Energy/Environmental Modeling With the MARKAL Family of Models

Ad J. Seebregts
Energy research Centre of the Netherlands (ECN)
Gary A. Goldstein
International Resources Group Ltd. (IRG), Washington DC

September 4 2001
Duisburg, Germany

Contents

- Overview MARKAL
- Questions answered by MARKAL (examples)
- Future developments
- Conclusion

MARKAL

- **MARK**et **AL**location
- Long-term, Technology-based Optimisation Model
- Development started in early 1980's
- MARKAL "*most widely used...*":
  more than 80 users in about 40 countries
- Supported, developed and maintained in IEA's ETSAP :
  Energy **T**echnology **S**ystem **A**nalysis **P**rogramme

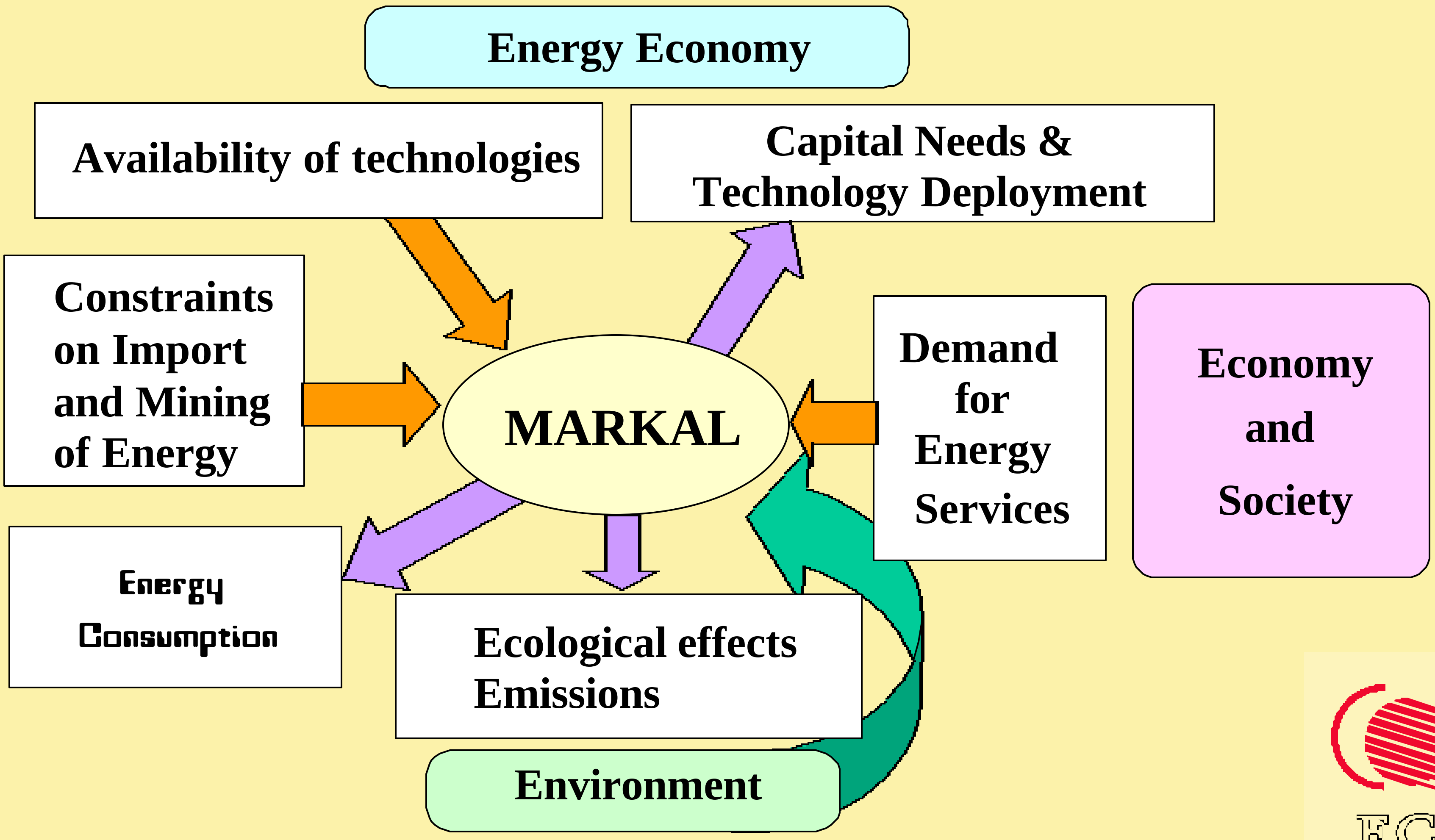
