



**Timing of Investments
in an Uncertain World
- Stochastic Scenario Runs with the
World Gas Model -**

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Agenda

- 1. World Gas Model Overview**
- 2. Implementation of Stochastic Scenarios**
- 3. Scenario Results**
- 4. Conclusions and Further Work**

The Standard World Gas Model (WGM)

- **WGM is a simulation model of the global natural gas market**
 - Market equilibrium model with optimization problems for individual player types
 - Decision variables: operating levels (production, trade,...) and capacity investments (infrastructure)
 - Mixed complementarity problem
- **Features:**
 - more than 80 countries, 95% of world natural gas production and consumption
 - time horizon until 2040 in 5-year intervals
 - Detailed player representation
 - market power for traders and regasifiers
 - endogenous investment in pipeline, storage and LNG capacity
 - LNG contract database
- **Publications**
 - R. Egging, F. Holz, C. v. Hirschhausen, S.A. Gabriel: Representing Gaspec with the World Gas Model. *The Energy Journal*, Special Issue „World Natural Gas Markets and Trade: A Multi-Modeling Perspective“, pp. 97-117, 2009.
 - D. Huppmann, R. Egging, F. Holz, S. Ruester, C. v. Hirschhausen, S.A. Gabriel: The World Gas Market in 2030 – Development Scenarios Using the World Gas Model. *DIW Discussion Paper*, 2009.

The World Gas Model – Players

- **Producer**

- **Trader**

- one trader per producer
- in charge of pipeline exports

- **Liquefier**

- **Regasifier**

- **Storage Operator**

- arbitrageur between low, high and peak demand seasons

- **Pipeline Operator**

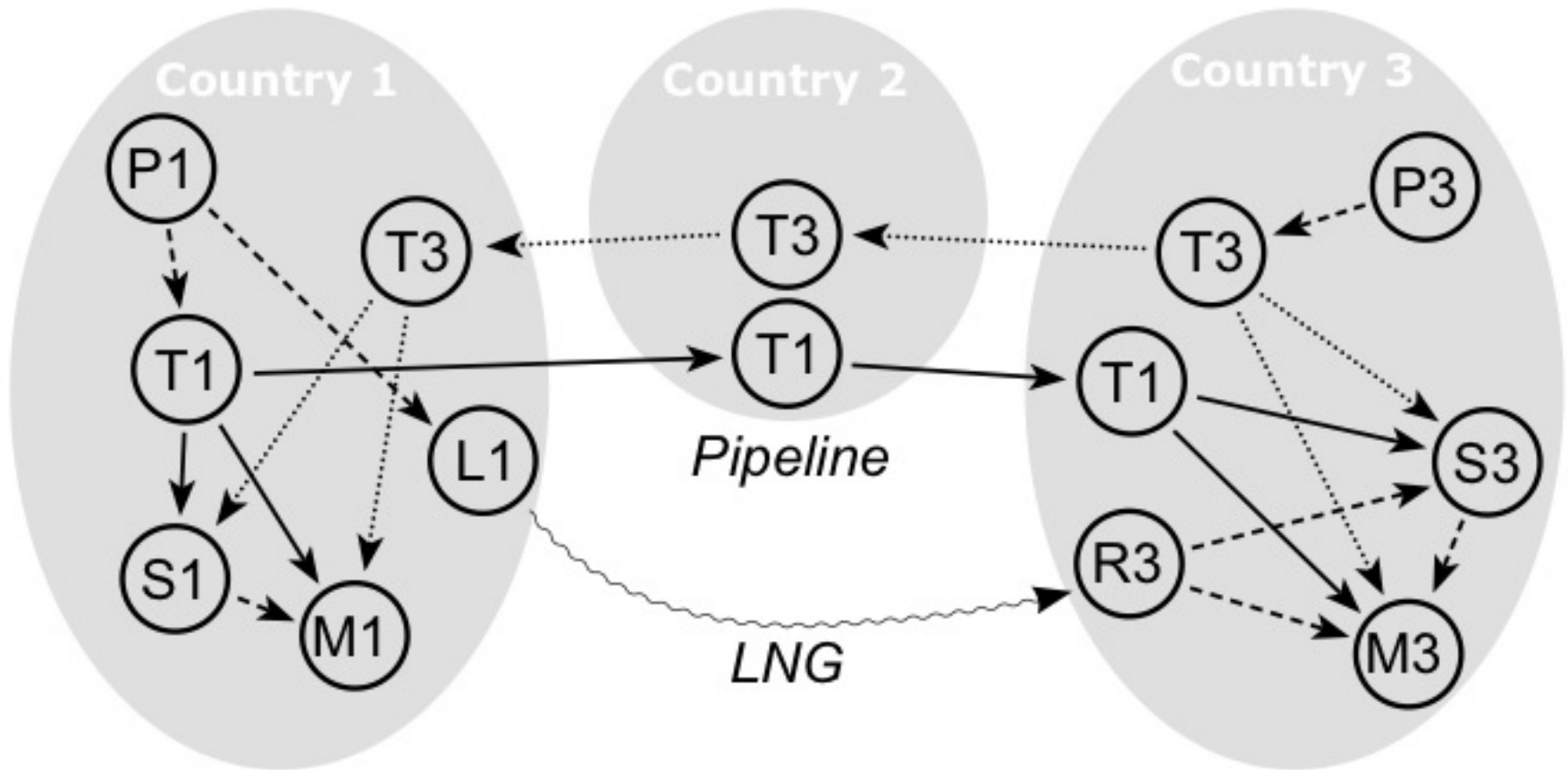
- to allocate pipeline capacity to traders respecting „Third Party Access“

- **(Marketer)**

- represented by inverse demand function of final consumer
- players in brackets are modelled implicitly

