

Energy/Environmental Modeling With the MARKAL Family of Models

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Contents

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



MARKAL

- MARKet ALlocation
- 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

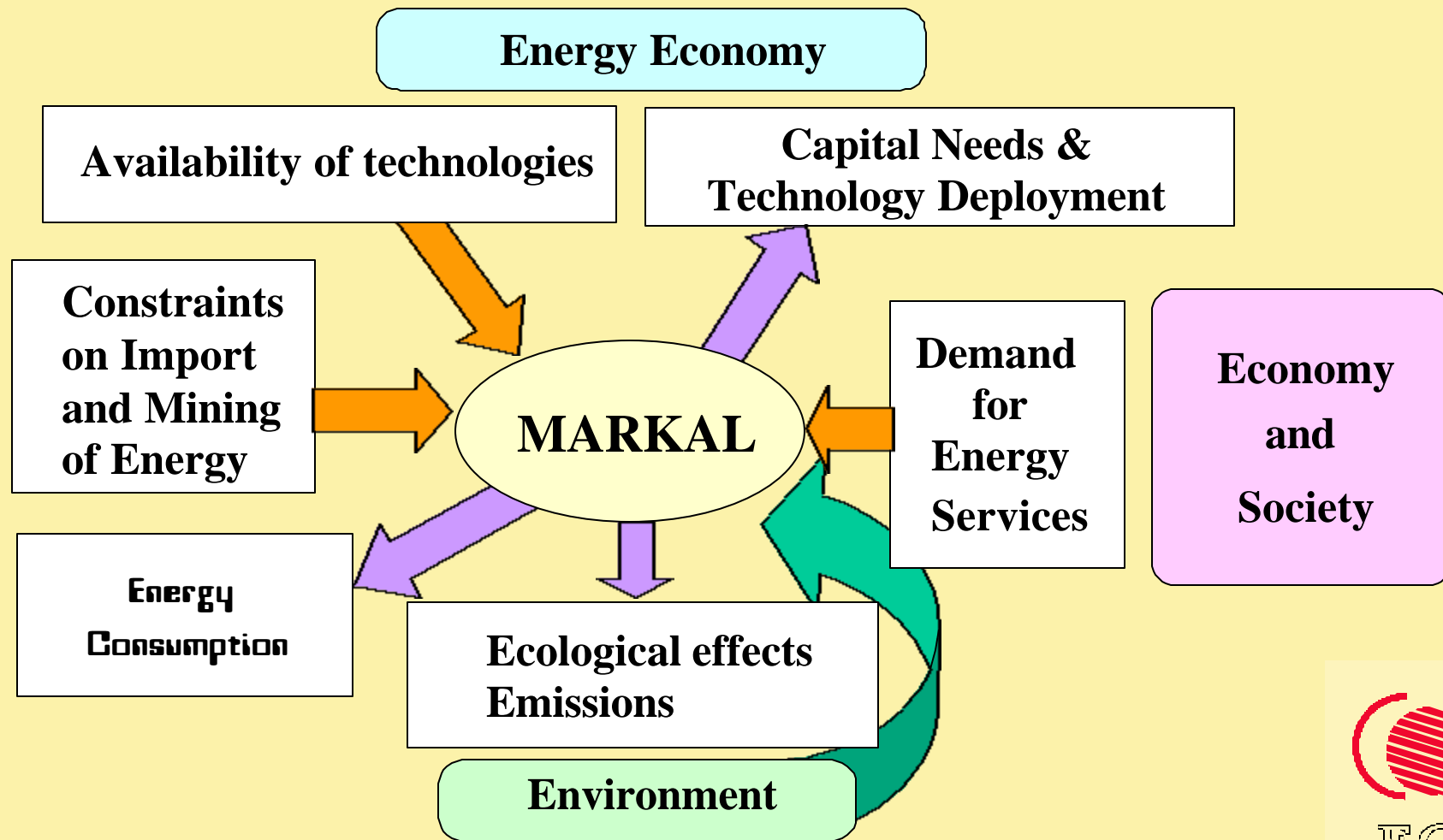


ETSAP

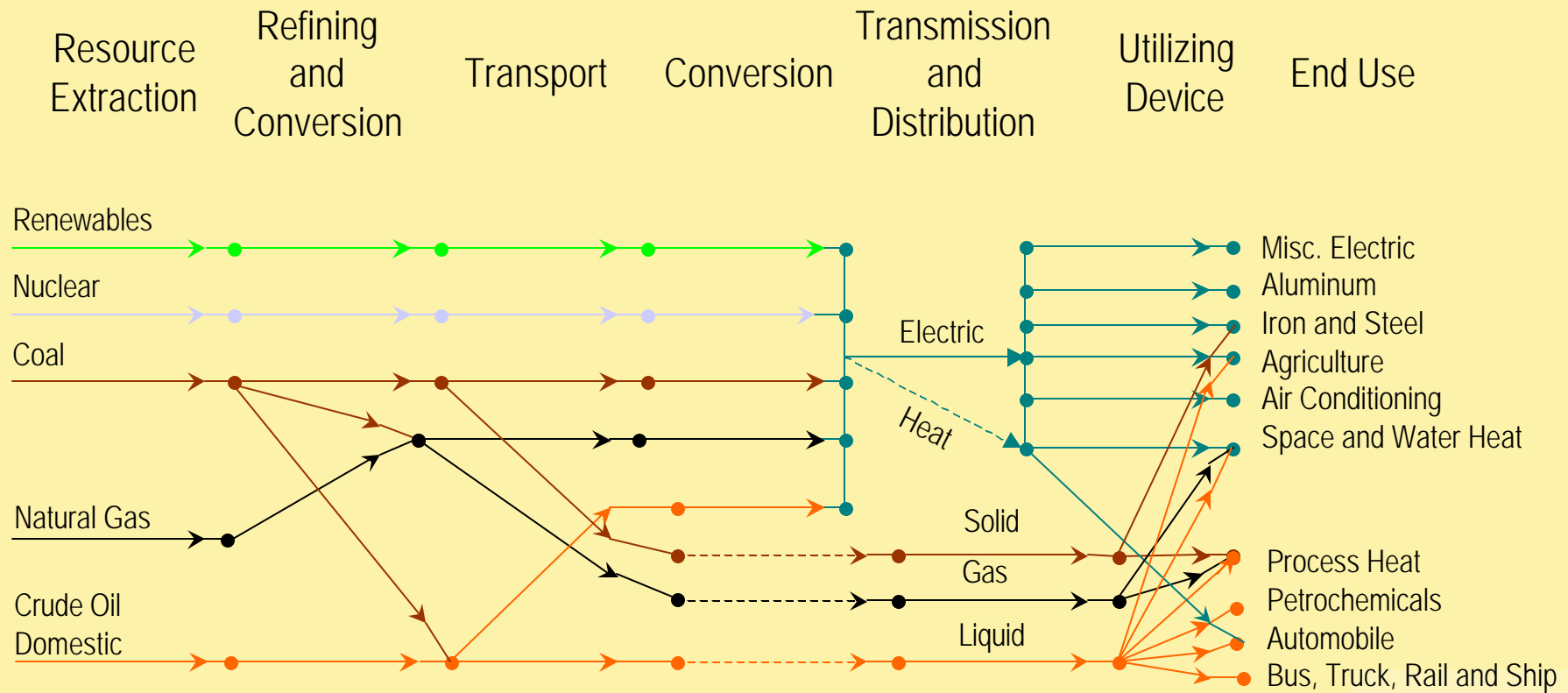
- Cooperative programme under IEA/OECD research agreement, 15 partners
- ECN is Operating Agent for ETSAP
- IRG subcontracted as primary software coordinator for MARKAL
- Own ETSAP website :
http://www.ecn.nl/unit_bs/etsap/main.html
– reports & information, activities, partners



MARKAL Model Structure



Simplified Reference Energy System



‘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



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 CO₂ and SO₂ or technology related like NO_x and PM
- User defined constraints



ANSWER User interface (1)

DemoElastRM - ANSWER-MARKAL Energy Modelling

File Edit View Run Tools Functions Help

Edit Data Items: All Scenarios: All

Global Energy Material Demand Emission Technology Constraint Tax/Subsidy Stochastic Parameter Region

Subset Items: All Technologies (TCH+SRCENCP)

Name	Description	Status
E01	COAL STEAM ELECTRIC	
E10	DST CONDENSING STEAM TURBINE +INT COMB	
E14	DST+NGA GAS TURBINE	
E21	LWR	
E30	Pumped - Hydroelectric	
E31	HYDROELECTRIC	
E32	GEOTHERMAL ELECTRIC	
E35	WIND CENTRAL ELECTRIC	
E3D	CENTRAL SOLAR VOLTAIC	

Item Management
Current Technology: E01
Sets?
New... Copy... Delete Edit...
Select All Items RES

Subset Parameters: *C Technology Specific TS, TID data ?