ECN IRG

ETSAP

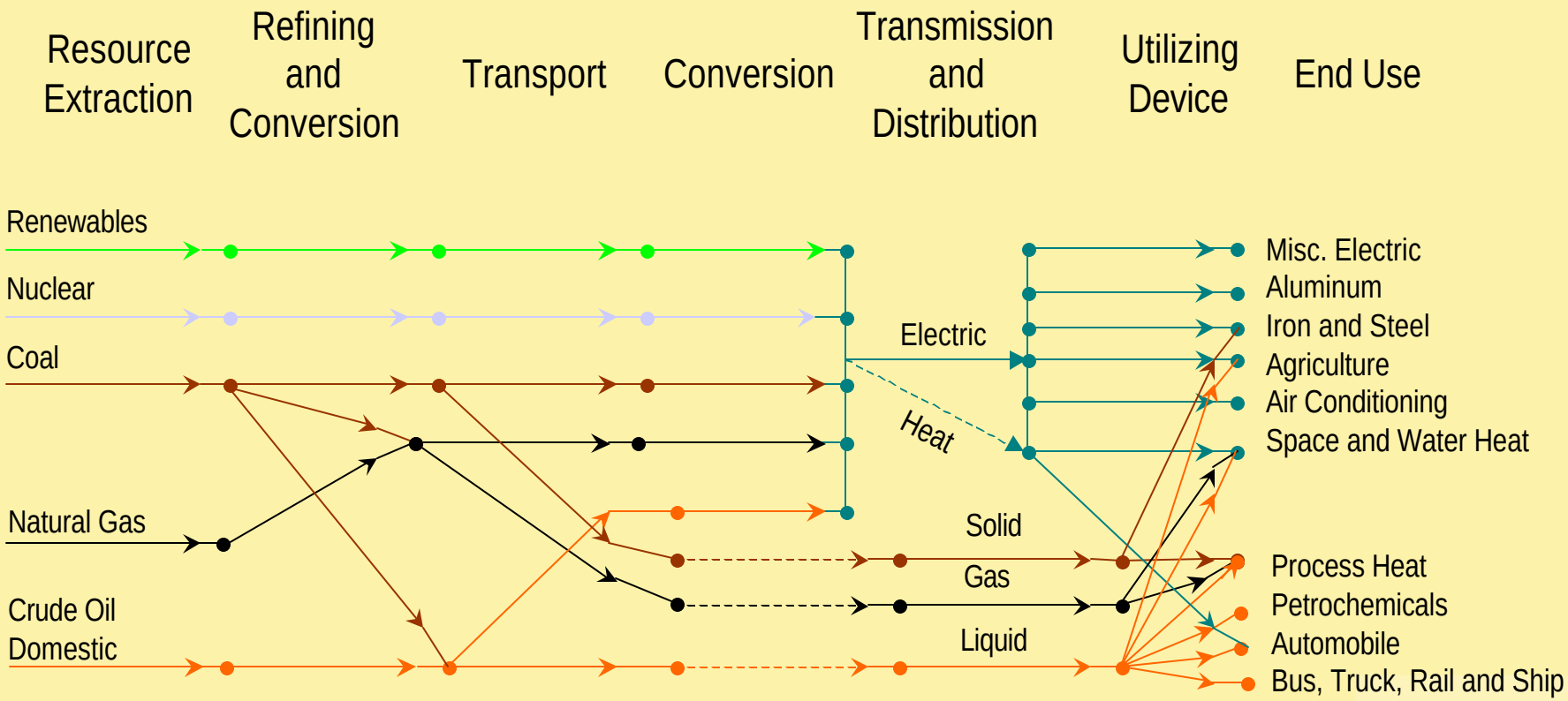
- Cooperative programme under IEA/OECD research agreement, 15 partners
- ECN is Operating Agent for ETSAP
- IRG subcontracted as primary software coordinator for MARKAL
- Own ETSAP website : http://www.ecn.nl/unit_bs/etsap/main.html
  - reports & information, activities, partners

ECN IRG

MARKAL Model Structure



Simplified Reference Energy System



ECN IRG

‘Standard’ MARKAL (LP)

- Technology process model
- Comprehensive energy sector (supply, conversion, distribution, end-use)
- Exogenous demands for energy services
- Competitive equilibrium (least-cost)
- Dynamic, perfect foresight, deterministic
- In GAMS; Windows user interface ANSWER

