Assessing Energy/Economy/Environment Interaction Using the MARKAL Family of Models

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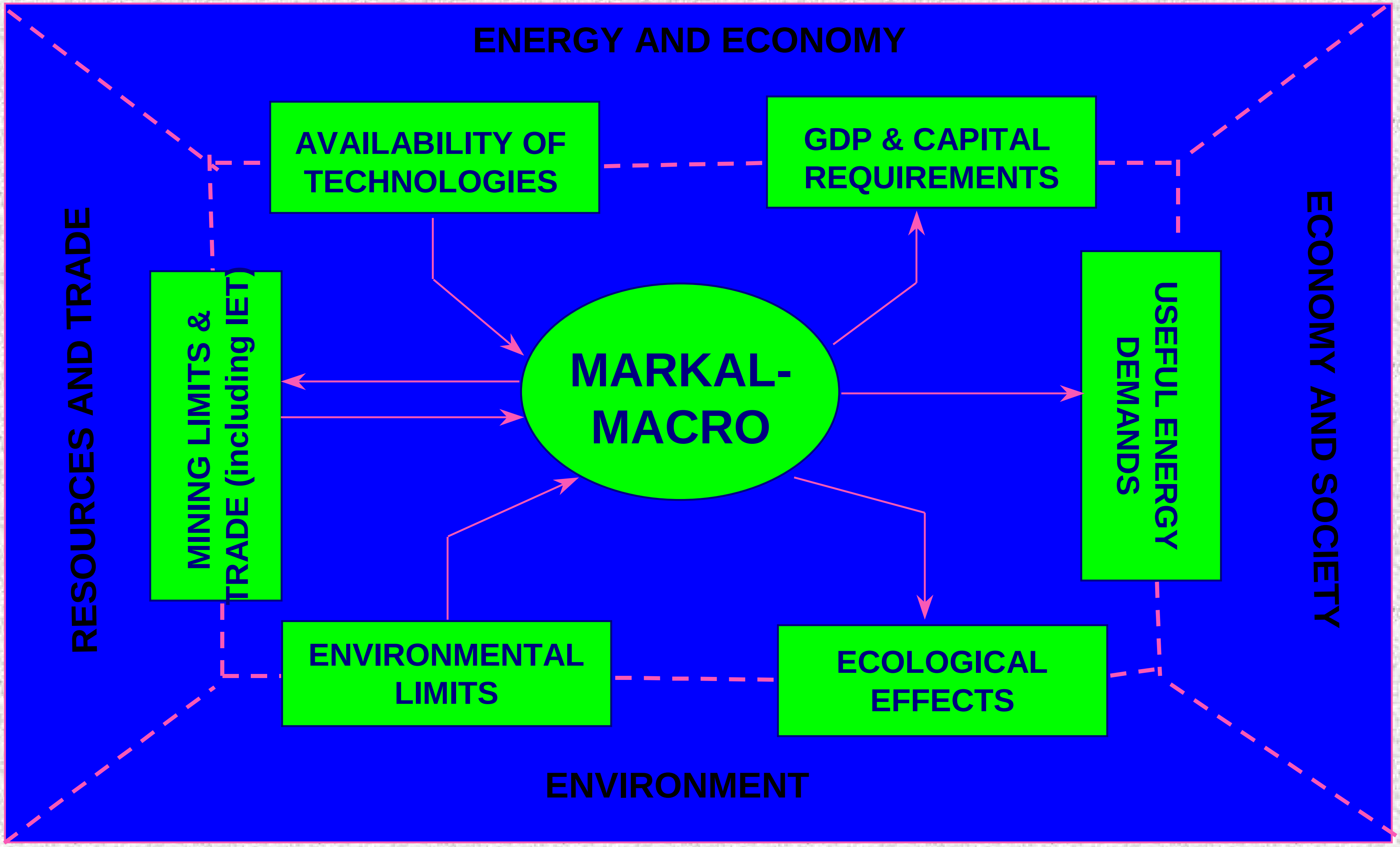
Presentation Topics

- What is MARKAL-MACRO
- Areas of Application
- Case Studies: Global Climate Change

What is MARKAL

- An integrated energy/economy/environment optimization modeling framework used to
  - assess the least-cost evolution of energy systems over a 20-50 year time horizon
  - identify key technologies for promoting environmentally responsible sustainable development
  - evaluate the implications of Global Climate Change (GCC) deliberations and policies
- A highly interactive database and modeling environment tailored for use by a wide range of individuals around the world
- A product of long-standing and ongoing international cooperation under the auspices of the International Energy Agency

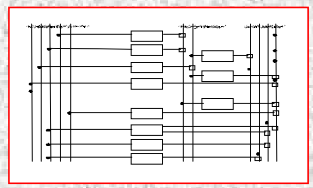
Assessing Energy, Economy, Environment & Trade Interactions



