TECHNISCHE UNIVERSITÄT DRESDEN

DIW BERLIN

Work Package 5.3
Coal Sector

secure

Security of Energy Considering its Uncertainty, Risks and Economic implications

SECURE Stakeholder Meeting

Paris/Nanterre, November 25-16, 20092

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Development and application of specific tools for energy security in the coal sector

- Objectives: Develop and apply tools to assess the security of supply situation in the (steam) coal sector with respect to the following specific aspects: import diversification; vertical integration; oligopolistic supplies; and future technologies for coal use

- Deliverable 1: Introduction to global coal markets
- Deliverable 2: Vertical integration in the CCS value chain
- Deliverable 3: Supply security and import dependency
- Deliverable 4: A model of international coal trade (COALMOD)
- Deliverable 5: Regulatory issues and downstream aspects (CCS)

6 Step Methodology of SECURE:
Upstream and Downstream

1. **Threat identification and assessment**
   - Deliverable 5.3.1: Introduction to Coal Markets
2. **Impact assessment**
   - Deliverable 5.3.4: COALMOD model of the international coal trade
   - Deliverable 5.3.5: Downstream aspects and regulatory issues of CCS
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Step 1: Threat Identification and Assessment

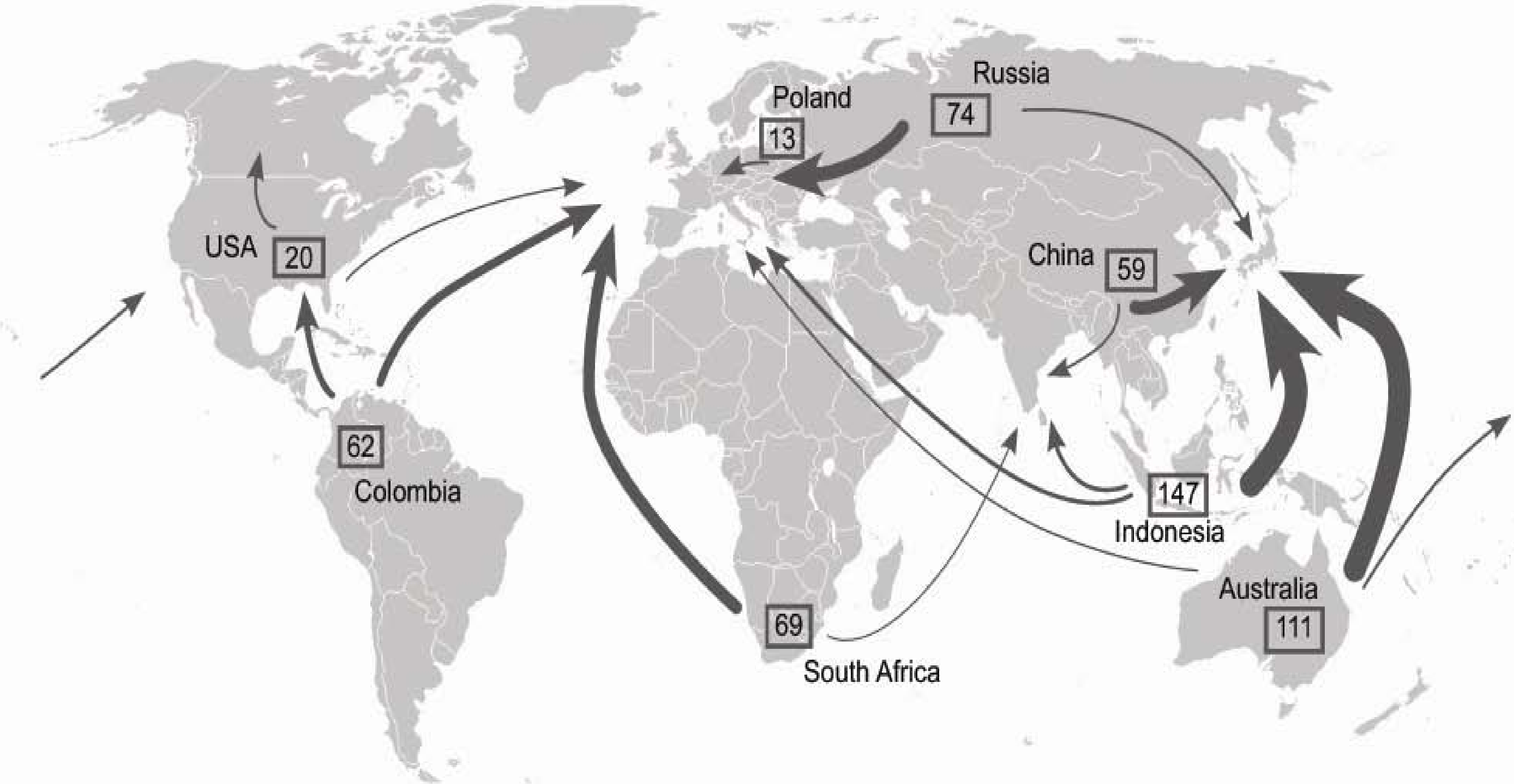
- **Large share of imports in many European countries**
- **Climate policies may result in reduction / abolition of coal use in power generation in Europe**

