



# IAEA Project MEX/0/012 : Comparative assessment of energy options and strategies until 2025

Mexico City, June 13, 2001

# VISION & OBJECTIVES

**VISION:** To promote the development of sustainable strategies, which provide energy services required for supporting economic growth and improving quality of life, while minimizing health and environmental impacts of energy supply.

**OBJECTIVE:** To enhance capabilities for comparative assessment of different energy supply options and strategies in the process of planning and decision making for the energy sector.



In order to achieve this objective, the project was divided in two parts :

Phase I. The acquisition, implementation and use of the computer-based tool (DECADES), a model that includes health and environmental factors in the process of planning and decision making for the **Electricity Sector**.

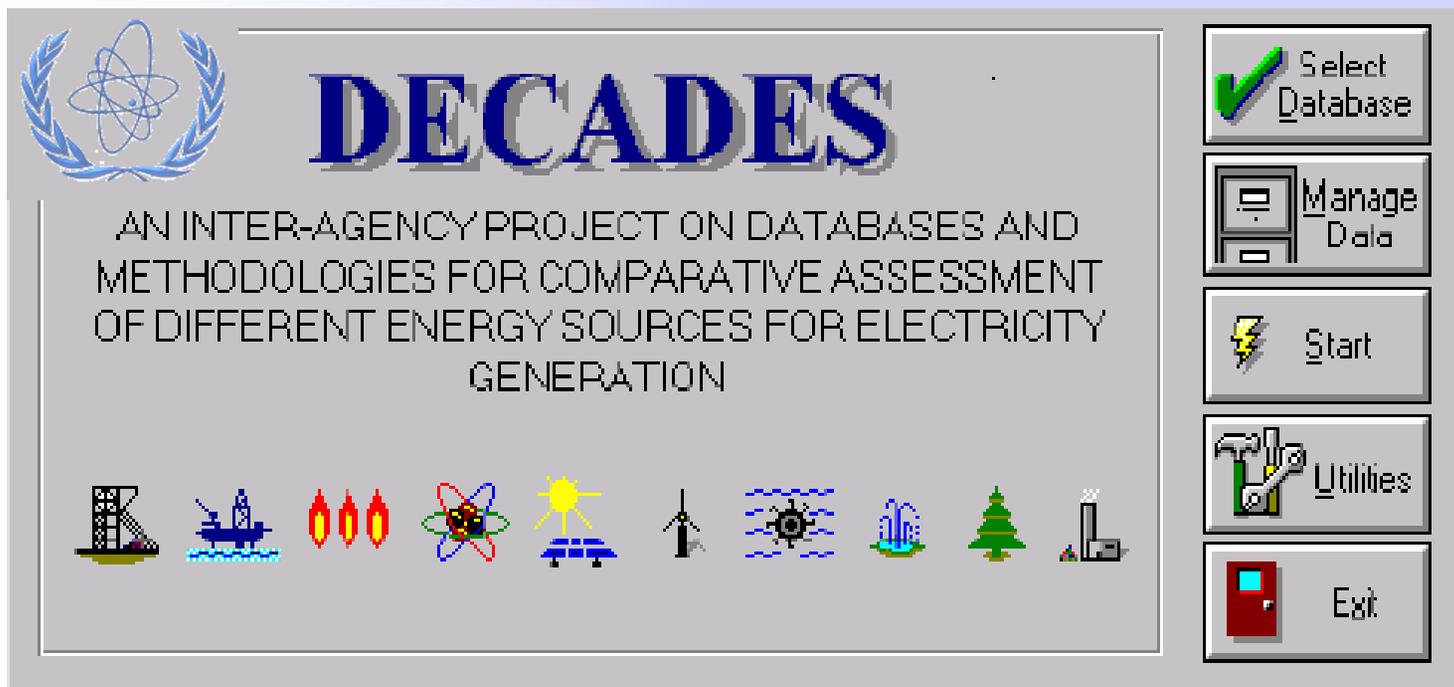
Phase II. The acquisition, implementation and use of the Energy and Power Evaluation Program (ENPEP), a model for planning and decision making for the **Energy System**.