<u>Components of MARKAL</u>

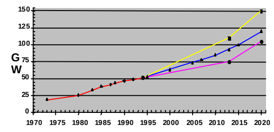
Components of an Energy System Model

* Energy system topology & organization



RES

* Numerical data



Time Series

* Mathematical structure
  - transformation equations
  - bounds, constraints
  - user defined relations

$$P_{BHKW\_S} = \eta_{BHKW} \cdot P_{Coal\_BHKW}$$
$$O_{BHKW\_CO_2} = \varepsilon \cdot P_{Coal\_BHKW}$$
$$Q_{BHKW\_H} = \eta_{2\_BHKW} \cdot P_{Coal\_BHKW}$$

GAMS Model

* Scenarios and strategies

Cases

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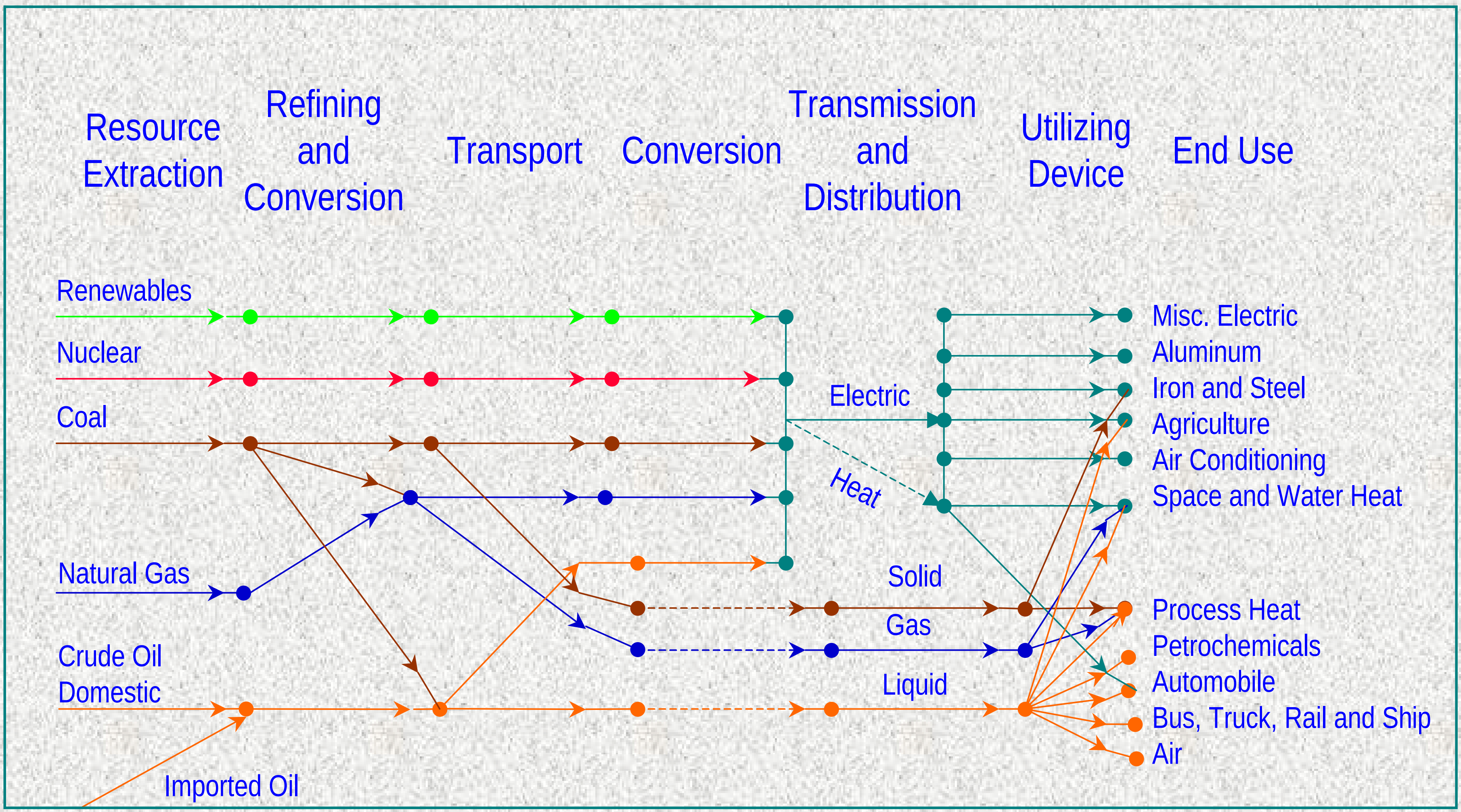
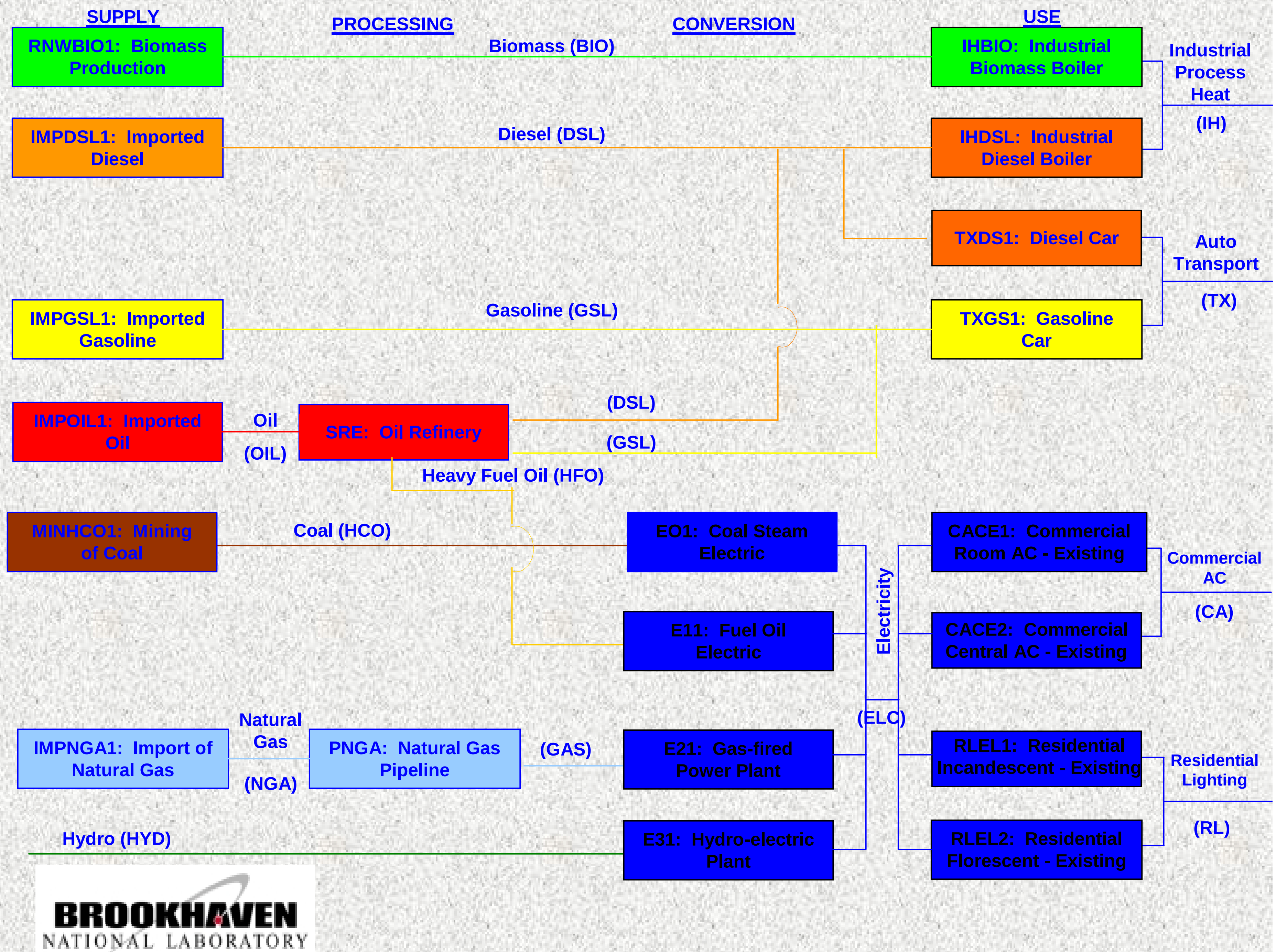
Simplified Reference Energy System