	Import dependency rate	Share of steam coal in electricity production
Germany	69.2%	20.6%
Italy	99.5%	14.4%
Spain	71%	23.5%
UK	63.4%	33.7%
USA	1.8%	47.9%
Japan	99.5%	24.5%
South Korea	95.4%	35.1%
Taiwan	100%	52.8%
China	11%	78.4%

Steam Coal Import Dependency Rate (2006)
Source: Deliverable 5.3.1, based on IEA (2007) Coal Information; IEA (2007) Electricity information

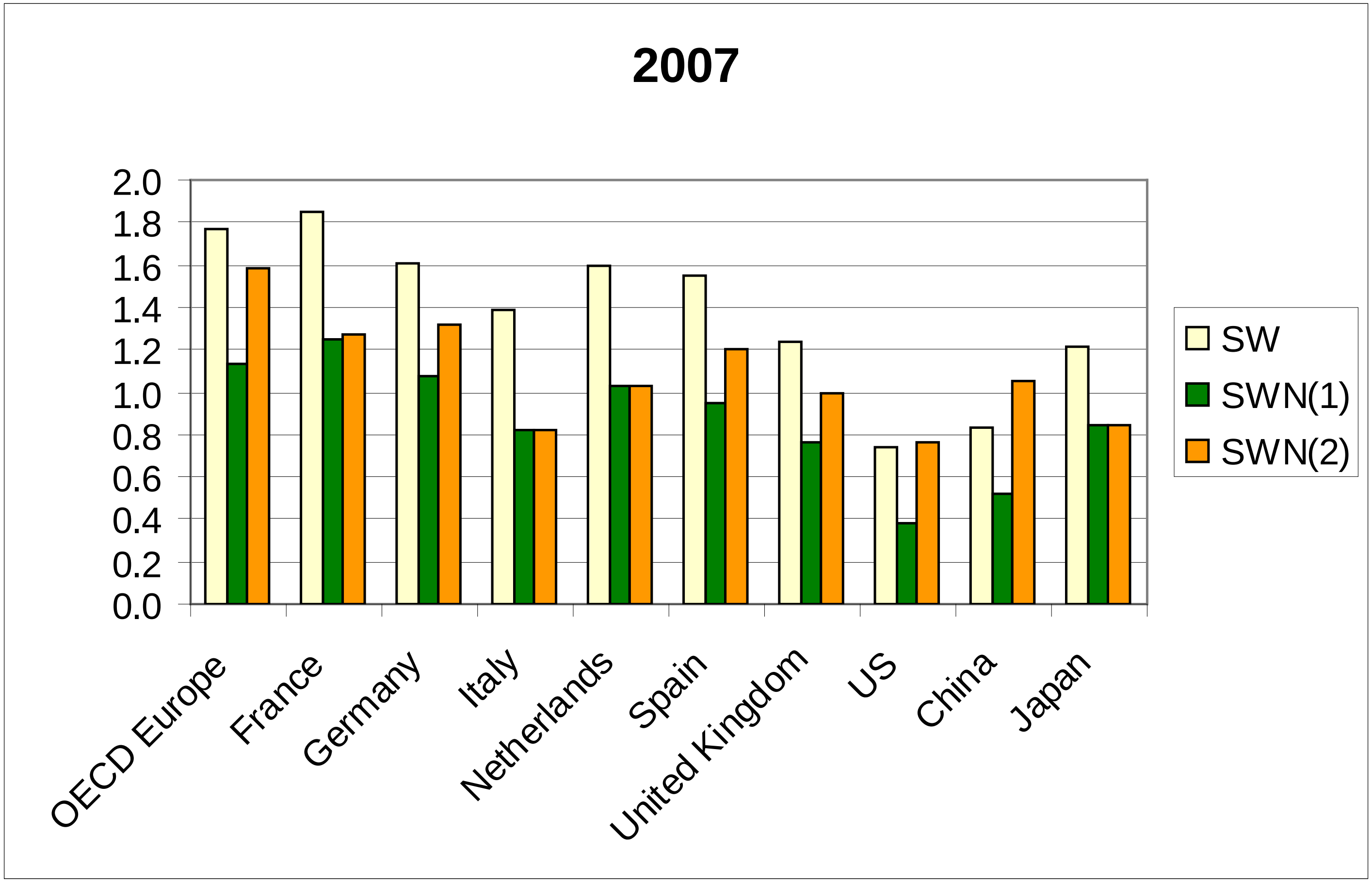