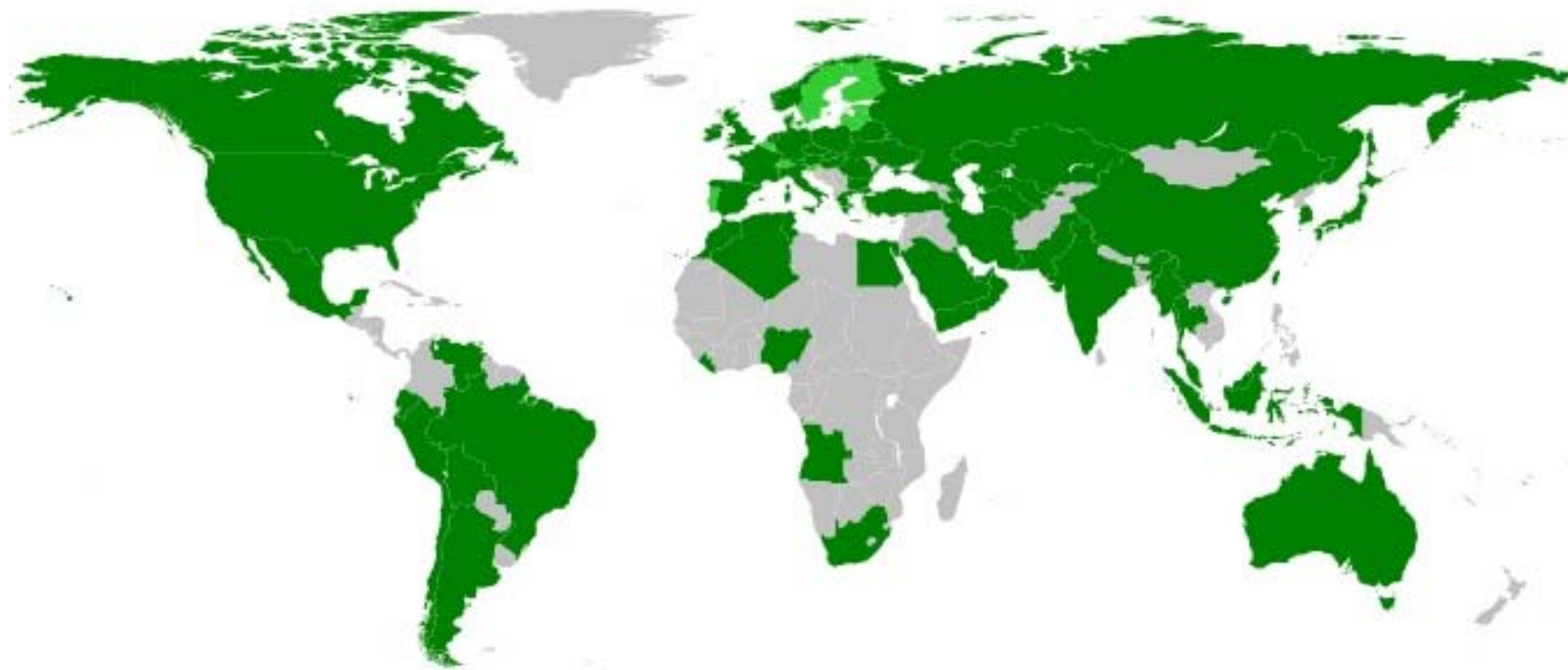
$$\begin{aligned} \max_{SALES_y, \Delta_{lm}^L} \quad & \sum_{y \in Y} \gamma_y \{ \pi_y SALES_y - c_y (SALES_y) - b_y \Delta_y \} \\ \text{s.t.} \quad & SALES \leq \overline{CAP} + \sum_{y' < y} \Delta_{y'} \quad \forall y \quad (\alpha_y) \\ & \Delta_y \leq \bar{\Delta}_y \quad \forall y \quad (\rho_y) \end{aligned}$$

The World Gas Model – Structure



Players and natural gas flows in the WGM

The World Gas Model – Countries in the Model



Countries included in the WGM (light green: consumption only)

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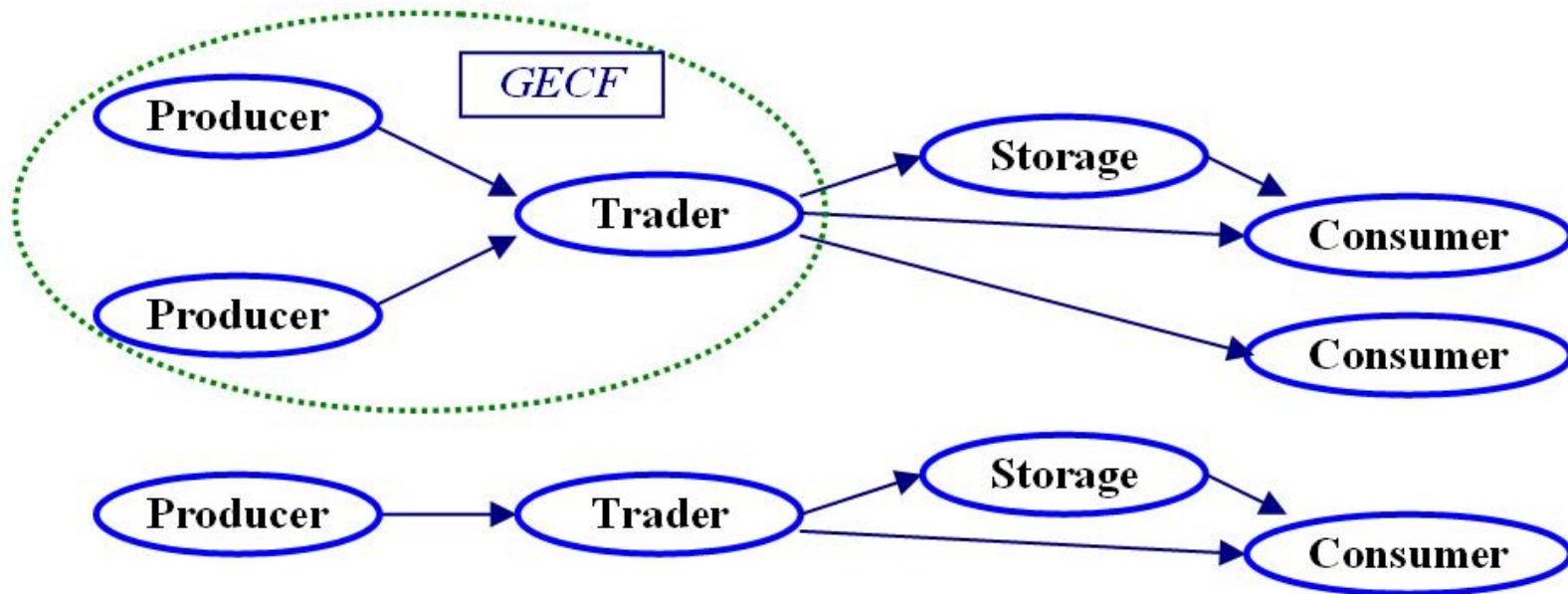
2. Implementation of Stochastic Scenarios