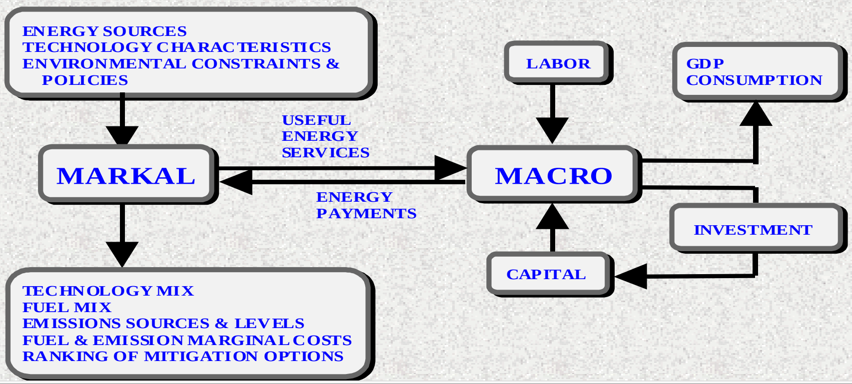


TRAINING REFERENCE ENERGY SYSTEM

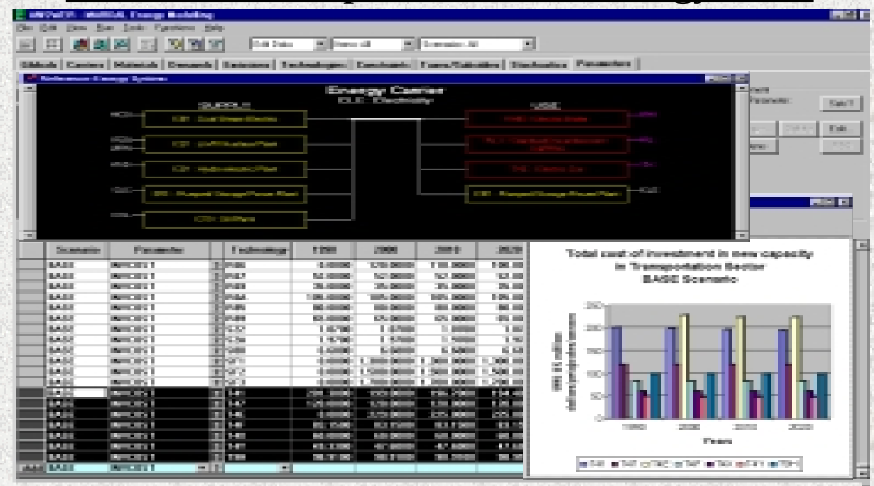


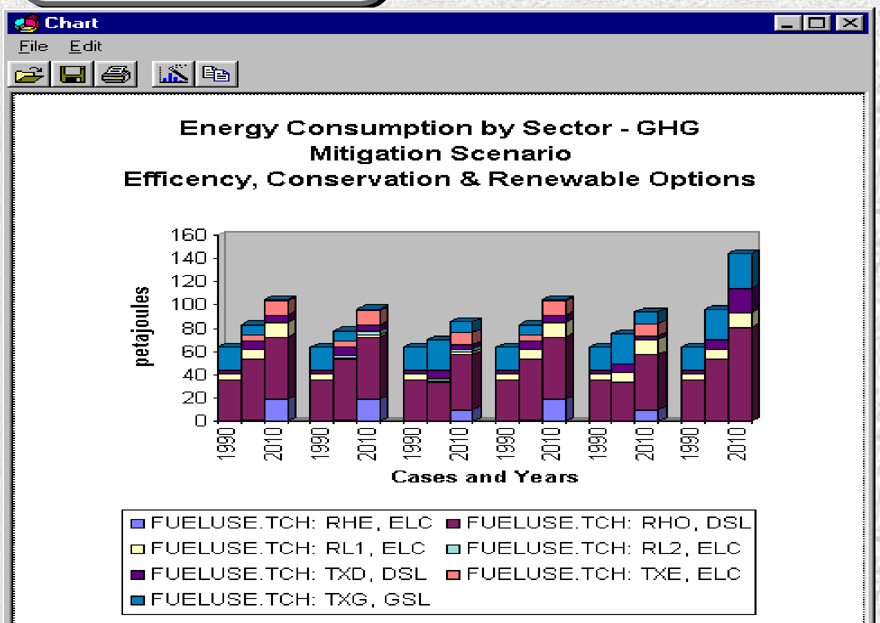
MARKAL-MACRO – A Snapshot

MARKAL-MACRO Overview

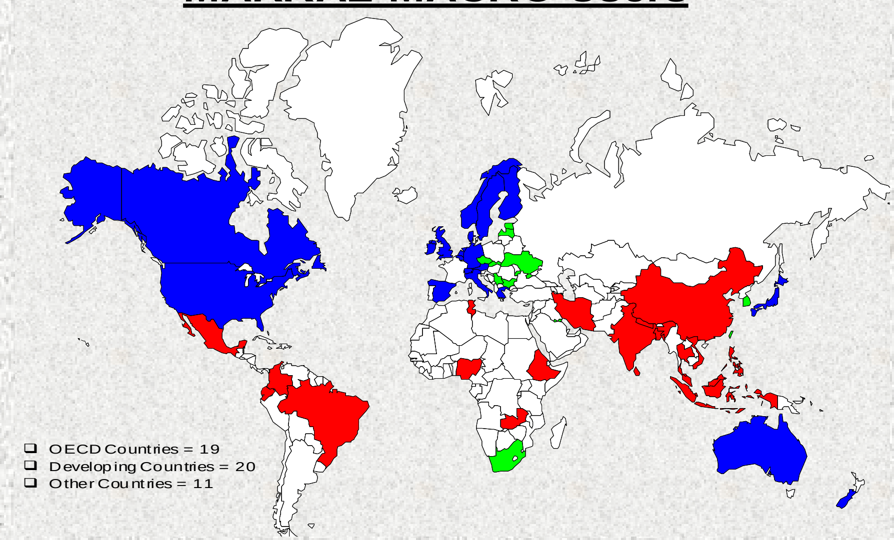


Network & Comparison of Technology Costs





MARKAL-MACRO Users



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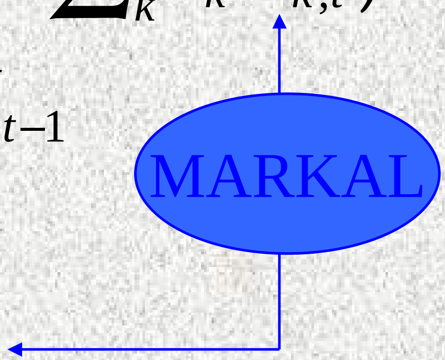
MARKAL Energy Modelling for Windows

MARKAL-MACRO Formulation

$$\begin{cases} \max U = \sum_{t=1}^{T} \beta_t \log C_t \\ \text{s.t.} \\ Y_t = \left(a K_t^{\rho\alpha} L_t^{\rho(1-\alpha)} + \sum_k b_k D_{k,t}^{\rho} \right)^{1/\rho} \\ K_t = I_t + (1-\delta) K_{t-1} \\ Y_t = C_t + I_t + EC_t \\ \text{Other MM equations} \end{cases}$$



where:

- U utility
- C consumption
- K capital
- L labor
- D_k energy services
- I investments
- EC energy costs
- Y production

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What Questions Can MARKAL Answer?