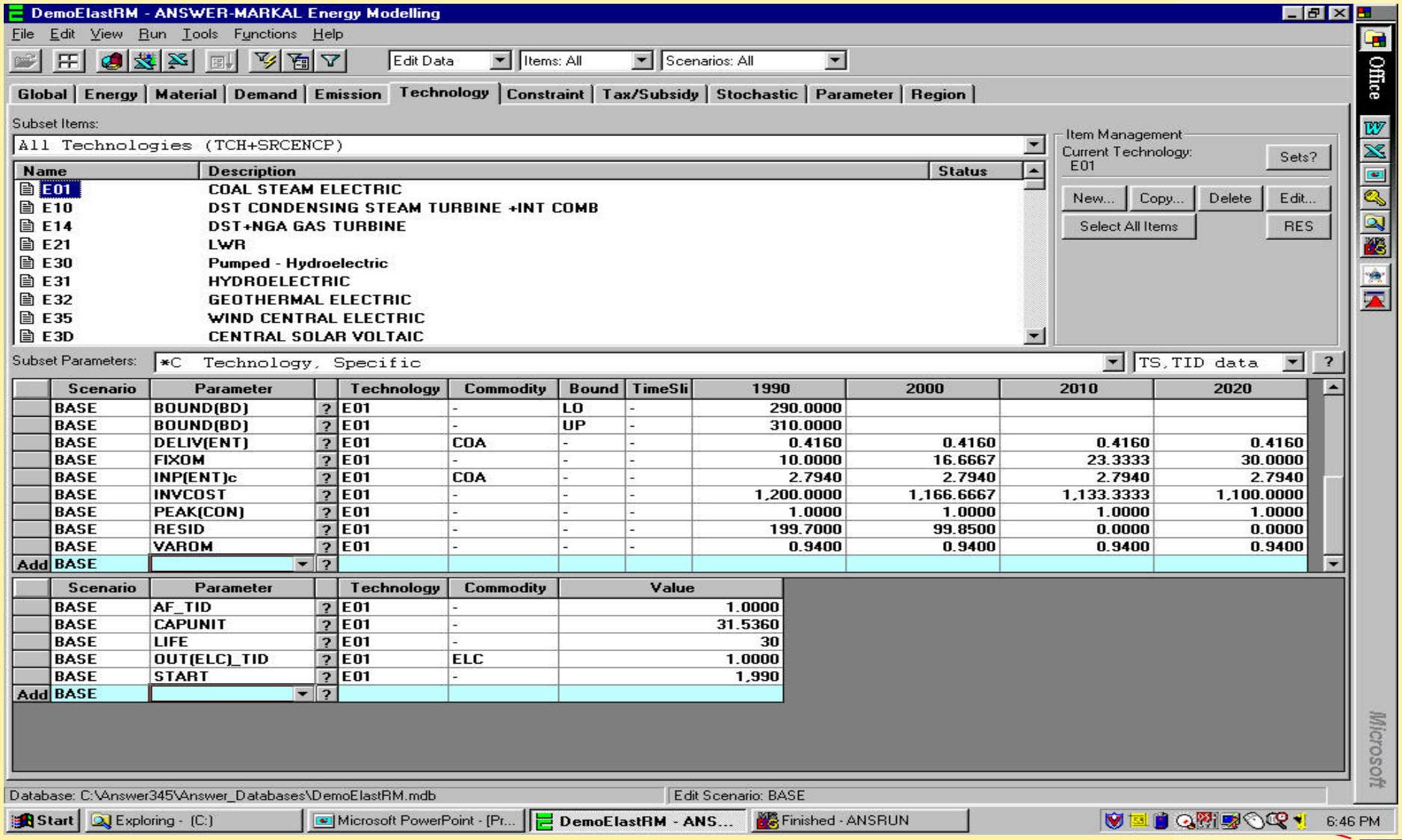
ECN IRG

MARKAL database

- Global economic parameters (discount rates, monetary units,…)
- End Use Demands (exogenous or endogenous)
- Technology data : technical (efficiency, fuels, lifetime ,…) and economic (investment costs, operating costs,…)
- Fuel data : availability, cost, ...
- Emission factors : fuel related like CO_2 and SO_2 or technology related like NO_x and PM
- User defined constraints

ECN IRG

ANSWER User interface (1)