3. Scenario Results

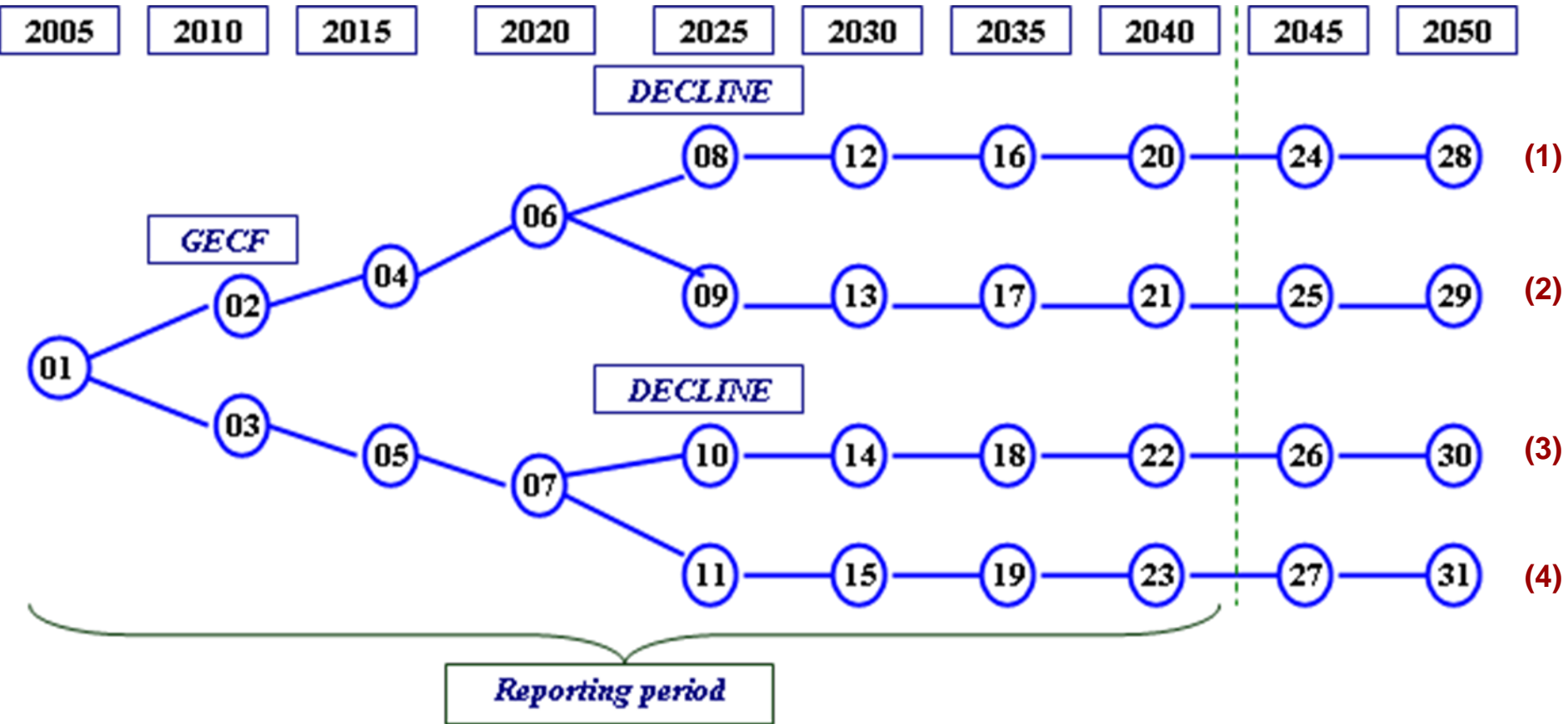
4. Conclusions and Further Work

Scenarios

- **Cartel:** realization of the Gas Exporting Countries Forum with effective market power by the Cartel trader and regasifier
- Fast decline of natural gas reserves in consuming regions in Europe, North America and Asia