# Project MEX0012: Comparative assessment of energy options and strategies until 2025

Phase I: The Databases and Methodologies for Comparative Assessment of Different Energy Sources for Electricity Generation

(DECADES) model



•The first objective of the project's phase I, was to produce a Country Specific Data Base (CSDB) for Mexico including:

- ✓ Technical parameters for energy sources.
- ✓ Technical, economic and environmental parameters of technologies for the generating system.
- ✓ Technical, economic and environmental parameters of energy chains.



•The second objective of the project's Phase I, was to study the economic and environmental impacts of expansion of the generating system until 2025, using one base and several alternative cases. The study was done in four stages:

- ✓ Plant level analysis.
- ✓ Fuel chain level analysis.
- ✓ System level analysis.
- ✓ Decision making analysis.



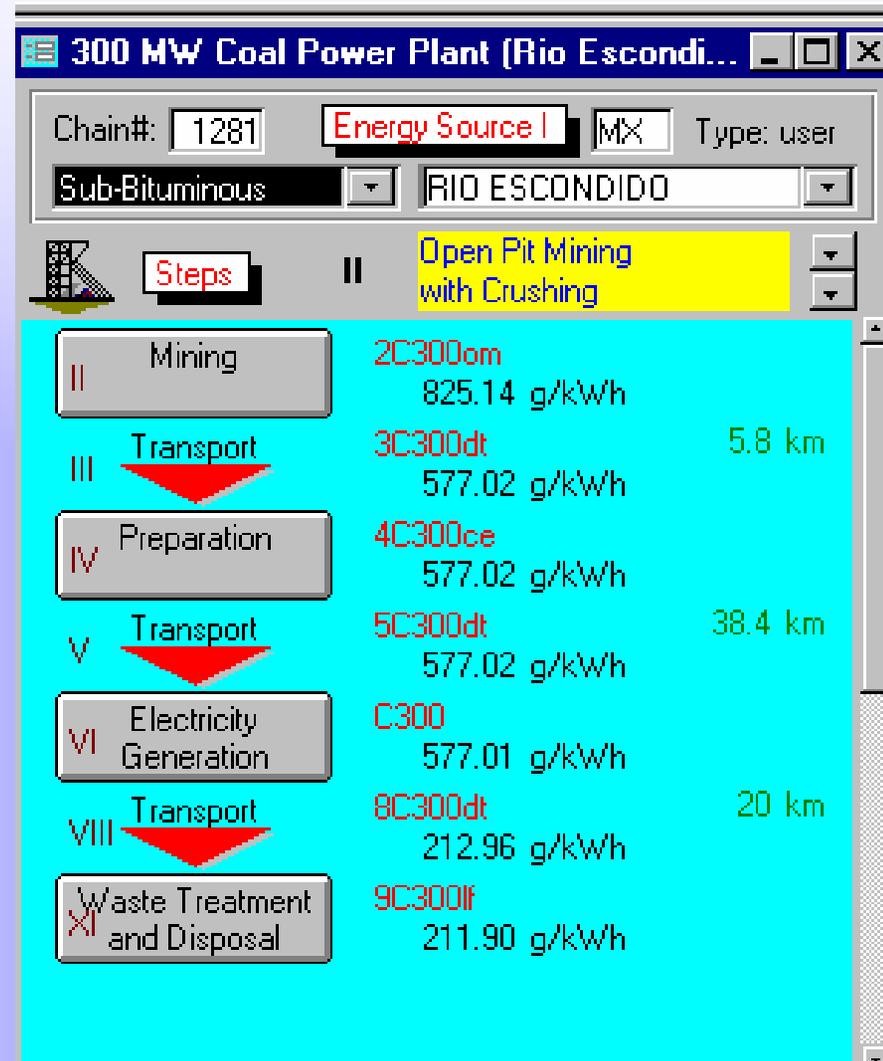
# PLANT LEVEL ANALYSIS

- The principal results of the plant level analysis were:
  - ✓ For base loaded operation at 80% capacity factor, the combined cycle has the lowest annual unit cost, at 179 USD/yr-kW.
  - ✓ The dual plant with 260 USD/yr-kW and the nuclear with 329 USD/yr-kW are not competitive, not even at 100% capacity factor.
  - ✓ For peak load operation below 20% capacity factor, the gas turbine with 85 USD/yr-kW has the lowest annual unit cost.



# FUEL CHAIN LEVEL ANALYSIS

- The principal results of the energy chain level analysis were:
  - ✓ Fuel oil chain.
  - ✓ Diesel chain.
  - ✓ Natural gas chain.
  - ✓ Coal chain.
  - ✓ Enriched uranium chain.
  - ✓ Geothermal chain.
  - ✓ Wind and solar chain.



# SYSTEM LEVEL ANALYSIS

General assumptions for the base case:

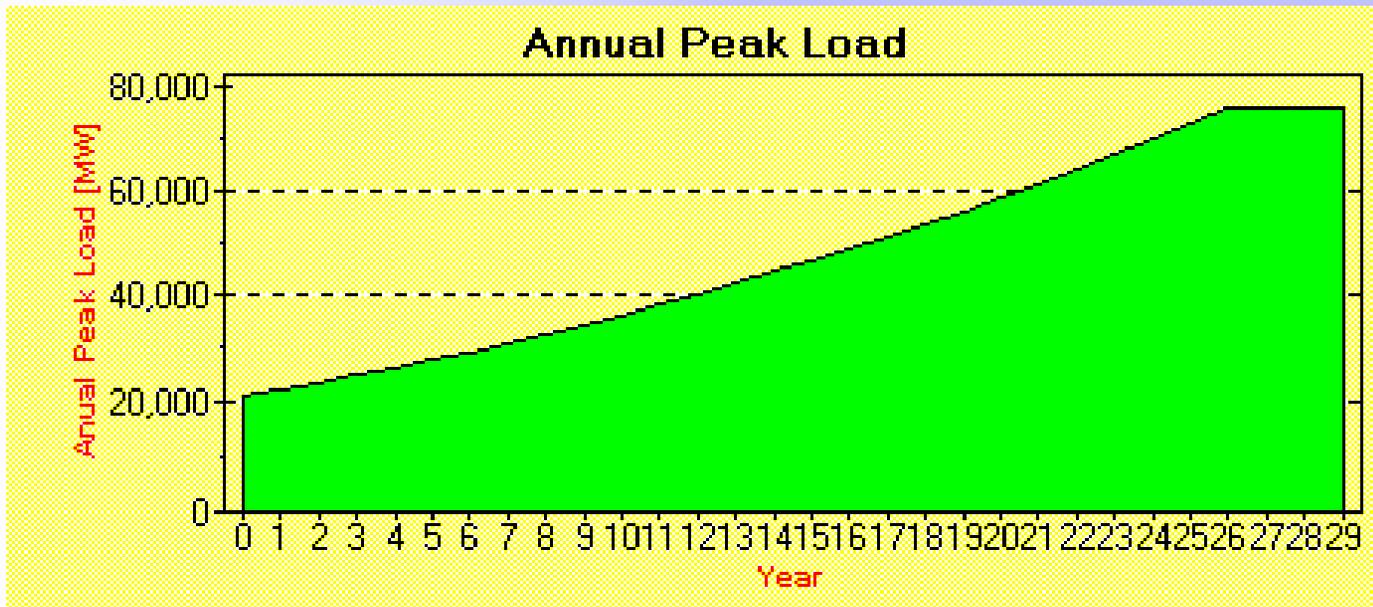
- ✓ Nuclear cost of 2,485 USD/kW.
- ✓ Price of natural gas of 2.66 USD/GJ in 1998, with an average escalation of 0.08% per year.
- ✓ No supply limit for natural gas.
- ✓ Real discount rate of 10% per year.
- ✓ Cost of energy not served of 1.50 USD/kWh.
- ✓ A maximum reserve margin of 30% and a minimum of 10%.
- ✓ Wet flue gas desulphurization (FGD) on new dual coal fired units.