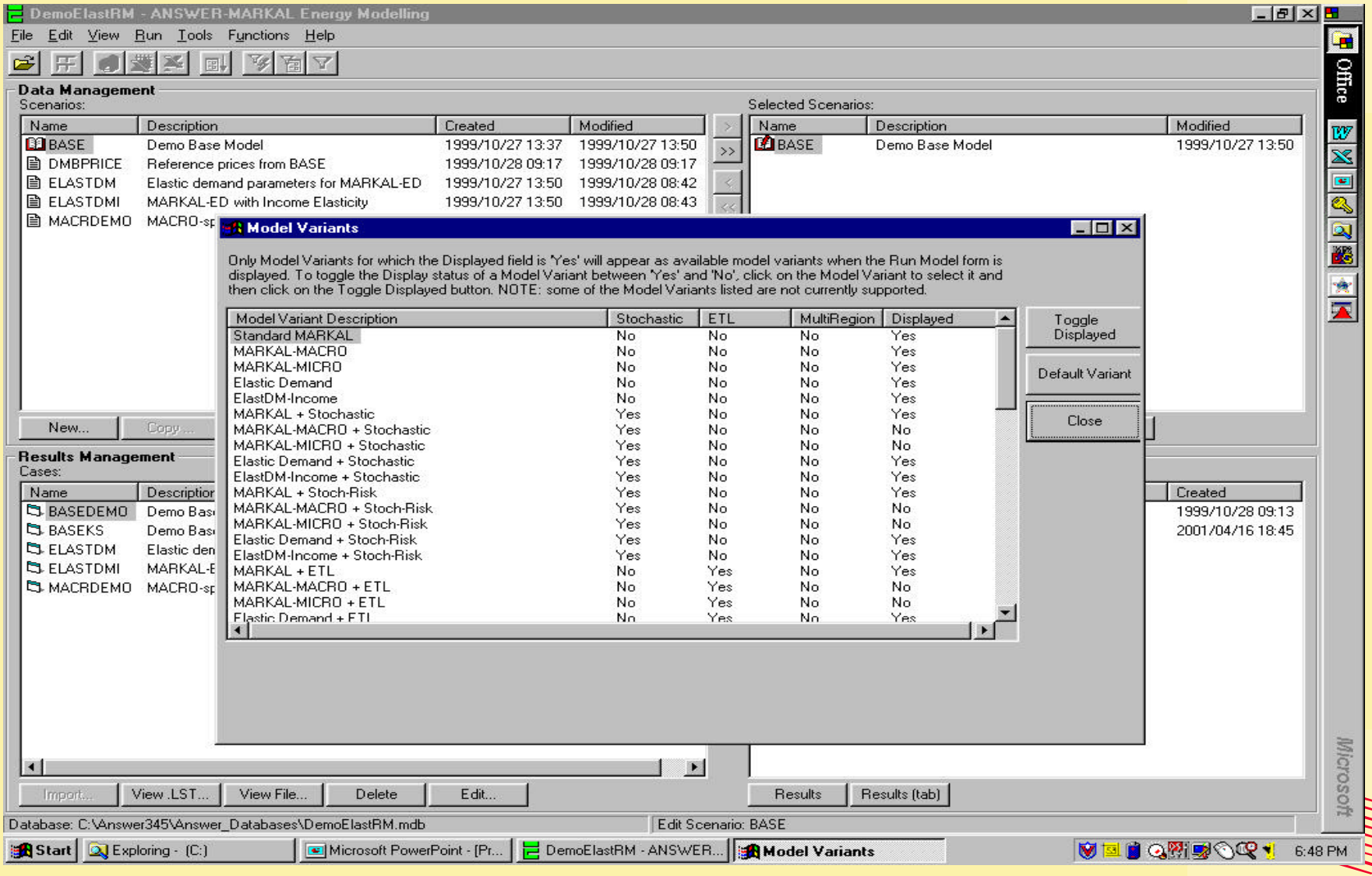
ECN IRG

MARKAL developments ('90's)
Family of Models

- Economic Interactions:
  - MARKAL-MACRO: Hard link with (simple) economic neoclassical growth model (*NLP*)
  - MARKAL-MICRO (*NLP*) /MARKAL-ED (*LP*): Own price (and cross-price) elasticities for demands
- Material Flows
- Multi-region (*NLP/LP*) incl. trade
- Stochastic, hedging strategies (*2-stage SP*)
- Endogenous Technology Learning (*MIP*)

ECN IRG

ANSWER User interface (2)



