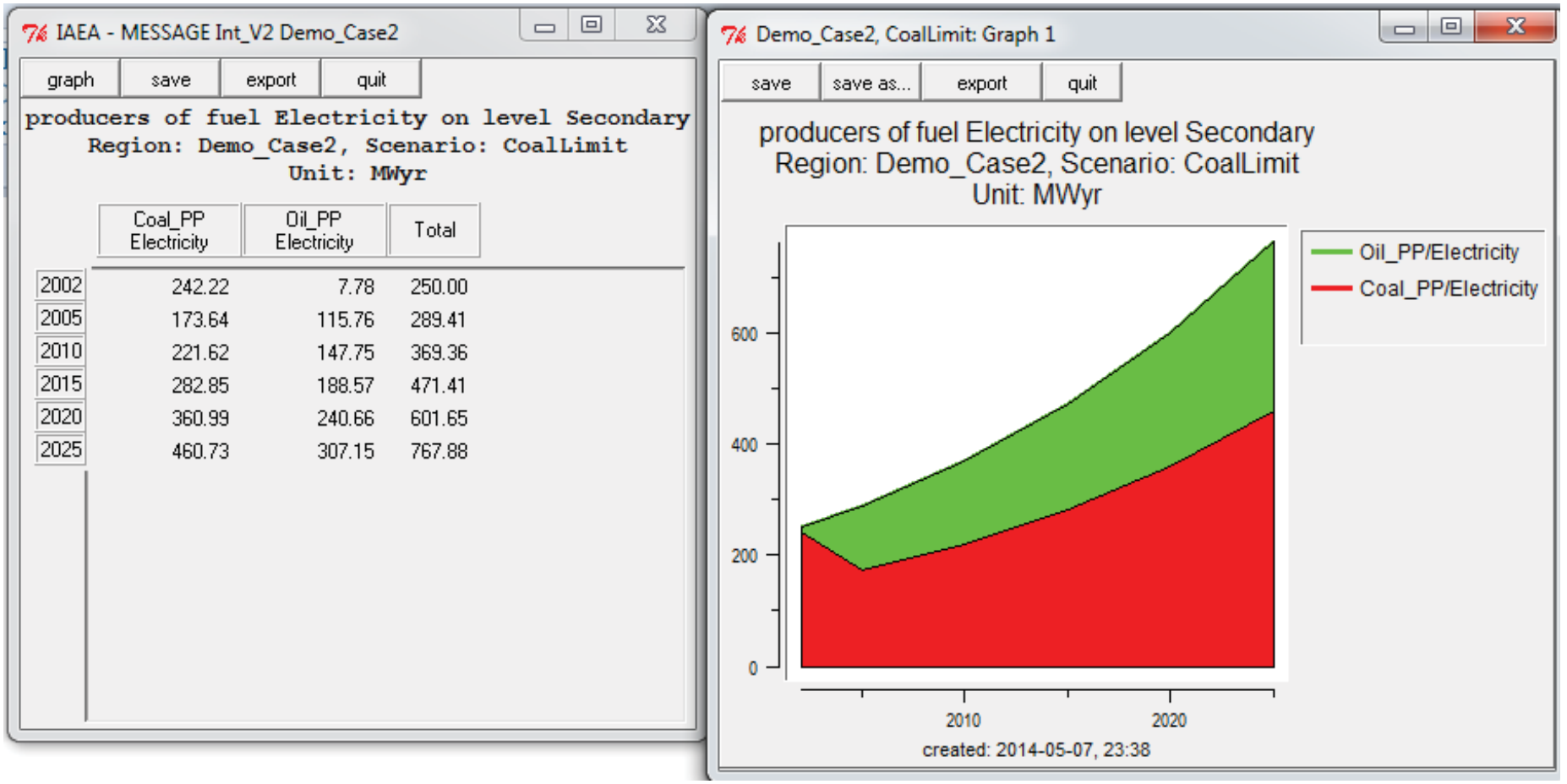


$$\frac{X_{coal}}{X_{coal} + X_{oil}} \leq 0.6$$

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

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

Results of Coal Power Limit 60%



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

IAEA - MESSAGE Int_V2 D...