- How do particular technologies and policies affect GHG and emissions of other pollutants?
- What are the costs of meeting mitigation targets or the value of carbon rights?
- How do demand-side actions affect the supply-side and vice versa?
- How do technology and fuel mix changes resulting from environmental policies affect energy prices?
- What are the benefits of cooperation mechanisms?

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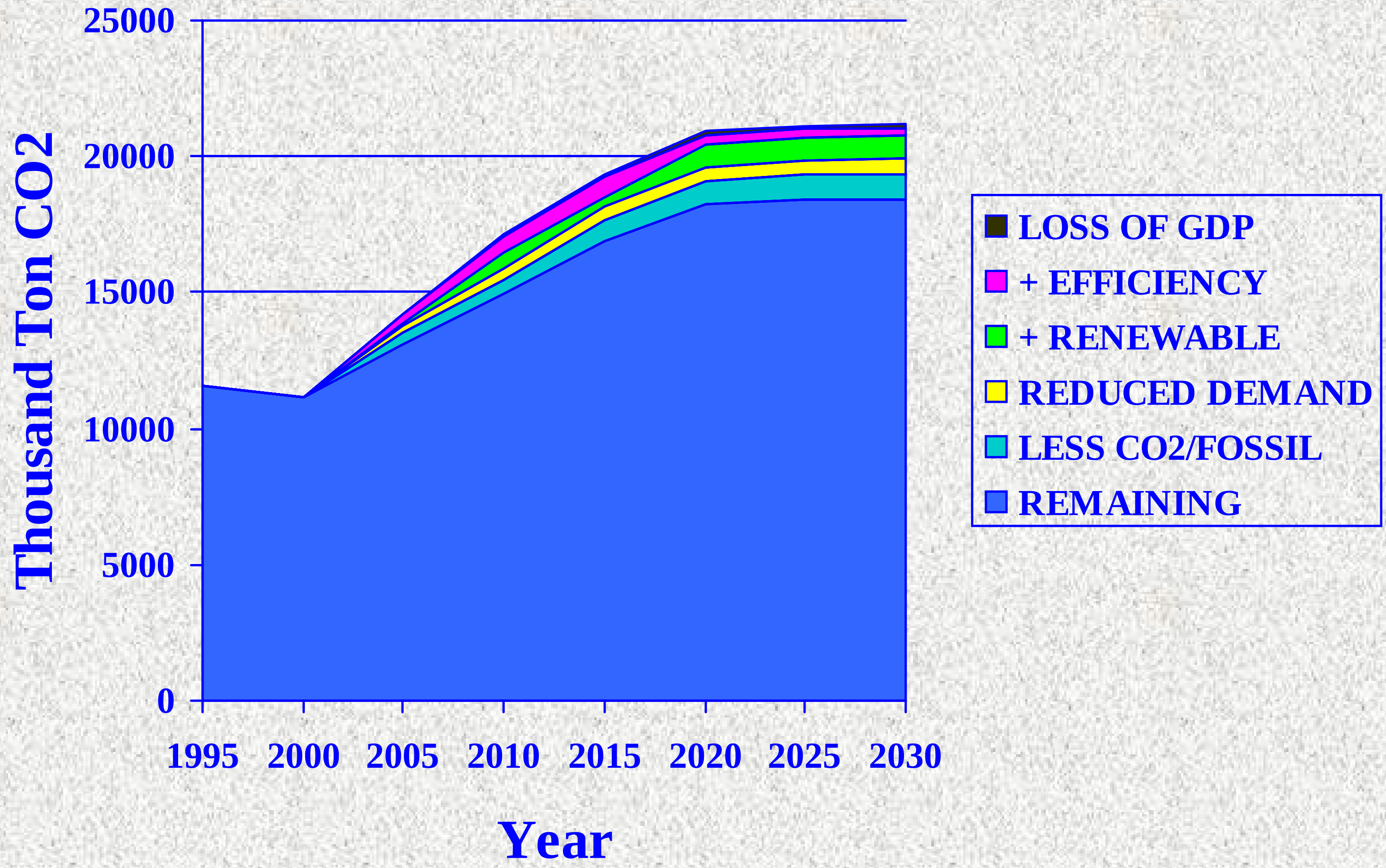
Contribution to Carbon Reduction