Scenario Tree



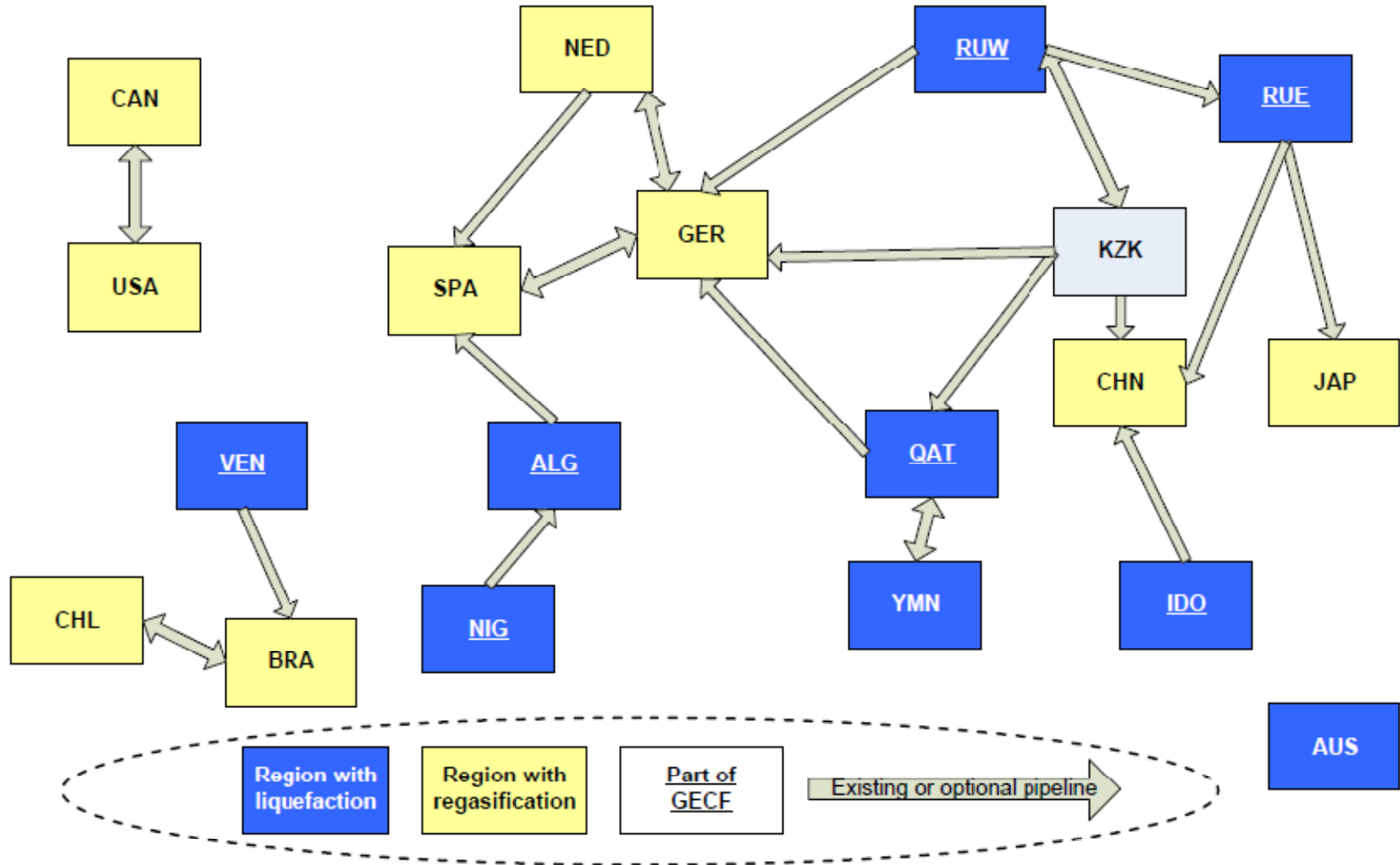
Scenario Overview

- **Stochastic scenarios 1 – 4 (after 2020): each scenario has a probability of 25 % to realize**
- **Four deterministic equivalents for each stochastic scenario (after 2020)**

Assumptions	BASE	CARTEL	DECLINE	DECLINE and CARTEL
Market Power	All traders in all periods 0.25, except for North America 0	Starting 2010 GECF trader with full market power selling gas from North & W. Africa, SE Asia, Caspian, Caribb., Middle East, Russia	Same as BASE	Starting 2010 GECF trader with full market power selling gas from North & W. Africa, SE Asia, Caspian, Caribb., Middle East, Russia
Production Rates	Same as standard WGM but for aggregate nodes	Same as BASE	Faster depletion in importing regions (GER, NED, SPA, CAN, USA, CHN, JAP) starting in 2020	Faster depletion in importing regions (GER, NED, SPA, CAN, USA, CHN, JAP) starting in 2020