graph | save | export | quit

Region: Demo_Case2, Scenario: adb
Unit: MWyr

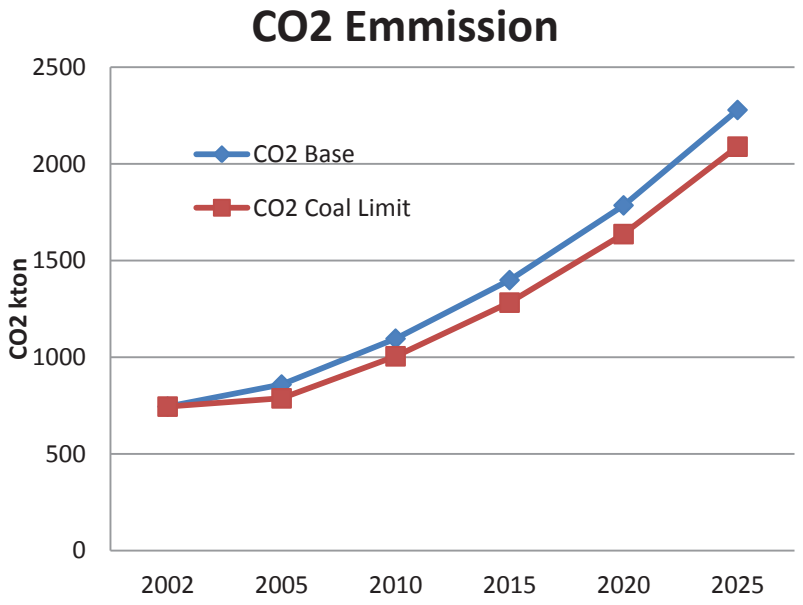
	CO2 value	Total
2002	744.55	744.55
2005	858.66	858.66
2010	1095.89	1095.89
2015	1398.67	1398.67
2020	1785.09	1785.09
2025	2278.28	2278.28

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 ≥ 0, XGS ≥ 0

Constraint 1	Demand	XCL	+ XGS ≥	250
Constraint 2	Coal resource availability	3*XCL	≤	600
Constraint 3	Gas resource availability		2*XGS ≤	300