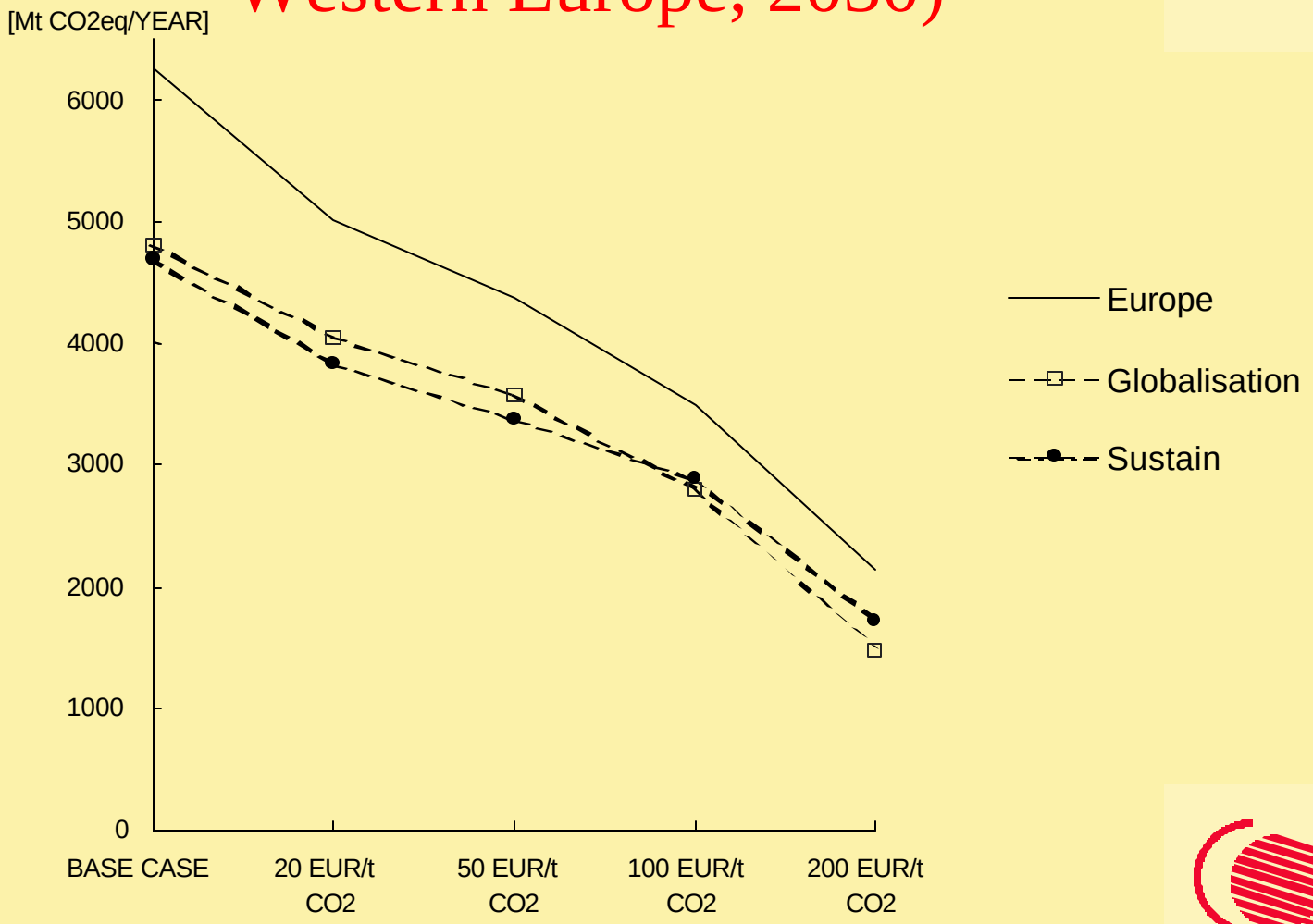
ECN IRG

Questions Answered by MARKAL

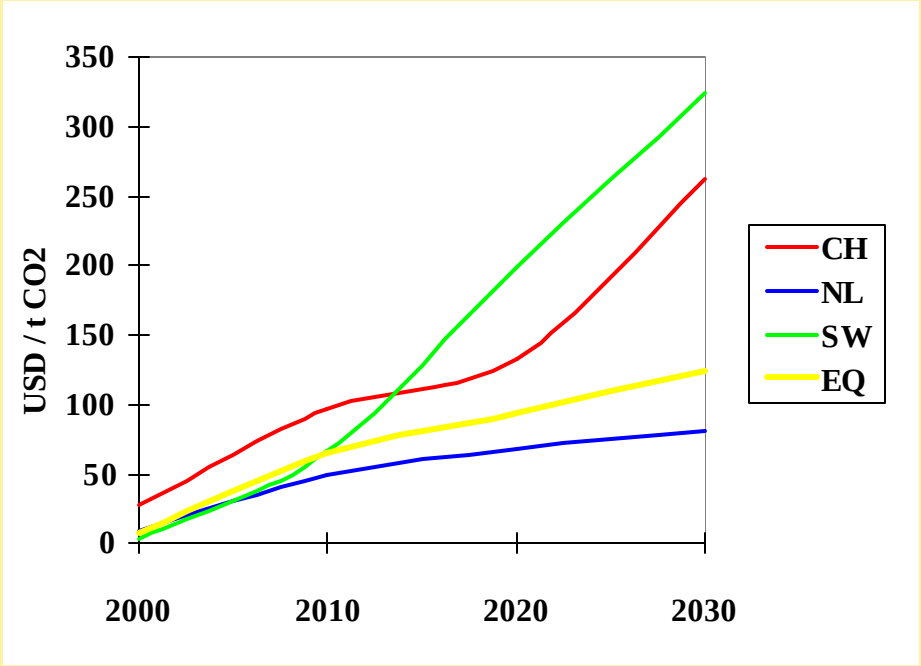
- How do particular technologies and policies affect GHG and emissions of other pollutants?
- What is the effect of market based instruments?
- How do demand-side actions affect the supply-side and vice versa?