Scaling Down the Data Set

19 Nodes



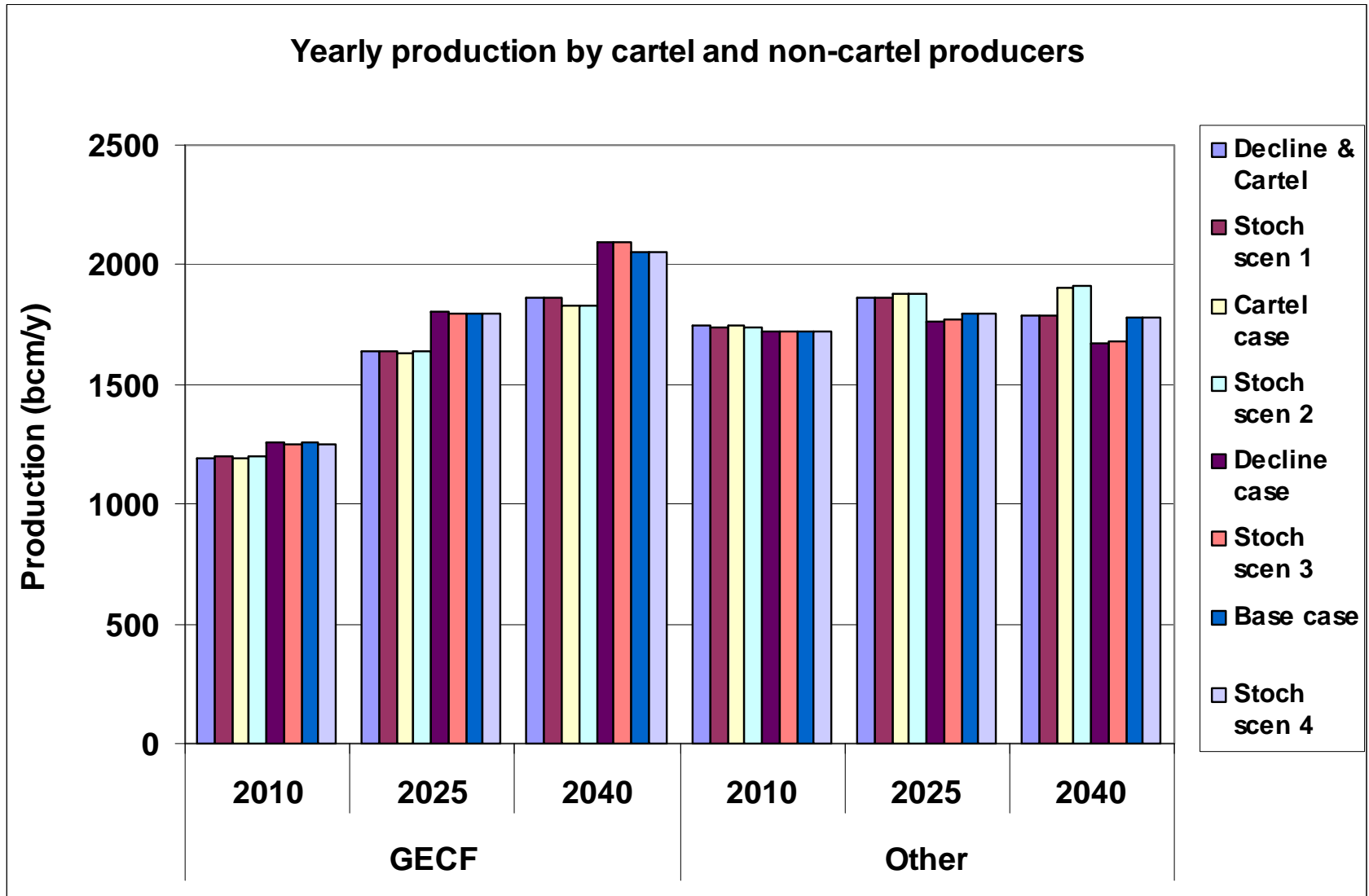
Implementation

- **Implemented in GAMS**
- **The full scenario tree is simulated**
- **This scenario tree increases the model size by a factor of approx. three**
- **With reduced data set (19 nodes): about 2,5 h**