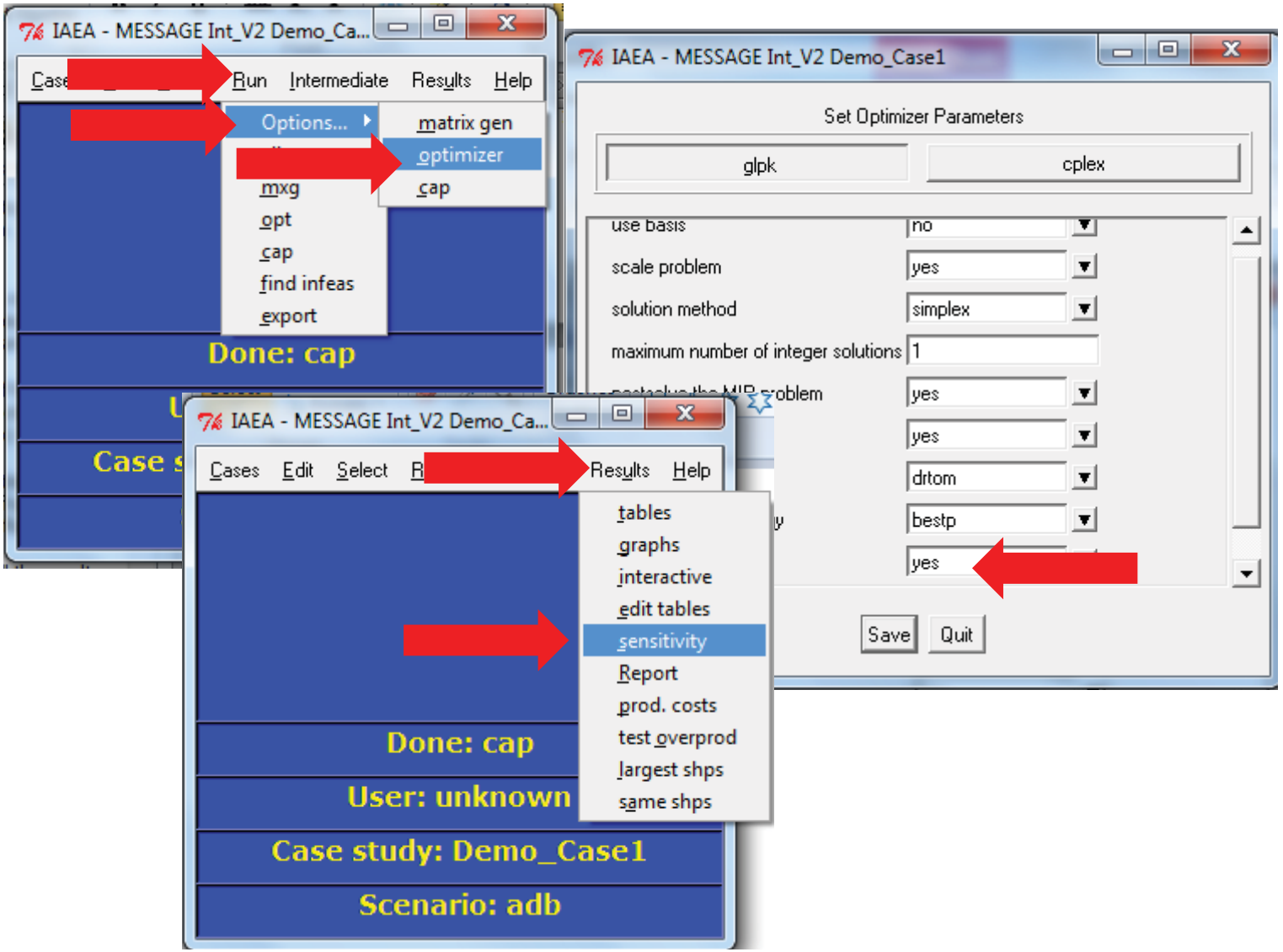
Principal approach

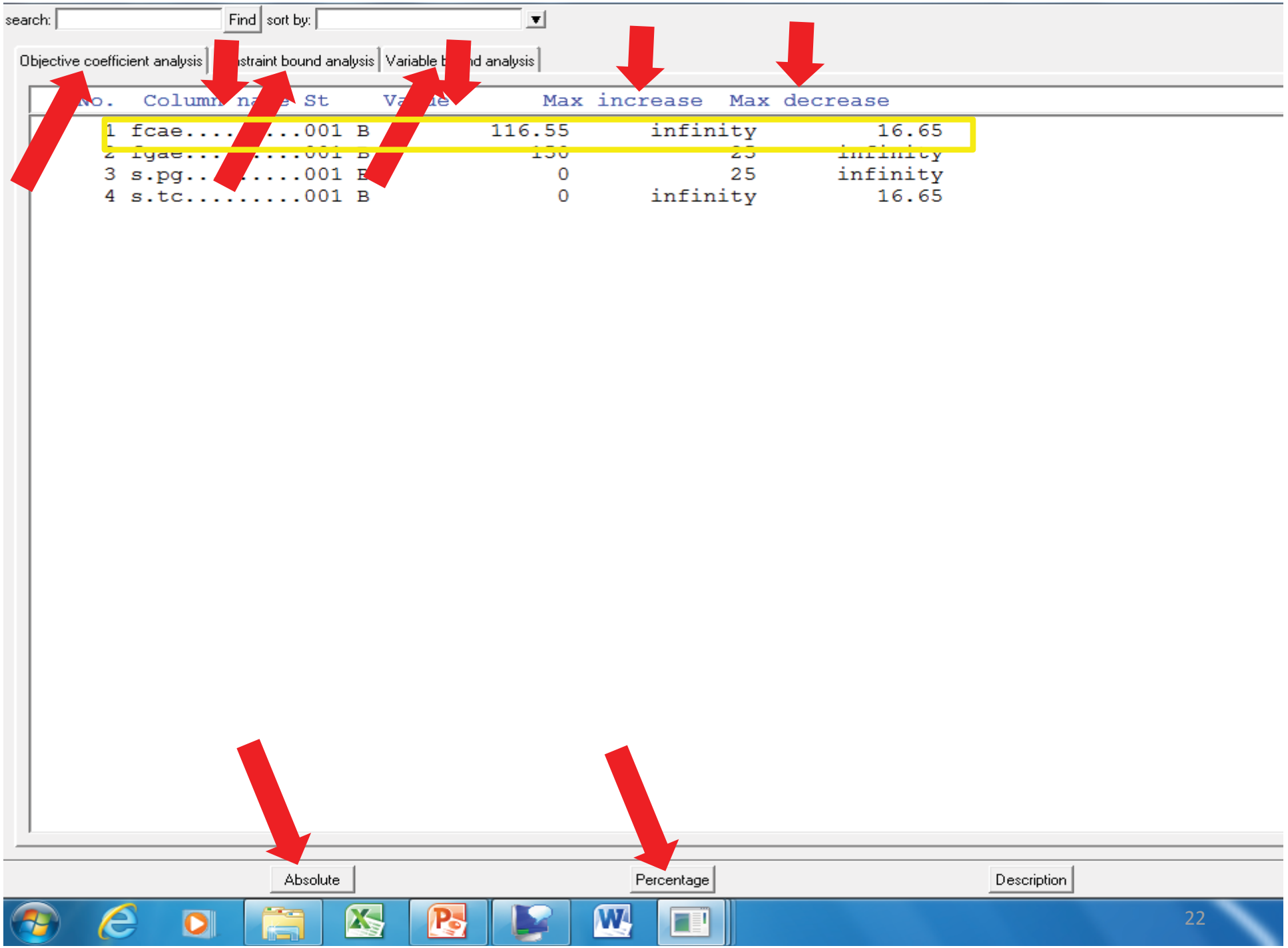
Focus on only one parameter at one time

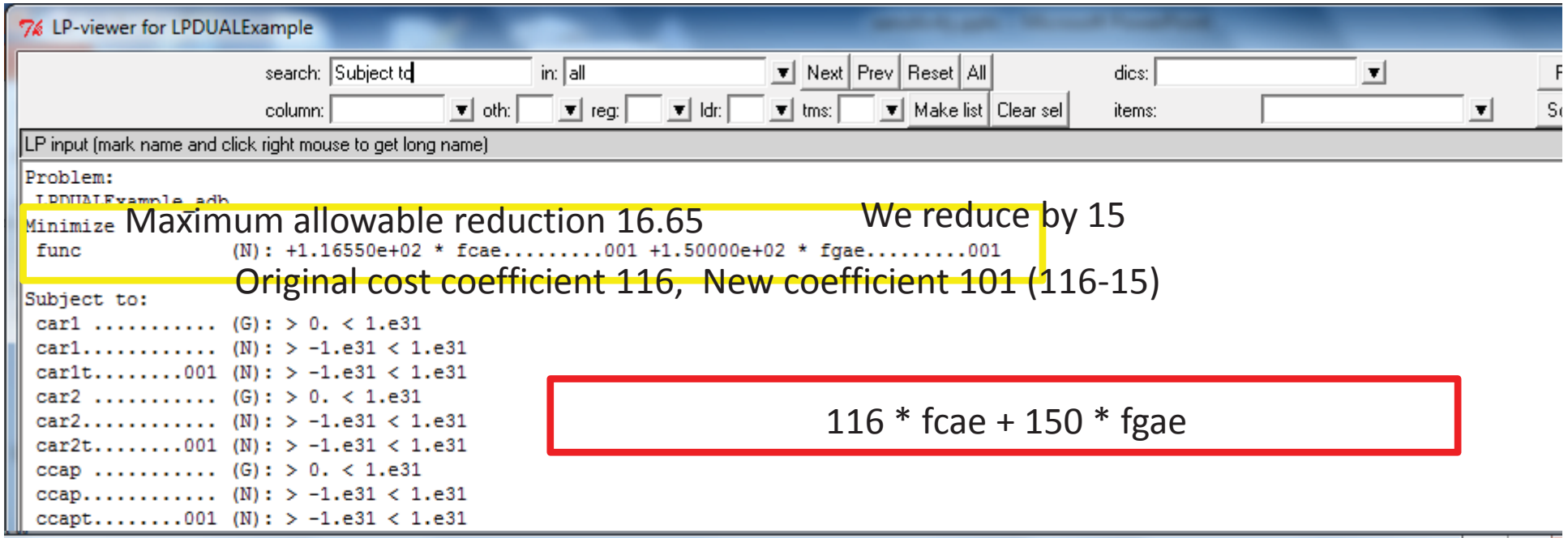
Assume that all parameters remain fixed

except the one in question

Sensitivity analysis with MESSAGE




search:
Find
sort by:
Objective coefficient analysis
straint bound analysis
Variable b d analysis
No. Column na e St Va ue Max increase Max decrease
1 fcae.... ...001 B 116.55 infinity 16.65
2 fgae... ...001 B 130 25 infinity
3 s.pg.. ....001 B 0 25 infinity
4 s.tc.....001 B 0 infinity 16.65
Absolute
Percentage
Description