Scenario	Parameter	Technology	Commodity	Bound	TimeSli	1990	2000	2010	2020
BASE	BOUND(BD)	? E01	-	LO	-	290.0000			
BASE	BOUND(BD)	? E01	-	UP	-	310.0000			
BASE	DELIV(ENT)	? E01	COA	-	-	0.4160	0.4160	0.4160	0.4160
BASE	FIXOM	? E01	-	-	-	10.0000	16.6667	23.3333	30.0000
BASE	INP(ENT)c	? E01	COA	-	-	2.7940	2.7940	2.7940	2.7940
BASE	INVCOST	? E01	-	-	-	1,200.0000	1,166.6667	1,133.3333	1,100.0000
BASE	PEAK(CON)	? E01	-	-	-	1.0000	1.0000	1.0000	1.0000
BASE	RESID	? E01	-	-	-	199.7000	99.8500	0.0000	0.0000
BASE	VAROM	? E01	-	-	-	0.9400	0.9400	0.9400	0.9400
Add	BASE	?							

Scenario	Parameter	Technology	Commodity	Value
BASE	AF_TID	? E01	-	1.0000
BASE	CAPUNIT	? E01	-	31.5360
BASE	LIFE	? E01	-	30
BASE	OUT(ELC)_TID	? E01	ELC	1.0000
BASE	START	? E01	-	1.990
Add	BASE	?		

Database: C:\Answer345\Answer_Databases\DemoElastRM.mdb Edit Scenario: BASE

Start Exploring - (C:) Microsoft PowerPoint - [Pr... DemoElastRM - ANS... Finished - ANSRUN 6:46 PM

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*)



ANSWER User interface (2)

Data Management

Scenarios:

Name	Description	Created	Modified
BASE	Demo Base Model	1999/10/27 13:37	1999/10/27 13:50
DMBPRICE	Reference prices from BASE	1999/10/28 09:17	1999/10/28 09:17
ELASTDM	Elastic demand parameters for MARKAL-ED	1999/10/27 13:50	1999/10/28 08:42
ELASTDMI	MARKAL-ED with Income Elasticity	1999/10/27 13:50	1999/10/28 08:43
MACRDEMO	MACRO-sp		

Selected Scenarios:

Name	Description	Modified
BASE	Demo Base Model	1999/10/27 13:50

Model Variants

Only Model Variants for which the Displayed field is 'Yes' will appear as available model variants when the Run Model form is displayed. To toggle the Display status of a Model Variant between 'Yes' and 'No', click on the Model Variant to select it and then click on the Toggle Displayed button. NOTE: some of the Model Variants listed are not currently supported.

Model Variant Description	Stochastic	ETL	MultiRegion	Displayed
Standard MARKAL	No	No	No	Yes
MARKAL-MACRO	No	No	No	Yes
MARKAL-MICRO	No	No	No	Yes
Elastic Demand	No	No	No	Yes
ElastDM-Income	No	No	No	Yes
MARKAL + Stochastic	Yes	No	No	Yes
MARKAL-MACRO + Stochastic	Yes	No	No	No
MARKAL-MICRO + Stochastic	Yes	No	No	No
Elastic Demand + Stochastic	Yes	No	No	Yes
ElastDM-Income + Stochastic	Yes	No	No	Yes
MARKAL + Stoch-Risk	Yes	No	No	Yes
MARKAL-MACRO + Stoch-Risk	Yes	No	No	No
MARKAL-MICRO + Stoch-Risk	Yes	No	No	No
Elastic Demand + Stoch-Risk	Yes	No	No	Yes
ElastDM-Income + Stoch-Risk	Yes	No	No	Yes
MARKAL + ETL	No	Yes	No	Yes
MARKAL-MACRO + ETL	No	Yes	No	No
MARKAL-MICRO + ETL	No	Yes	No	No
Elastic Demand + ETL	No	Yes	No	Yes

Results Management

Cases:

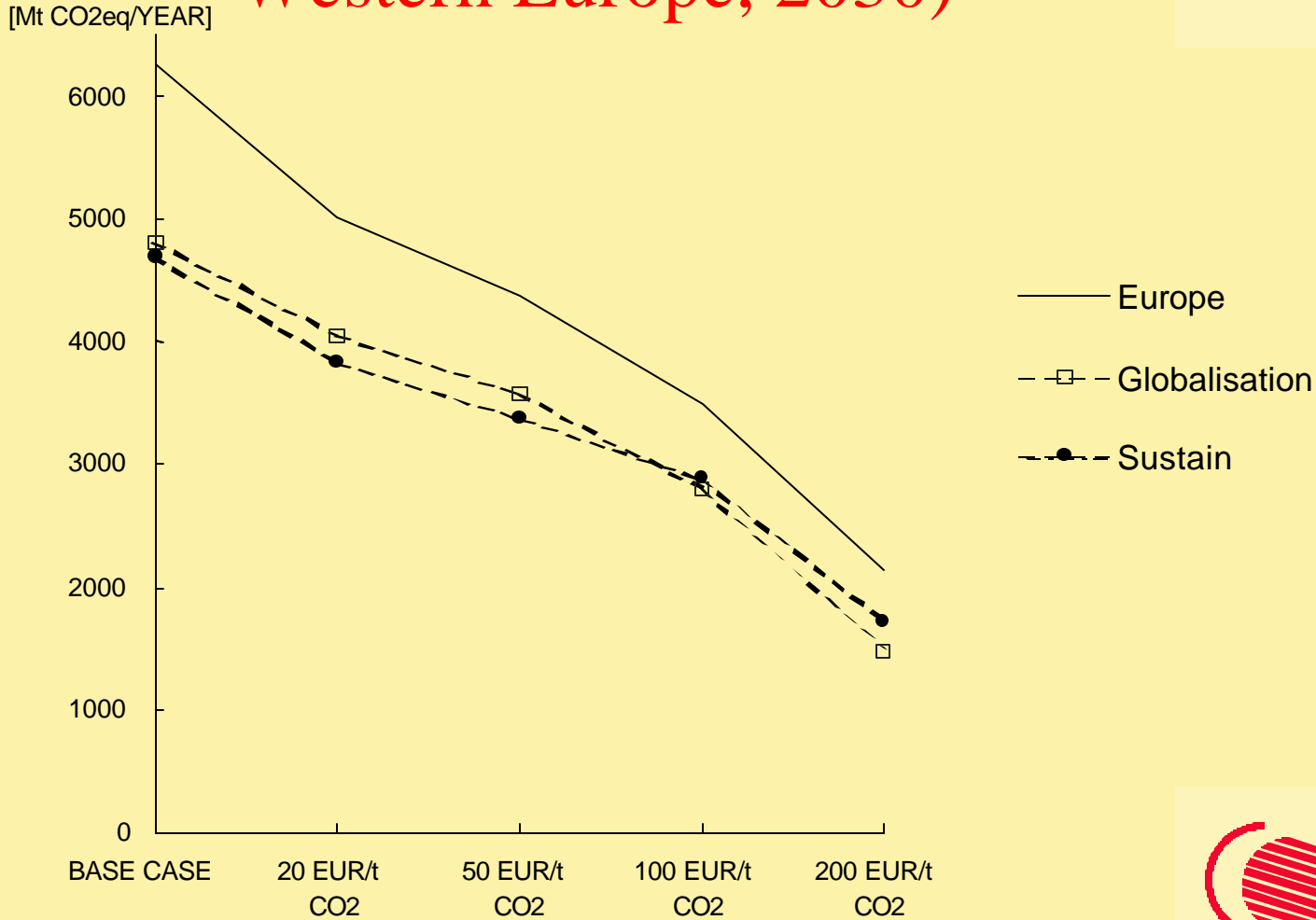
Name	Description	Created
BASEDEMO	Demo Bas	1999/10/28 09:13
BASEKS	Demo Bas	2001/04/16 18:45
ELASTDM	Elastic den	
ELASTDMI	MARKAL-E	
MACRDEMO	MACRO-sp	