- What are the benefits of cooperation mechanisms?
- How to model technology dynamics and the impact of R&D

ECN IRG

Example 1: Emission reduction (MARKAL-ED, Western Europe, 2030)



Example 2: Emission trading (MARKAL multi-region)



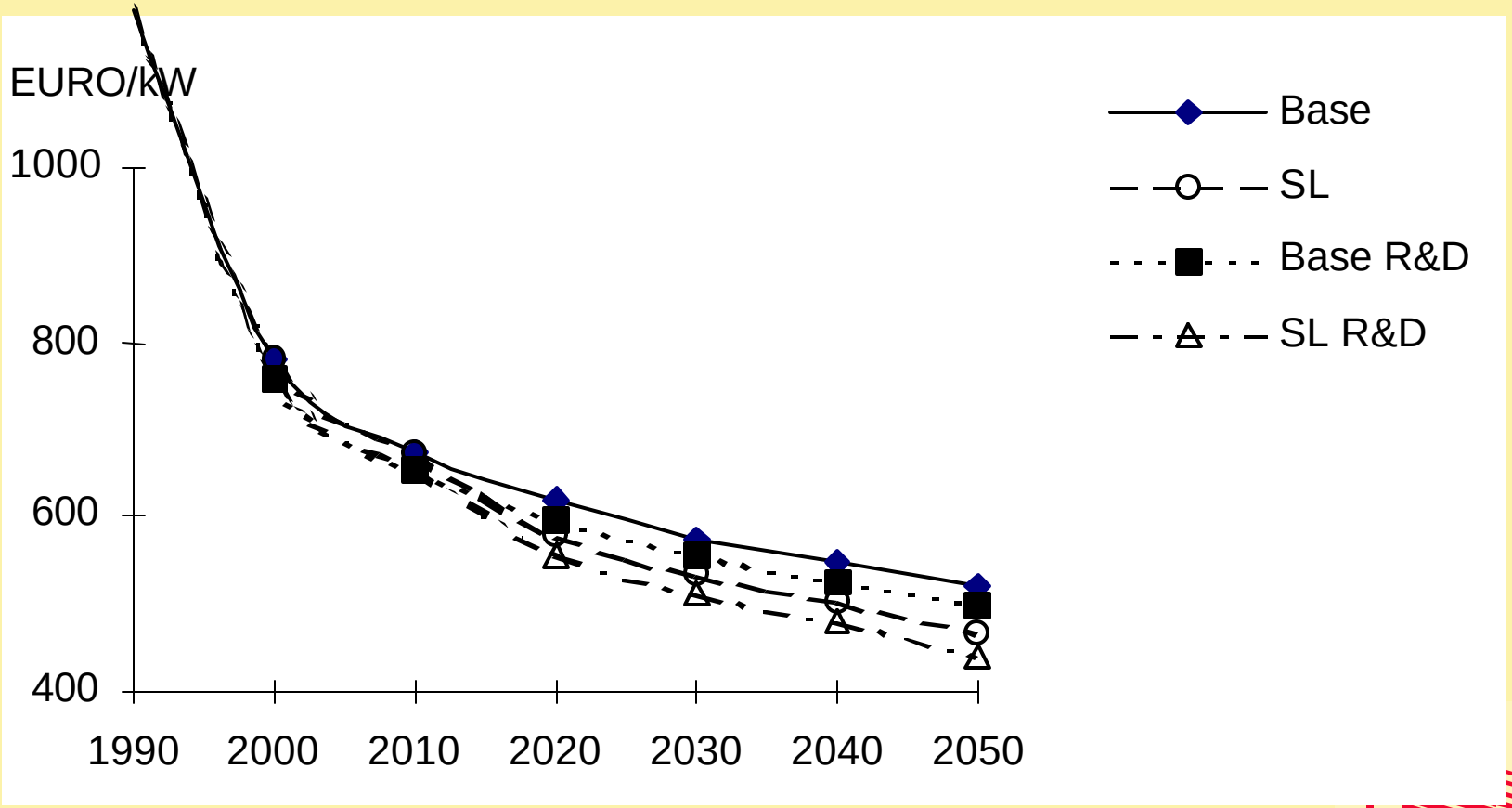
Undiscounted marginal reduction costs & permit prices