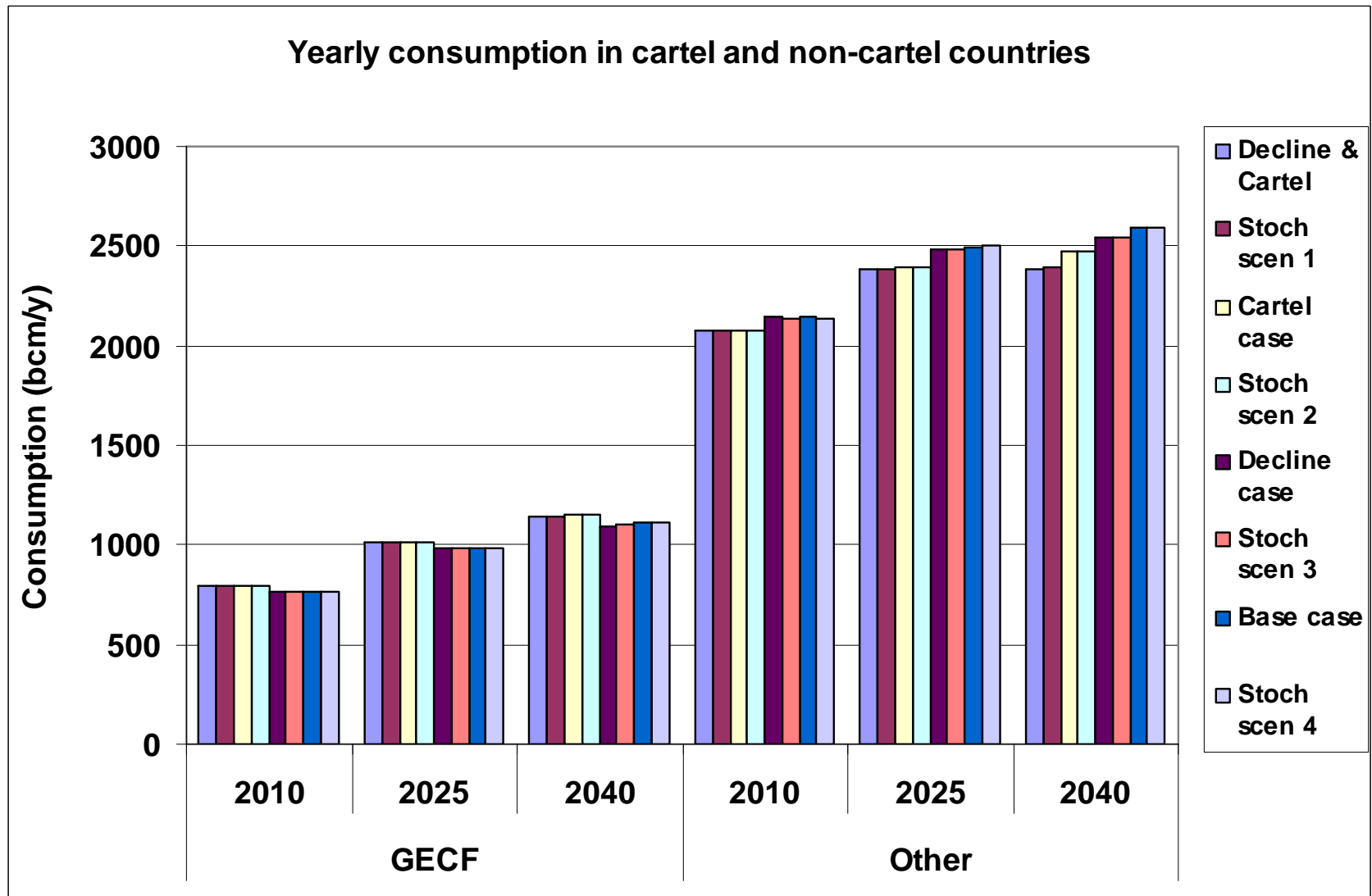
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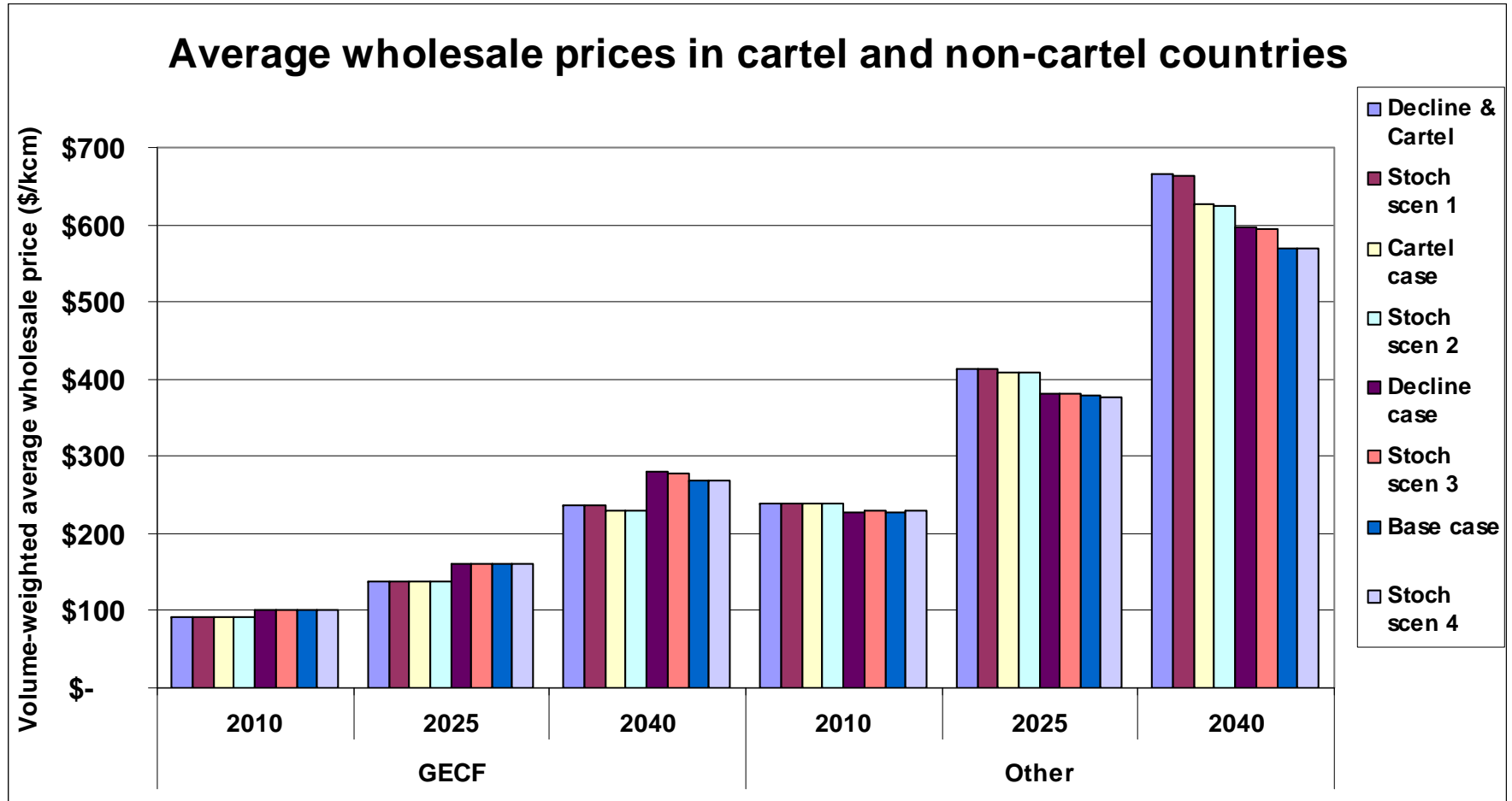
Production