Database: C:\Answer345\Answer_Databases\DemoElastRM.mdb | Edit Scenario: BASE

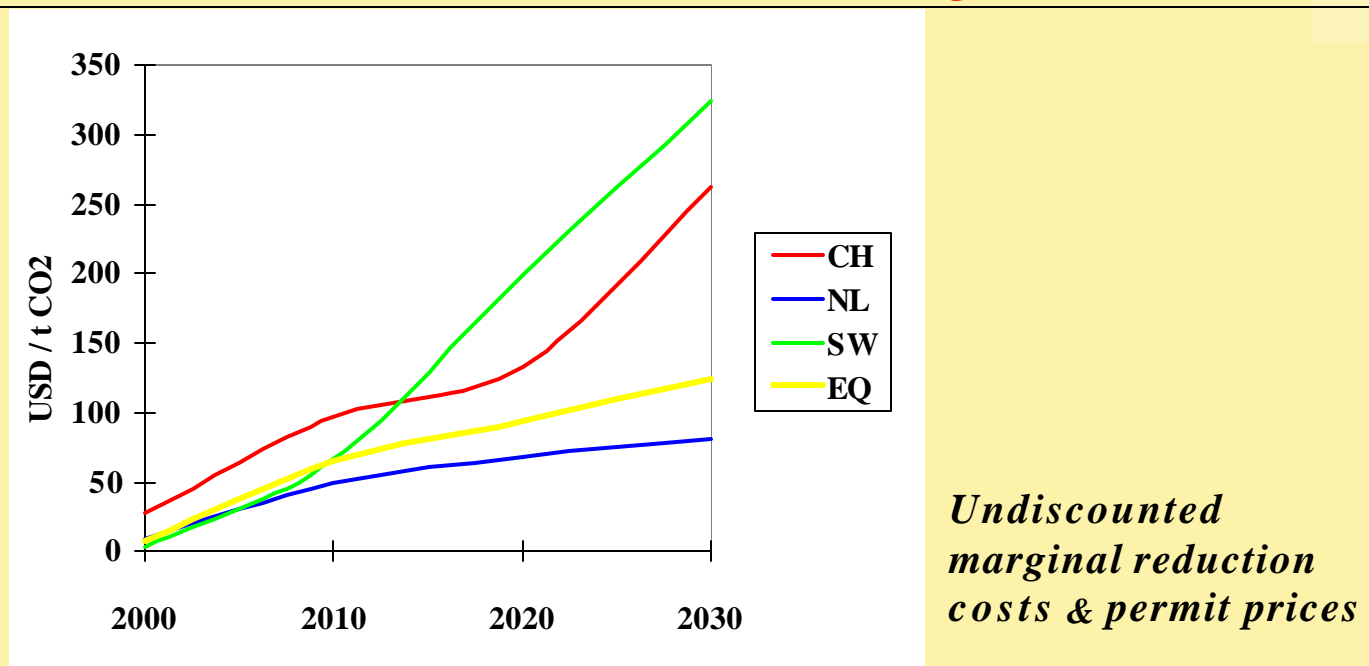
Questions Answered by MARKAL

- 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