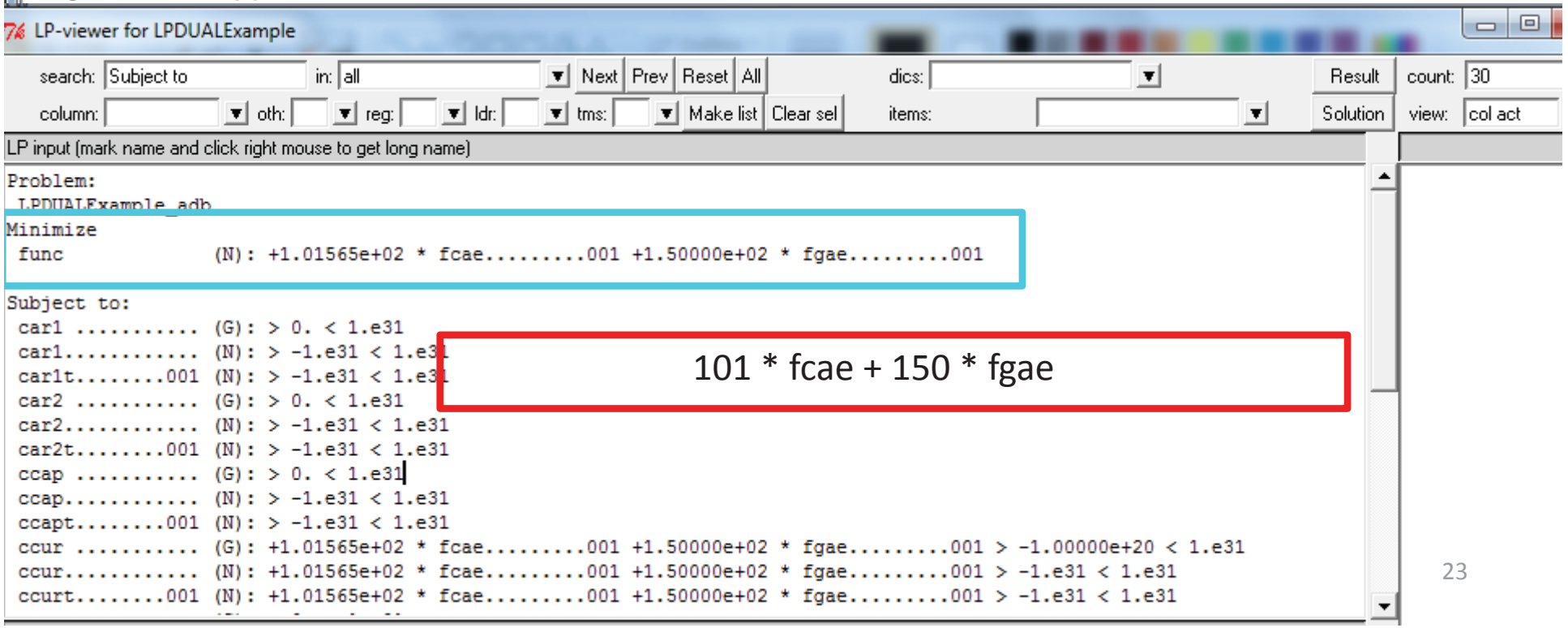


Maximum allowable reduction 16.65

We reduce by 15

Original cost coefficient 116, New coefficient 101 (116-15)