Variants of MARKAL

- MARKAL: Least-cost energy system configuration within constraints (demands levels and environmental limits)
- MARKAL-Elastic: MARKAL + demands that respond to prices
- MARKAL-MACRO: MARKAL + price sensitive demands + GDP impacts
- MARKAL-Multi-region: MARKAL/Elastic/MACRO coupling of >1 database (towards 22-region Global)
- MARKAL-Stochastic: MARKAL/Elastic with multi-stage stochastics
- MARKAL-ETL: MARKAL/Elastic/Stochastic with endogenous technology learning

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Case Studies: Global Climate Change

- World Bank Prototype Carbon Fund: Latvia Municipal Solid Waste Project
- Switzerland/Colombia “Emissions Trading”

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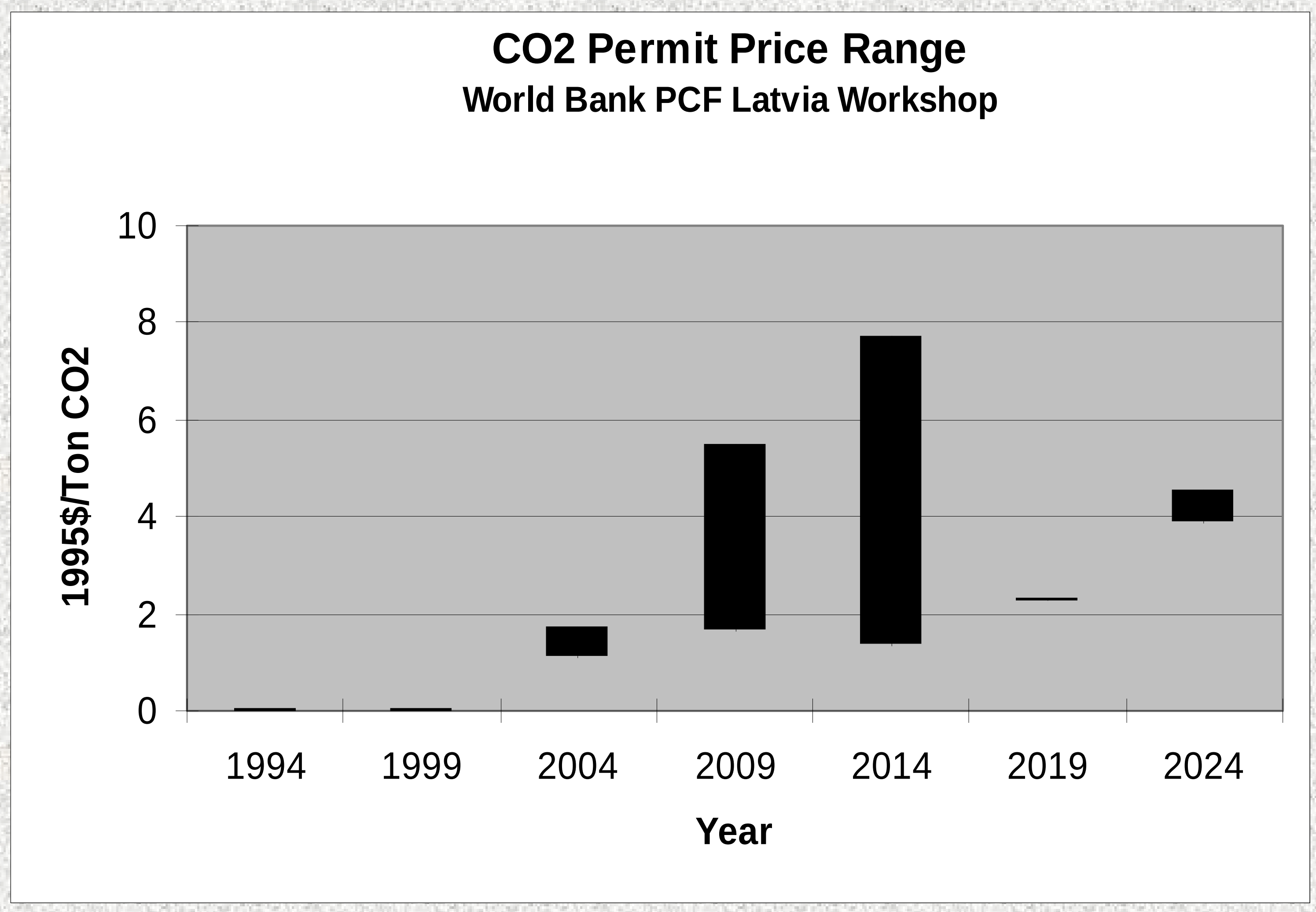
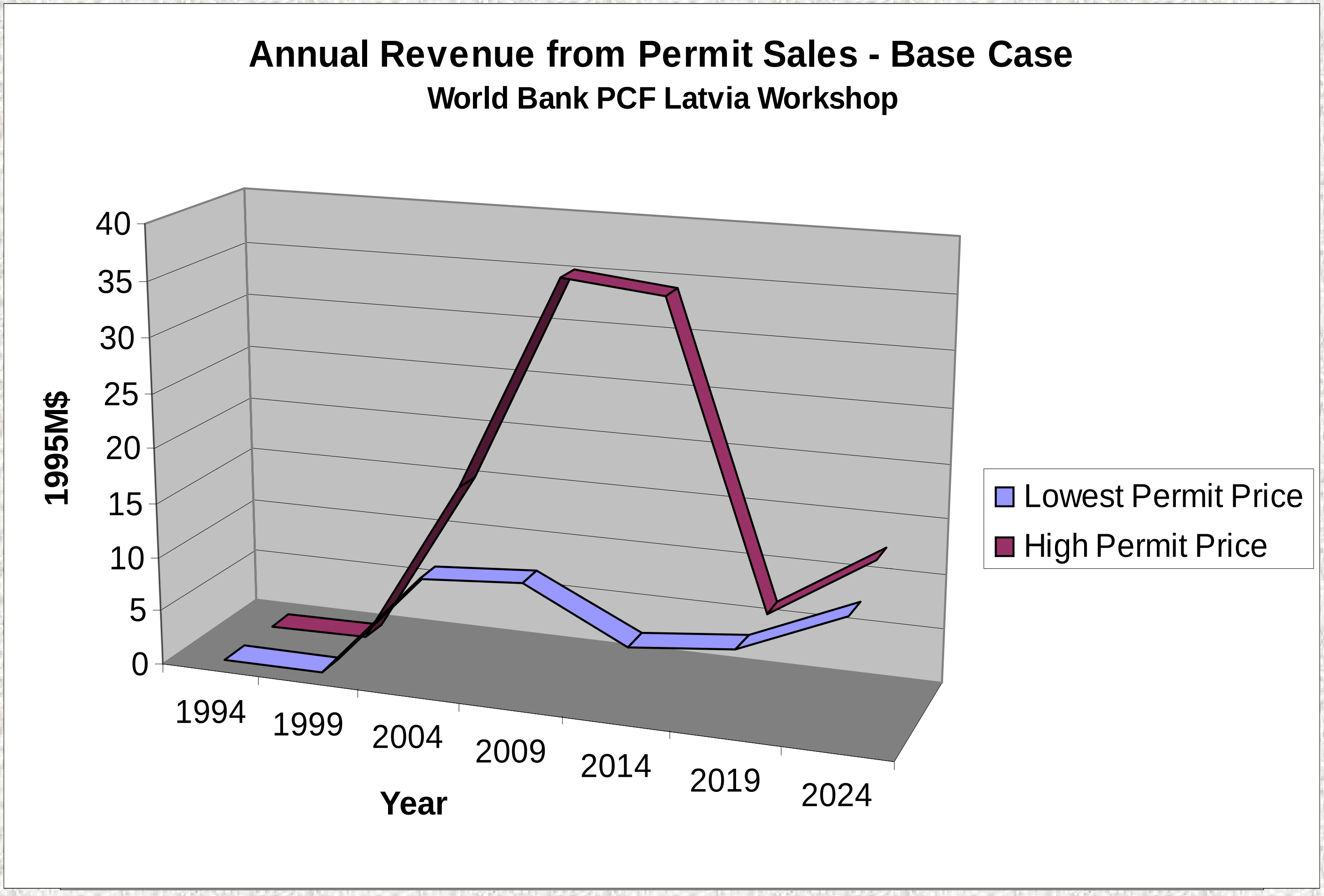