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



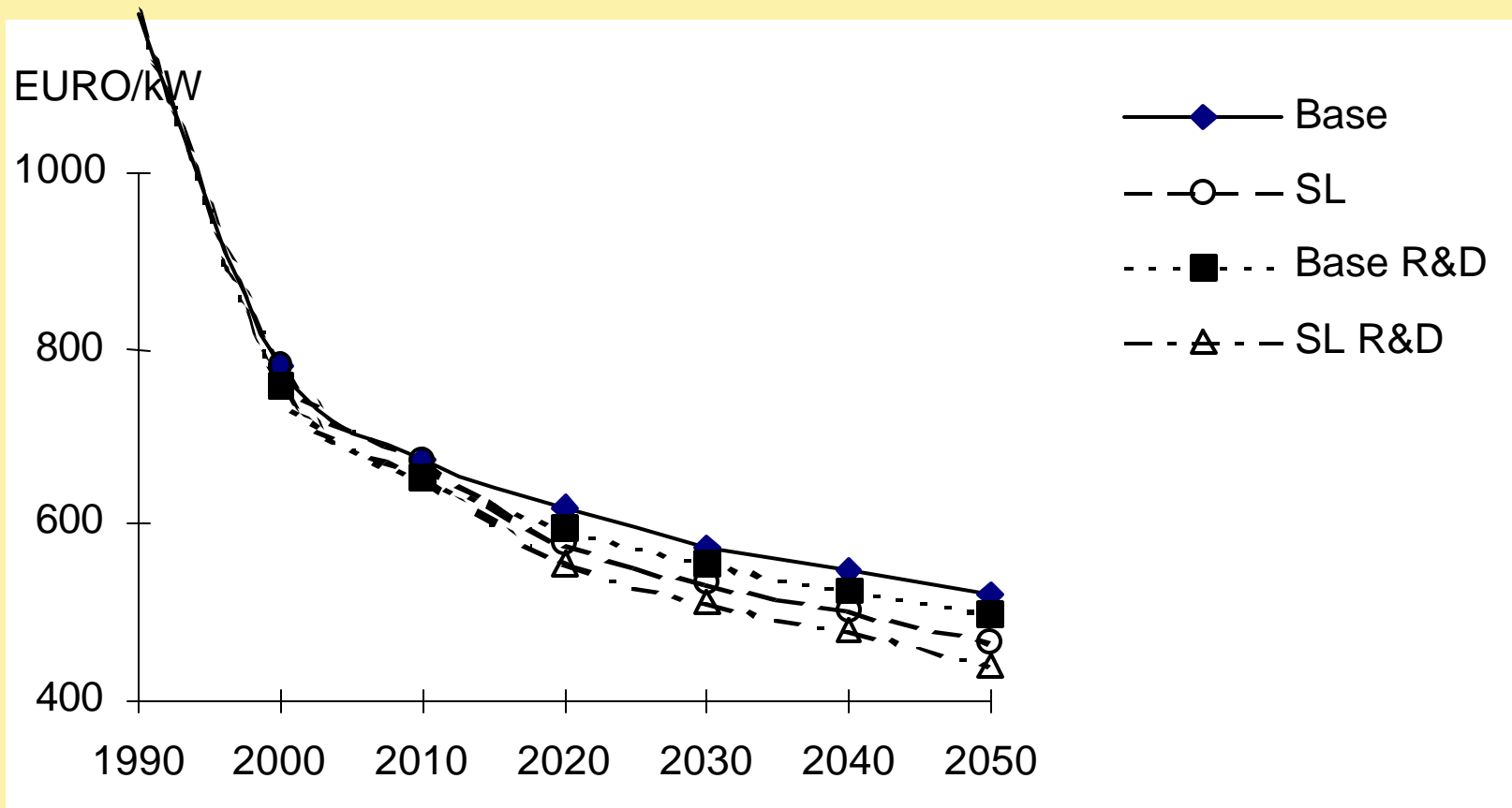
Example 2: Emission trading (MARKAL multi-region)



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 CO₂ permits (Mt/year)