Scenario	Country	2000	2010	2020	2030
-20%	CH	-0.8	-1.5	-1.7	-3.7
	NL	-0.6	4.6	12.2	25.5
	SW	1.4	-3.2	-10.8	-22.2

Net export of CO_2 permits (Mt/year)

ECN IRG

Example 3: Technology dynamics/R&D (MARKAL ETL, wind energy, Western Europe)



Recent/Future developments

- TIMES (see next presentation MESAP/TIMES) and new user shells
- Goal Programming, MARKAL_Timestep
- Monte Carlo

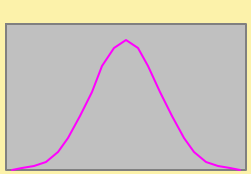
ECN IRG

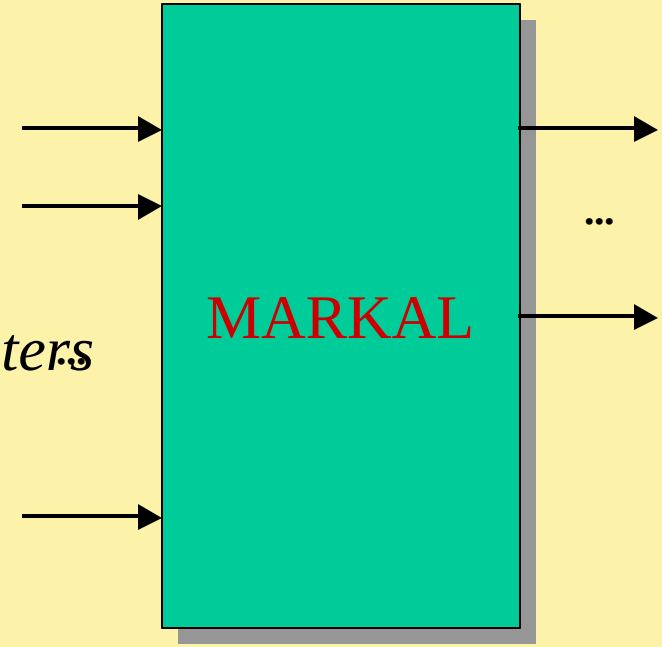
Why Monte Carlo simulation?

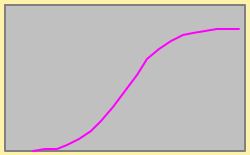
- Explore uncertainty in full-size model, with focus on data uncertainties
- Role complementary to usual way of scenario analysis, sensitivity analysis, cost-benefit analysis, stochastic programming?
- Tested for MARKAL ETL, Western Europe, 1990-2050

ECN IRG

Monte Carlo: principle







Uncertain parameters
(distribution)

Endpoints, selected results
(distribution, importance measures, Tornado diagram)