Consumption

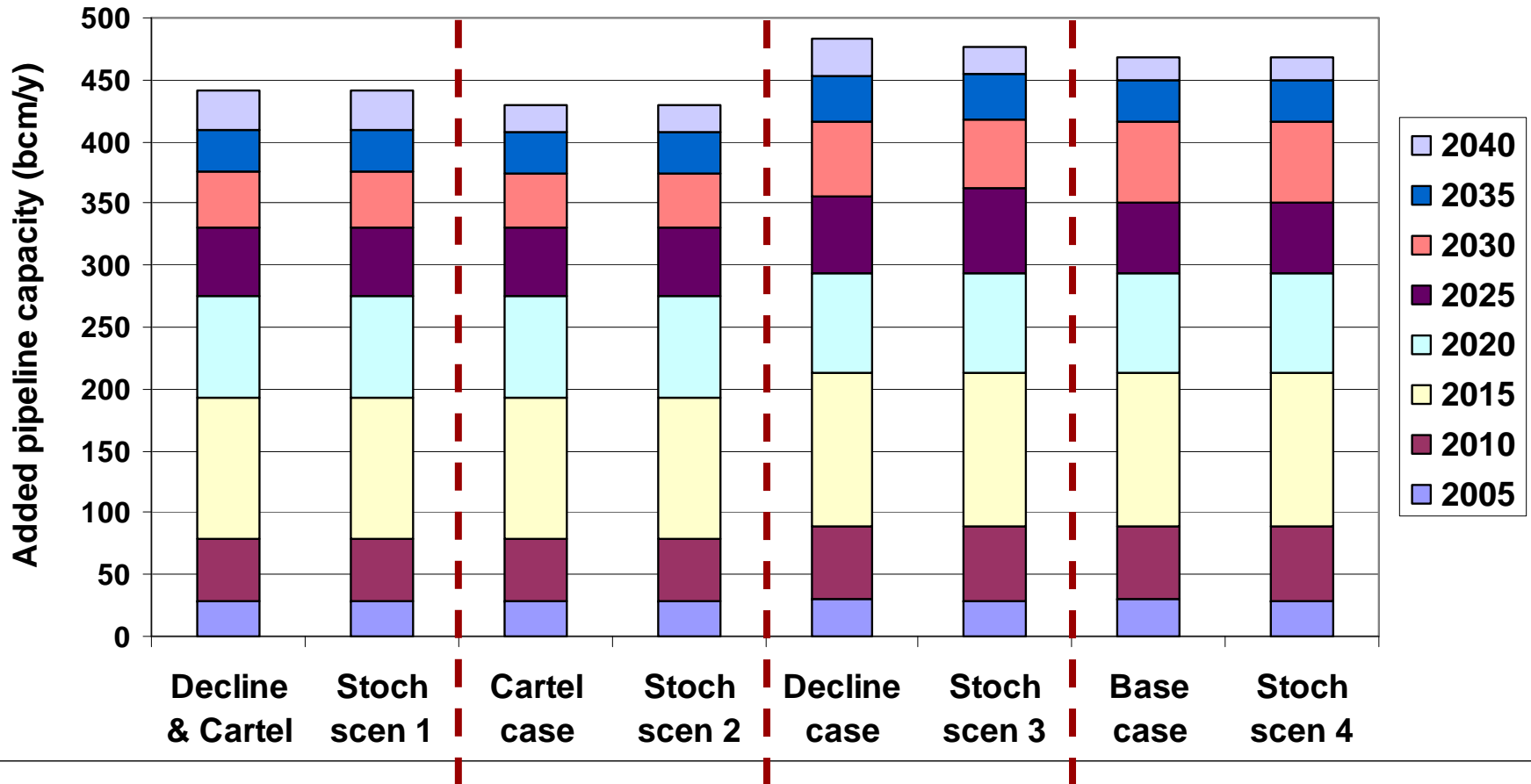


Prices

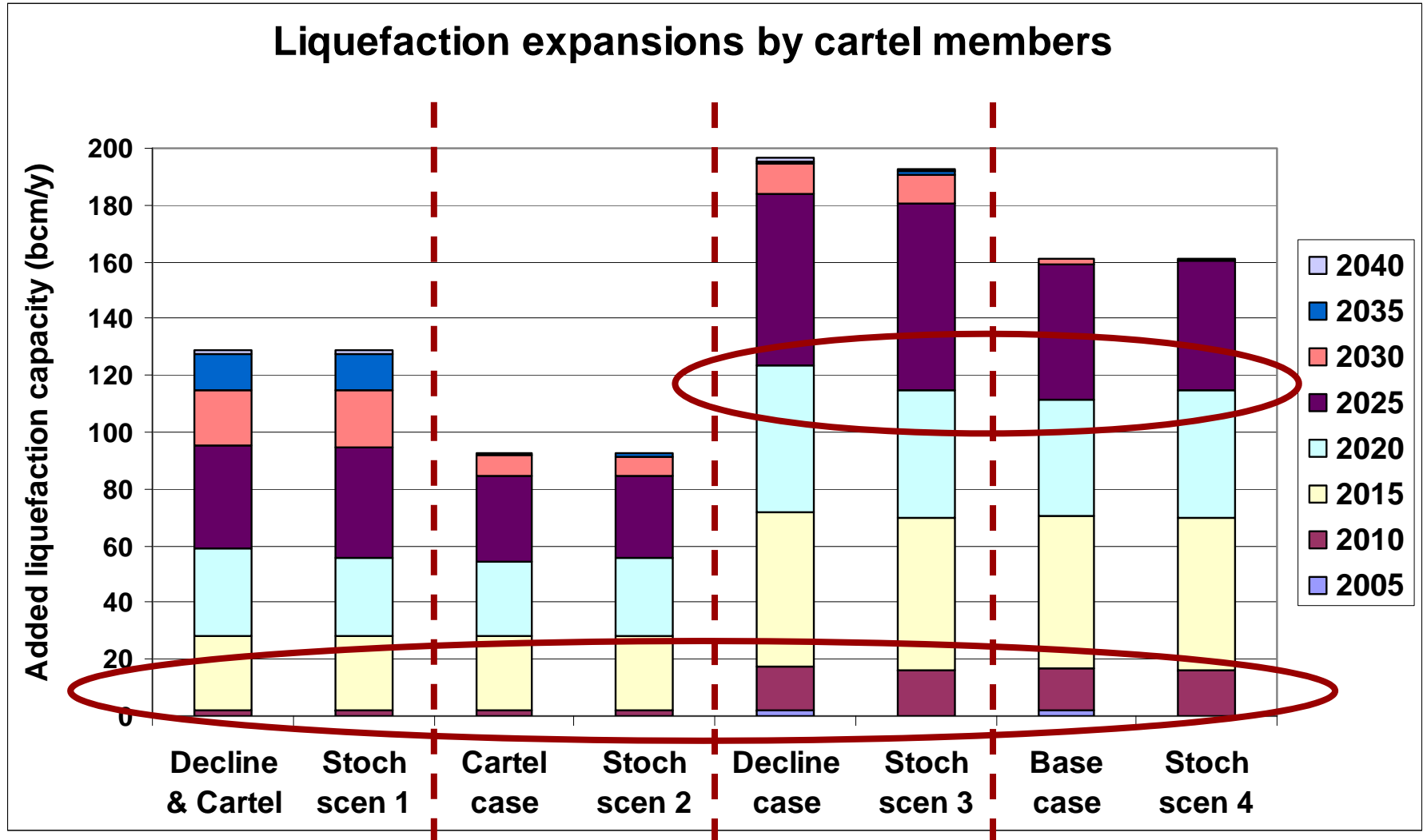


Investments I

Pipeline expansions from cartel to non-cartel countries

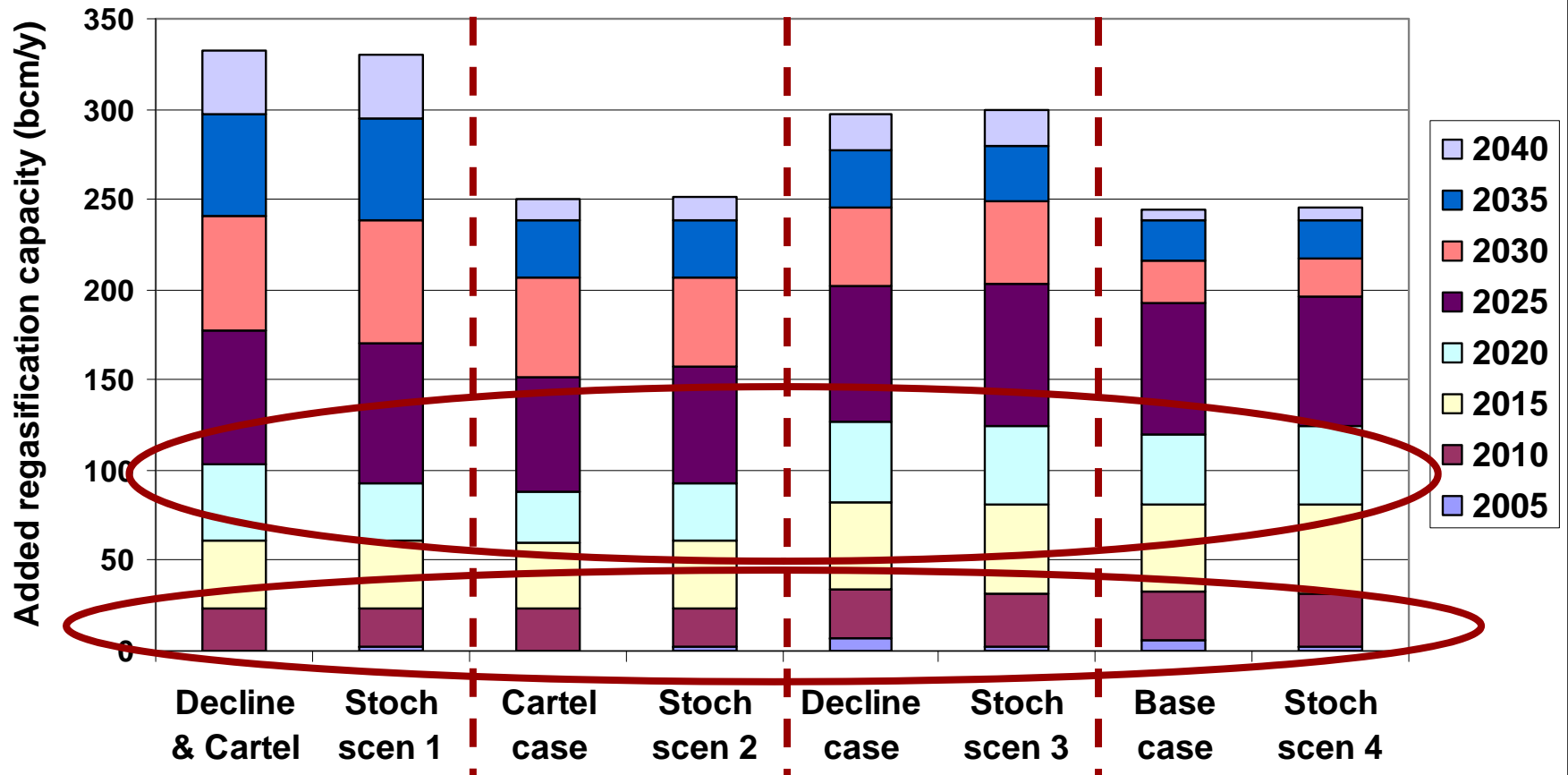


Investments II



Investments III

Regasification expansions



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Conclusions and Further Work

- **Deterministic simulation: „myopic“ decisions (but perfect foresight within the scenario) and no consideration of alternative realization**
- **Stochastic simulation: the eventuality of alternative realizations is taken into account**
 - **more realistic representation of the market and the decision process**
- **Large-scale model is solvable reasonably only when reduction is done**
 - **Data set reduction (done here)**
 - **Scenario reduction (e.g., Gabriel, Zhuang, Egging, 2009. Solving Stochastic Complementarity Problems in Energy Market Modeling Using Scenario Reduction, *European Journal of Operational Research*, 197(3), 1028-1040) → work in progress**
- **In the stochastic model, investments are delayed until more information is available**



Thank you for your attention!

Questions? Comments?

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