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

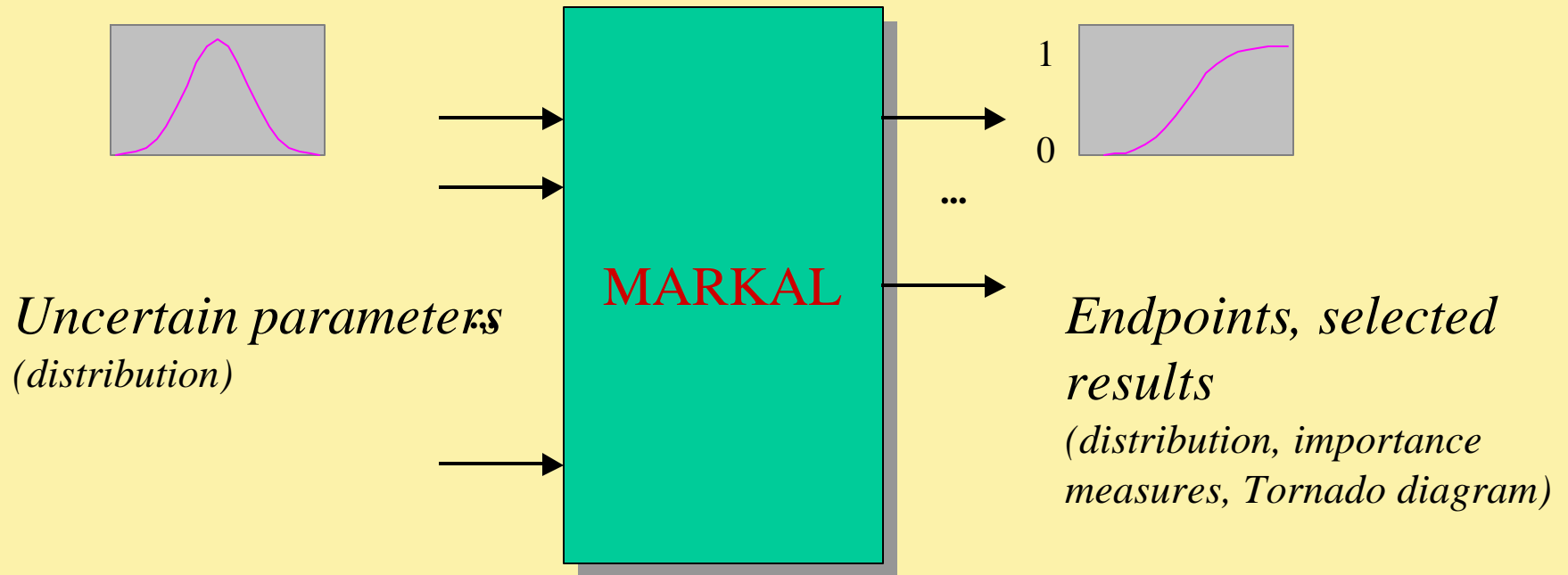


Why Monte Carlo simulation?

- 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



Monte Carlo: principle



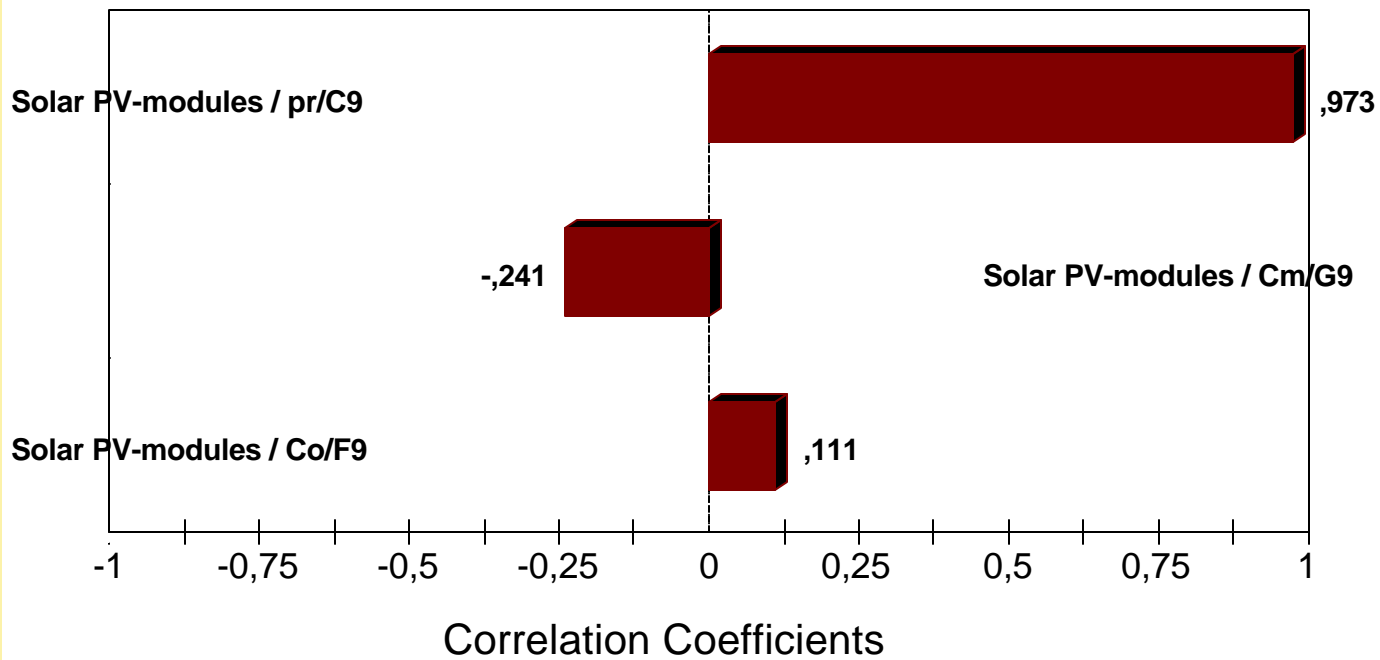
Monte Carlo output (1): spread in results of selected endpoints

Marginal Cost of CO₂ [€/ton]

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

Monte Carlo output (2): Tornado diagram

Correlations for Solar PV-modules / Implied
"floor-costs..."



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’



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