ECN IRG

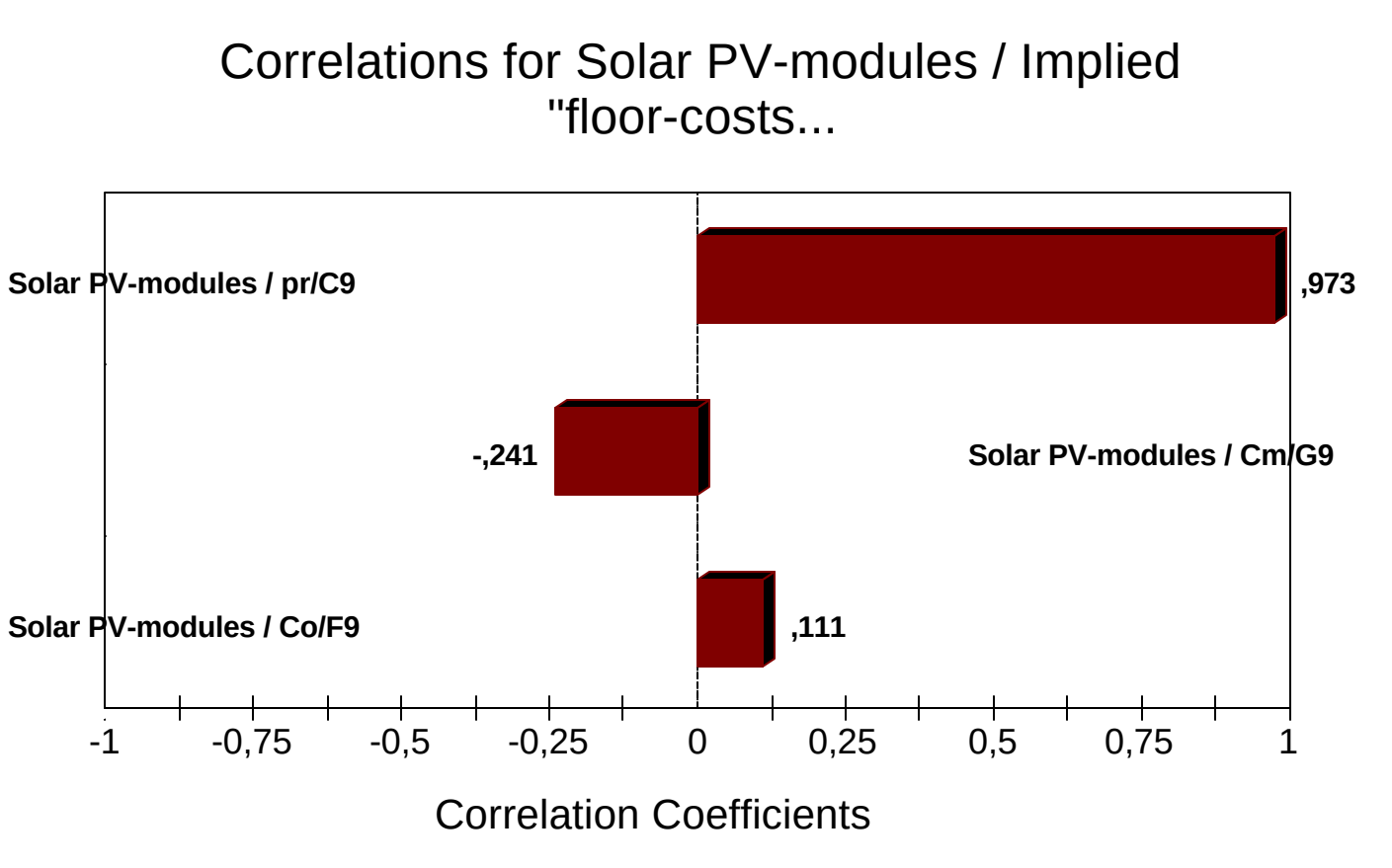
Monte Carlo output (1): spread in results of selected endpoints

Marginal Cost of CO_2 [€/ton]

	2030	2040	2050
Minimum	52	56	91
5^{th}- percentile	53	59	91
Mean	63	66	94
95^{th}-percentile	67	75	98
Maximum	67	76	99

ECN IRG

Monte Carlo output (2): Tornado diagram



Monte Carlo and MARKAL: first conclusions

- 100 runs feasible in terms of solution time

  'slow' 400 MHz PC: 15-24 hours, MARKAL ETL (MIP) for Western Europe

- Sufficient number to get spread in results and relative importance of uncertainties

- Based on soft-linkage to @Risk (Excel add-on): more experience needed to make it a 'member'

ECN IRG

Conclusions

- MARKAL family of models most widely used energy system analysis models
- Powerful tool, still evolving, to address new environmental issues (e.g. arising from Kyoto Protocol)
- TIMES will be the next generation tool

ECN IRG