# DEMAND

•The scenario of evolution of the demand of electricity in the interconnected system, adopted for the system level analysis was:

- ✓ Starting with 21,236 MW in 1998, an average growth rate of 5.4% per year to reach 37,962 MW in 2009.
- ✓ A projection until 2027 with an average growth rate of 4.5% per year, to reach 73,686 MW.

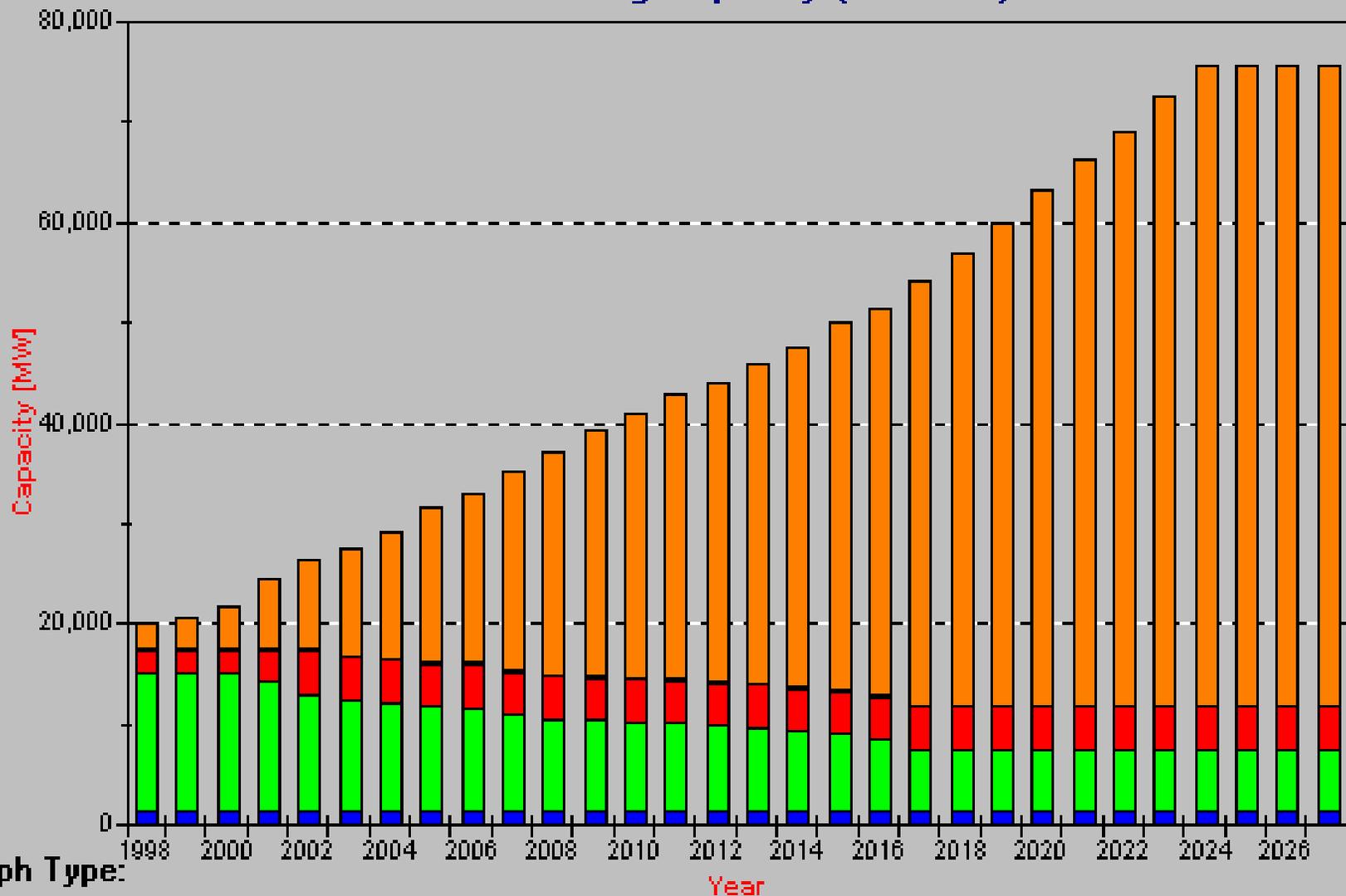


# RESULTS

- The least cost expansion plan in the base case was:
  - ✓ 118 combined cycle plants, with 64,428 MW.
  - ✓ 6 gas turbines, with 1,074 MW.
  - ✓ 2,539 MW of 5 committed hydro projects.



# Total Generating Capacity (Thermal)



Graph Type:

Line

Stacked Bar

Area

NUCL

COMB

CARB

GEDE

GDCC

- There were 14 alternative cases selected for study:

### **A. Impact of higher demand growth**

- ✓ A1: Demand growth of 6 % per year.

### **B. Analysis of the nuclear option**

- ✓ B1. Nuclear unit cost of only 1,292 USD/kW.
- ✓ B2. Forced Nuclear introduction: one unit forced in 2012.

### **C. Impact of escalation of fossil fuel prices**

- ✓ C1. Slightly higher fossil fuel prices.
- ✓ C2. Natural gas prices 38% higher.
- ✓ C3. Relative to 1998, the natural gas price increases to a factor of 4.14 higher in 2010 and declines to 1.38 higher in 2024.



## **D. Limitation on the introduction of new gas-fired units**

- ✓ D1. Limitation to only 3 combined cycle units per year.
- ✓ D2. Limitation in the supply of natural gas starting in 2010.

## **E. Variation of the discount rate**

- ✓ E1. Real discount rate of 12 % per year.
- ✓ E2. Real discount rate of 8% per year.

## **F. Changes of the System reliability**

- ✓ F1. Loss of load probability of 1 day per year.
- ✓ F2. Loss of load probability of 5 days per year.
- ✓ F3. Decreased cost of energy not served.