CO2 Permit Price Range
World Bank PCF Latvia Workshop
1995$/Ton CO2
10
8
6
4
2
0
1994
1999
2004
2009
2014
2019
2024
Year

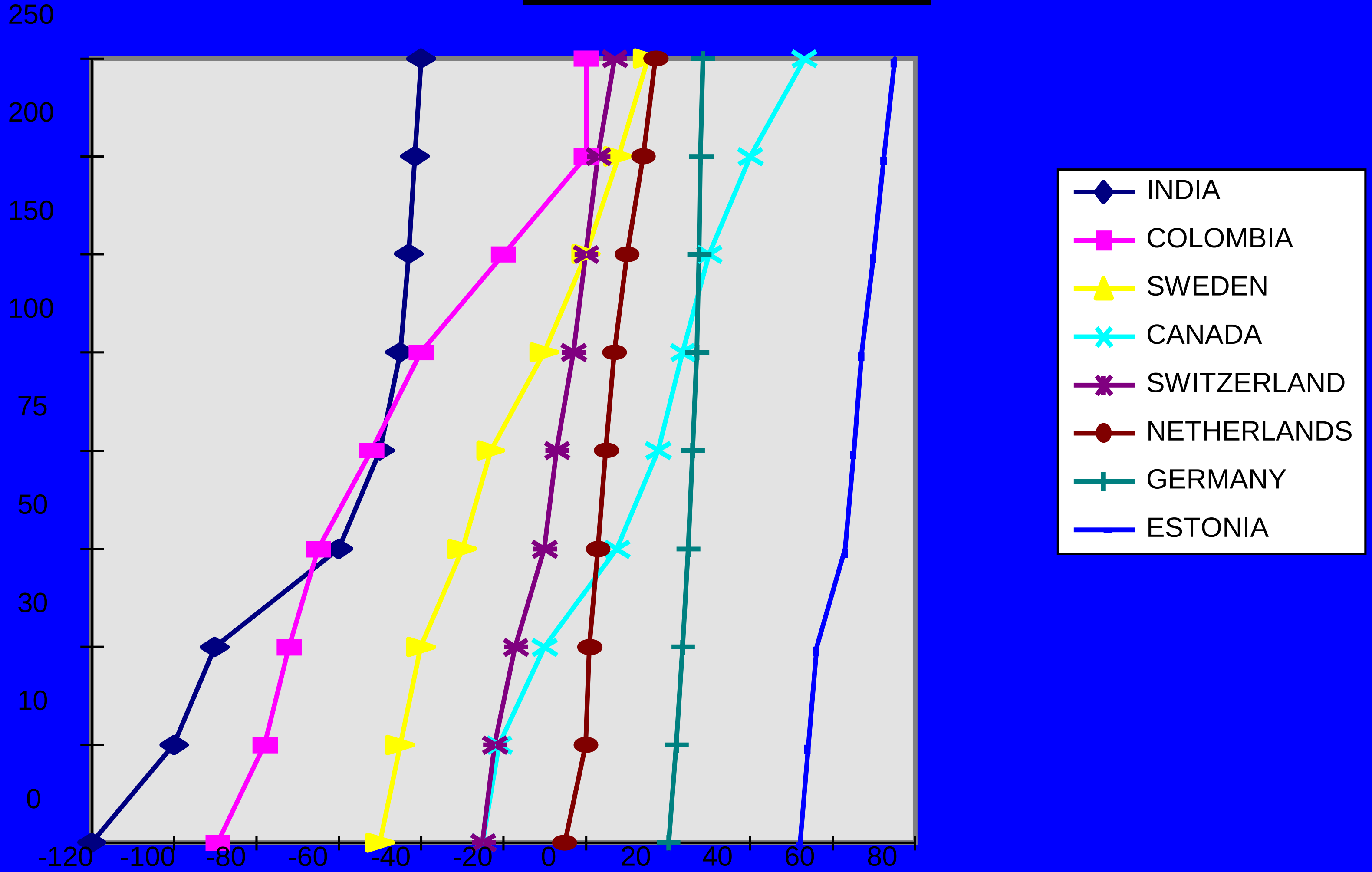

Annual Revenue from Permit Sales - Base Case
World Bank PCF Latvia Workshop
1995M$
40
35
30
25
20
15
10
5
0
1994
1999
2004
2009
2014
2019
2024
Year
Lowest Permit Price
High Permit Price

Liepajas Municipal Solid Waste Project – Baseline Avoided Emissions

- Displaces Some Natural Gas and Dual-fired Power Generation
- Avoided Emissions 2001- 2012 (TonsC)
  - Methane displaced 119.298
  - Power Sector Fuel Switching 16.965

  - **TOTAL** **136.263**

Marginal Cost of CO_2 Emission Reduction



Switzerland & Colombia CO_2 Emissions (million tonnes) and Undiscounted Marginal Reduction Cost (USD per tonne CO_2)

Switzerland

Scenario	2000		2010		2020	
Baseline	43.3		48.7		52.2	
Stabilisation	42.0	($72)	42.0	($144)	42.0	($116)
13% reduction	42.0	($9)	39.2	($216)	36.4	($499)

Colombia

Scenario	2000		2010		2020	
Baseline	86.0		115.5		156.8	
Stabilisation	61.1	($62)	61.1	($201)	61.1	($655)
Swiss 13% reduction	84.7	($4)	106.0	($20)	141.0	($103)

Source: O. Bahn, et al.

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CDM Results (O. Bahn, et al., 1998)

CO_2 emission paths (million tonnes) and sharing of emission reduction efforts (%)

Scenario	Country	2000		2010		2020	
Stabilisation	Switzerland	43.2	(6%)	47.2	(23%)	51.0	(11%)
	Colombia	84.8	(94%)	110.3	(77%)	147.8	(89%)
13% reduction	Switzerland	43.2	(7%)	47.0	(18%)	49.8	(15%)
	Colombia	84.8	(93%)	107.7	(82%)	143.4	(85%)

Undiscounted marginal costs of joint reduction (in USD per tonne CO_2)

Scenario	2000	2010	2020
stabilisation	$9	$6	$35
13% reduction	$11	$12	$62

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Conclusions

- The GCC Deliberations are Ongoing, with Difficult Issues Left to be Resolved.
- Access to Analytic Tools for Assessing the Implications of Proposals on National Economies is Crucial.
- MARKAL-MACRO is a Proven Methodology for Better Regional, National and Local Decision-making.
- Analytic Capabilities Embodied in MARKAL-MACRO are Ideally Suited for Assessing the Role of Technology and the Benefits of Cooperation Mechanism to Address GCC.
- MARKAL-MACRO Empowers Policy-makers in Host Countries, Encouraging Participation in GCC Deliberations.

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