116 * fcae + 150 * fgae



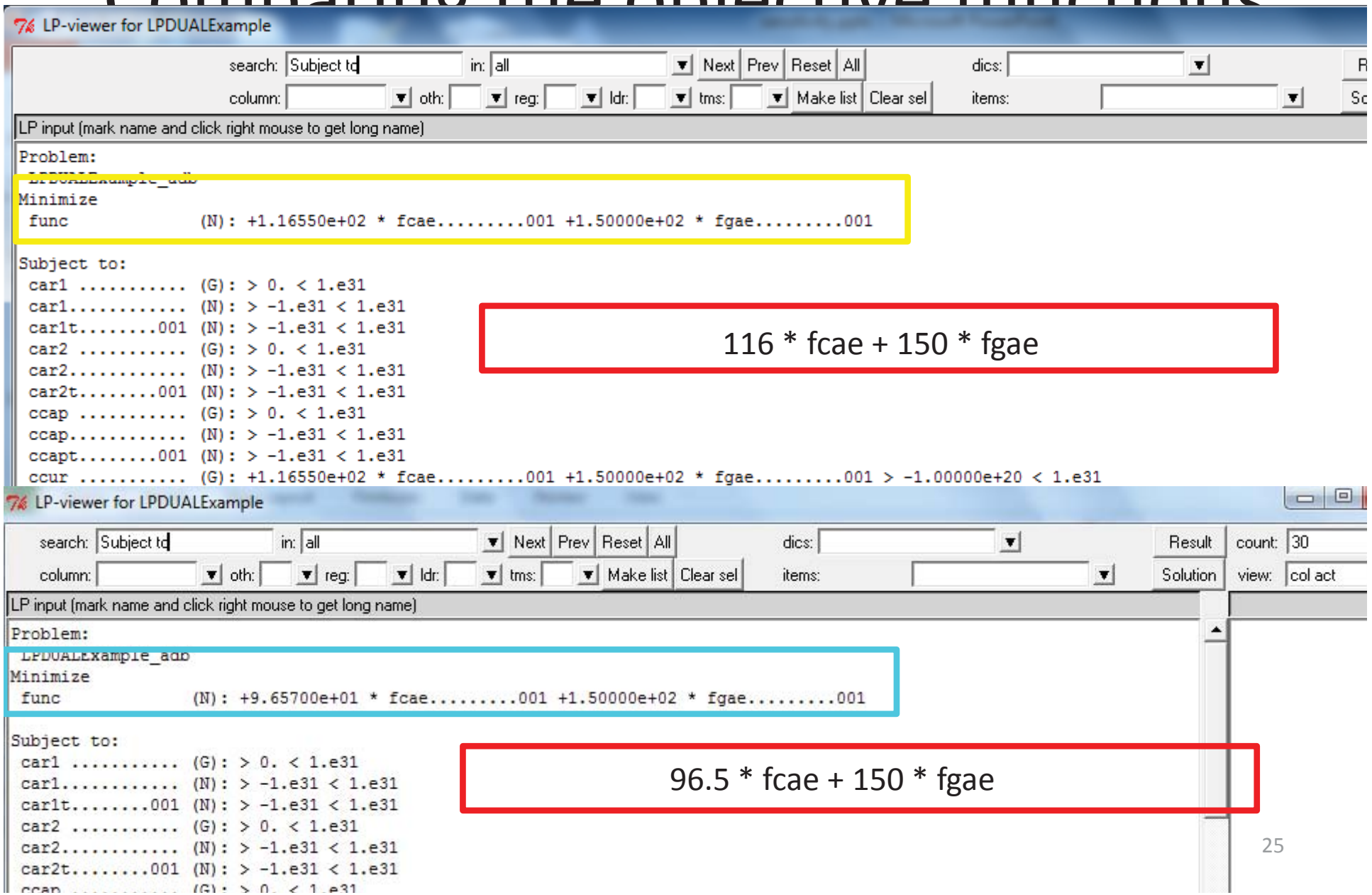
101 * fcae + 150 * fgae

Results before and after changes

```
Problem:    LPDUALExample_adb
Rows:       30
Columns:    4
Non-zeros:  22
Status:     OPTIMAL
Objective:  func = 80000 (MINimum)


   No. Column name  St   Activity     Lower bound
------ ------------ -- ------------ ------------
     1 fcae.........001
                     B         300.3            0
     2 fgae.........001
                     B           300            0
     3 s.pg.........001
                     B           300            0
     4 s.tc.........001
                     B         300.3            0

End of output
```

```
Problem:    LPDUALExample_adb
Rows:       30
Columns:    4
Non-zeros:  22
Status:     OPTIMAL
Objective:  func = 75500 (MINimum)


   No. Column name  St   Activity     Lower bound   Upper
------ ------------ -- ------------ ------------ ------
     1 fcae.........001
                     B         300.3            0
     2 fgae.........001
                     B           300            0
     3 s.pg.........001
                     B           300            0
     4 s.tc.........001
                     B         300.3            0

End of output
```

Comparing the objective functions



Results before and after changes

```
Problem:    LPDUALExample_adb
Rows:       30
Columns:    4
Non-zeros:  22
Status:     OPTIMAL
Objective:  func = 80000 (MINimum)

   No. Column name  St   Activity     Lower bo
------ ------------ -- ------------ ----------
     1 fcae.....001
                    B        300.3
     2 fgae.....001
                    B          300
     3 s.pg.....001
                    B          300
     4 s.tc.....001
                    B        300.3

End of output
```

```
Problem:    LPDUALExample_adb
Rows:       30
Columns:    4
Non-zeros:  22
Status:     OPTIMAL
Objective:  func = 73002 (MINimum)

   No. Column name  St   Activity     Lower bound   Upper bo
------ ------------ -- ------------ ------------ ----------
     1 fcae.....001
                    B          600            0
     2 fgae.....001
                    B        100.4            0
     3 s.pg.....001
                    B          300            0
     4 s.tc.....001
                    B          600            0

End of output
```

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.