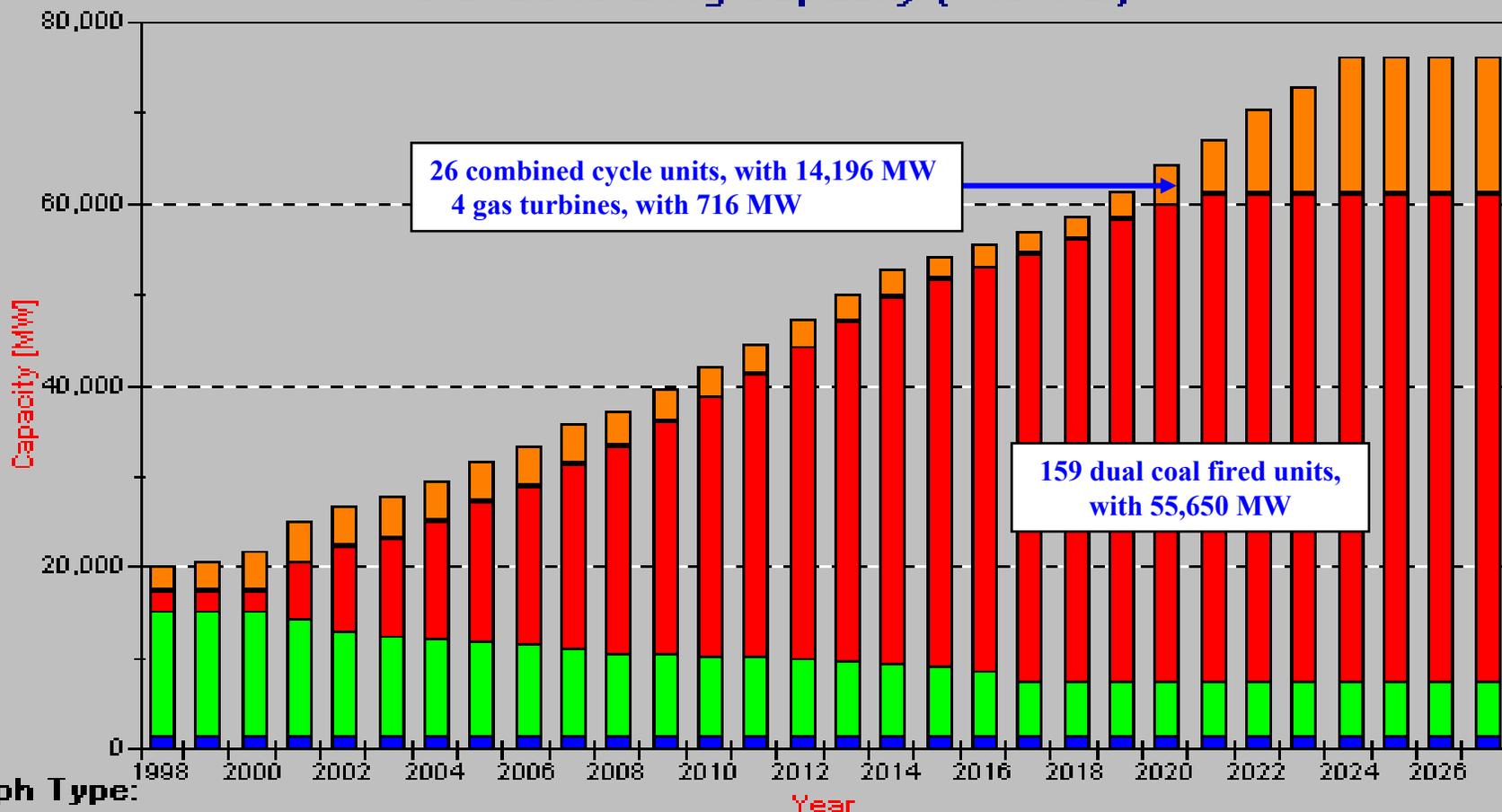
## **H. Introduction of renewal technologies**

- ✓ H2. New solar and wind candidates, which was not evaluated for lack of data in COPAR.



- Relative to the base case, case of high gas prices (C3) has the highest impact in the expansion plan. Total discounted cost increases to 76.3 billion USD.

**Total Generating Capacity (Thermal)**



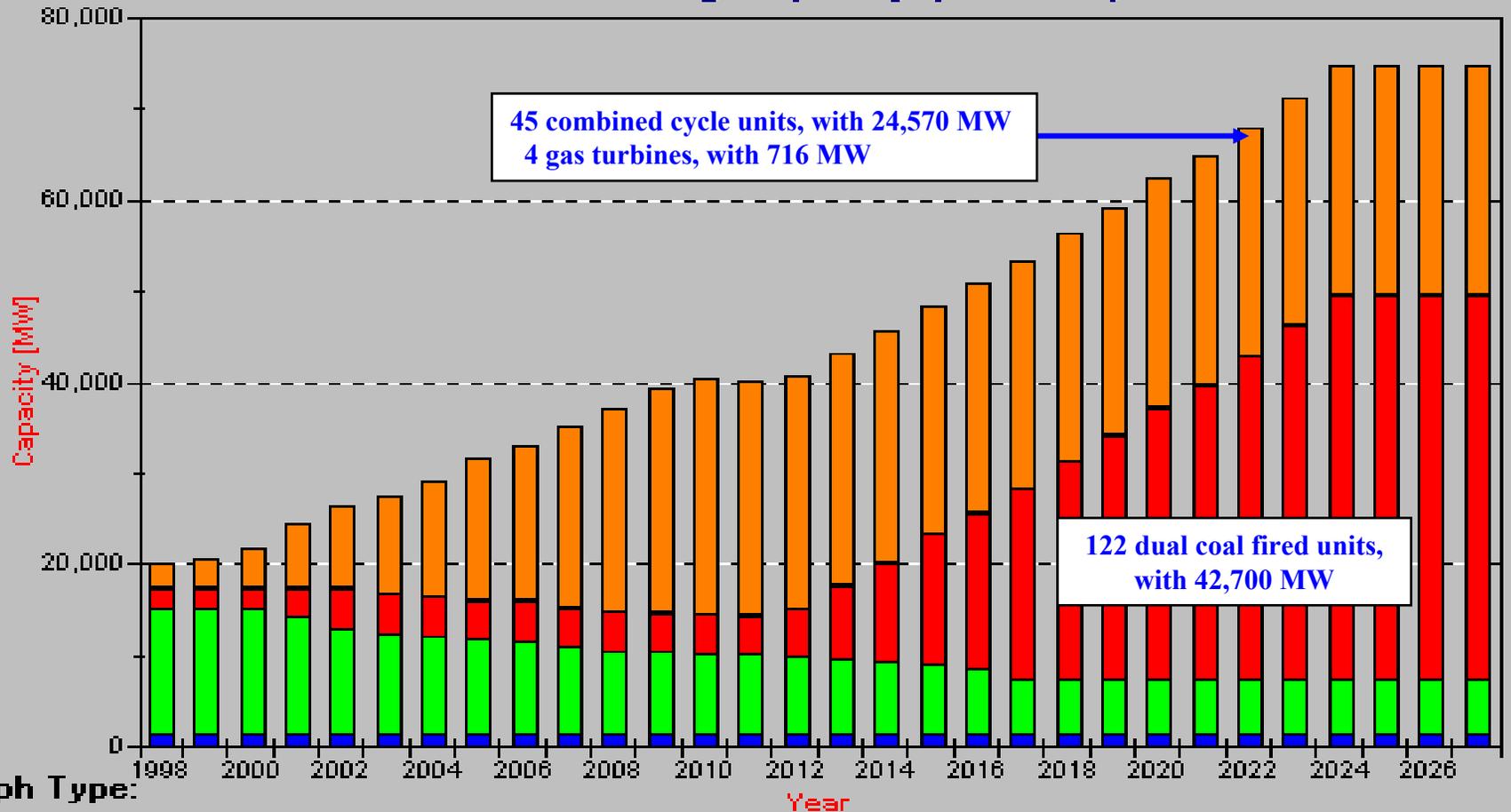
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•Relative to the base case, case of gas supply limitation (D2) decreases 61% the capacity based on natural gas in the expansion plan. Total discounted cost increases to 55.9 billion USD.

### Total Generating Capacity (Thermal)



Graph Type:

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# DECISION ANALYSIS

The decision analysis module (DAM) was used to compare the base case objective function cost, environmental emissions and a parameter called Stirling diversity index with those of Alternatives:

- ✓B2. One forced nuclear plant in 2012
- ✓D1. Limitation to only 3 combined cycle units per year.
- ✓D2. Limitation in the supply of natural gas starting in 2010.
- ✓F1. Loss of load probability of 1 day per year.
- ✓F2. Loss of load probability of 5 days per year.

A range of costs for the emissions taken from the European ExternE study were chosen as follows:

- ✓18-100 USD/ t of CO<sub>2</sub>.
- ✓1,115-3,300 USD/t of SO<sub>2</sub>.
- ✓1,265-3,850 USD/t of NO<sub>x</sub>.
- ✓1,210-5,775 USD/t of TSP.



- If only cost is considered, the decreased reliability case and the base case are the best ones.
- If the emissions costs are included, then the case of forced nuclear and the high reliability case are the best.
- If the diversity index is included, then cases assuming lower shares of gas-fired units become potentially optimal.



# CONCLUSIONS

The main results of the project are:

1. The CSDB was created with a great amount of detailed and complex information.
2. The plant level analysis produced an initial selection of candidate technologies.
3. The fuel chain level analysis was completed (with some difficulties because of the type of information required).



4. The system level analysis was performed successfully for the base case and 13 alternatives.
5. The tools supplied by the IAEA to the Government of Mexico for the project and the CSDB will be very useful for future studies to be done by SENER, CFE, IIE and UNAM.
6. DECADES gave useful information about the optimal expansion plans, taking into account costs, environmental emissions and diversity of the capacity mix.



7. The possibility of increases in natural gas prices or gas supply limitations makes it desirable to consider some diversification using alternative technologies such as coal-fired units, fuel oil units, or nuclear units.
8. The potential of wind and solar energy was not evaluated because of lack of technical and economic information in COPAR. Therefore, it is recommended to include such technologies in COPAR.



# CASES IN MEX/0/012

## OPTIMAL SOLUTION UNTIL 2024

CASE ID	DESCRIPTION	NUC 1356	DUAL 350	C.C. 546	TG 179	HIDA	HIDB	10 <sup>6</sup> t CO <sub>2</sub>	10 <sup>3</sup> t SO <sub>x</sub>	10 <sup>3</sup> t NO <sub>x</sub>	10 <sup>3</sup> t Part	OBJ. FUNC. (M\$98)
106	BASE CASE	0	0	118	6	3	2	195.52	344.00	338.01	16.27	53,124.55
65	HIGH DEMAND Growth 6%	0	0	157	27	3	2	250.86	378.15	409.09	18.33	60232.13
63	LOW NUCLEAR COST - 48 % Investment Costs	5	0	105	9	3	2	177.03	356.58	315.16	17.02	53325.42
74	FORCED NUCLEAR Year 2012	1	0	115	9	3	2	191.96	352.82	333.92	16.80	53530.67
71	SLIGHTLY HIGHER FUEL SCENARIO	0	0	119	4	3	2	195.14	326.41	336.48	15.21	57510.68
78	HIGH SCENARIO FOR GAS 4 \$/tcf	0	0	110	30	3	2	205.33	845.04	361.12	46.44	61907.21
82	MEDIUM-TERM INCR. GAS PRICE 2.88, 12 , 4 \$/tcf	0	159	26	4	3	2	322.60	630.00	1192.42	58.26	76269.05
68	LIMITATION C.C. 3 units year	0	57	85	4	3	2	241.29	444.32	646.08	31.25	54266.12
70	LIMITED GAS Gas supply is limited (2010)	0	122	45	4	6	2	293.37	590.39	998.76	50.22	55870.5
58	DISCOUNT RATE 12%	0	0	118	5	3	2	195.52	344.01	338.02	16.27	44714.56
31	DISCOUNT RATE 8%	0	0	118	8	3	2	195.52	343.63	337.94	16.25	64346.51
73	INCREASED RELIABILITY 1 day/year, ENSC = 13 \$/kWh	0	0	119	15	3	2	195.16	327.00	336.35	15.24	53230.12
66	DECREASED RELIABILITY 5 days/year, ENSC = 0.55 \$/kWh	0	0	116	4	3	2	196.52	394.93	341.22	19.34	53089.17
77	DECREASED RESERVE MARGIN ENSC = 0.25 \$/kWh	0	0	113	4	3	2	198.12	476.82	346.29	24.29	53056.69