Seaborne Trade of Steam Coal

Seaborne traded steam coal 2007: 607 Mio. t



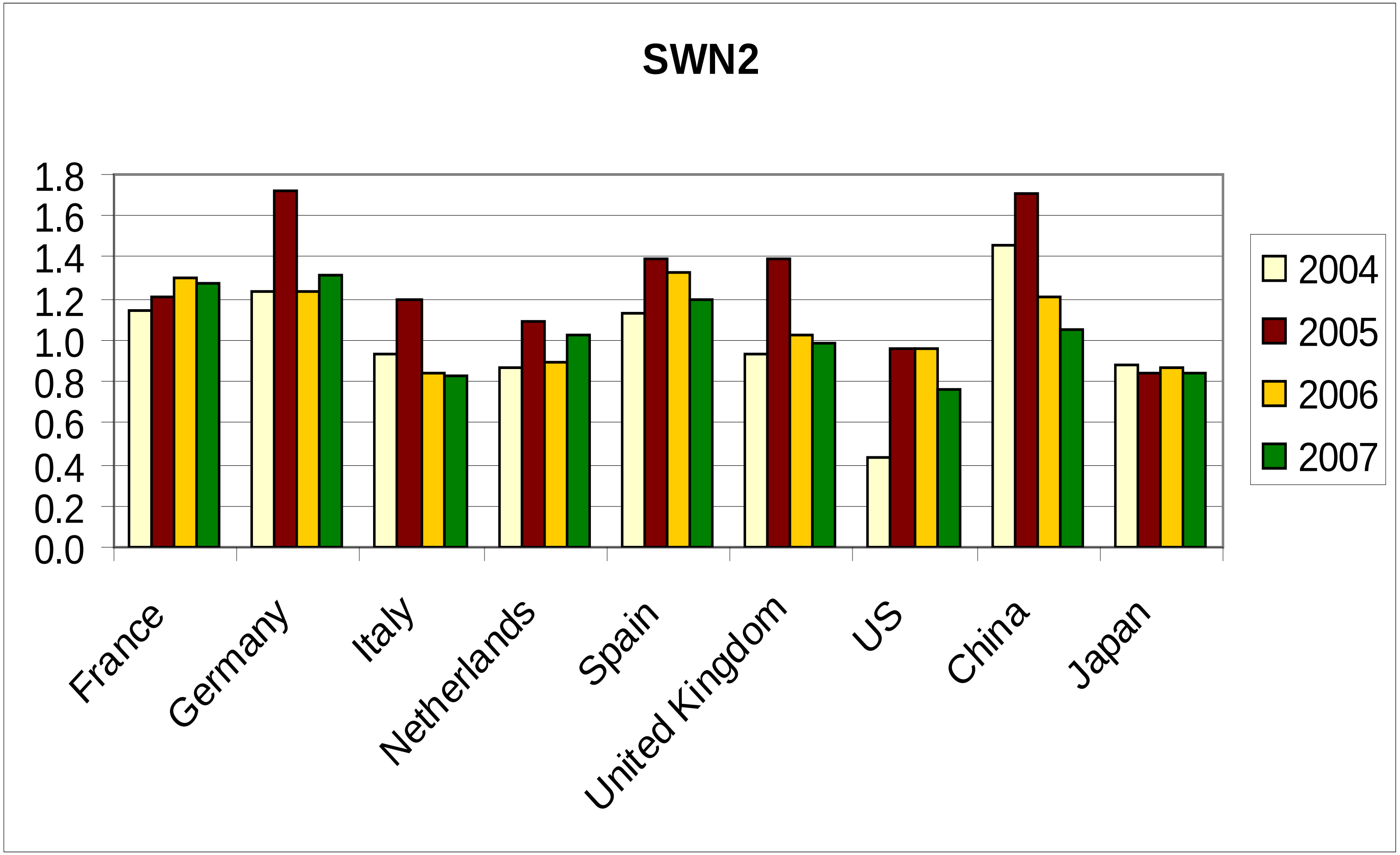
Source: IEA (2008) Coal Information

Step 3: Assessment of Vulnerability of European Importers



Diversification Indices for Major European and non-European Importers in 2007
Source: Deliverable 5.3.2

Diversification of Coal Supplies over Time
Taking into Account Political Risk and Domestic Production



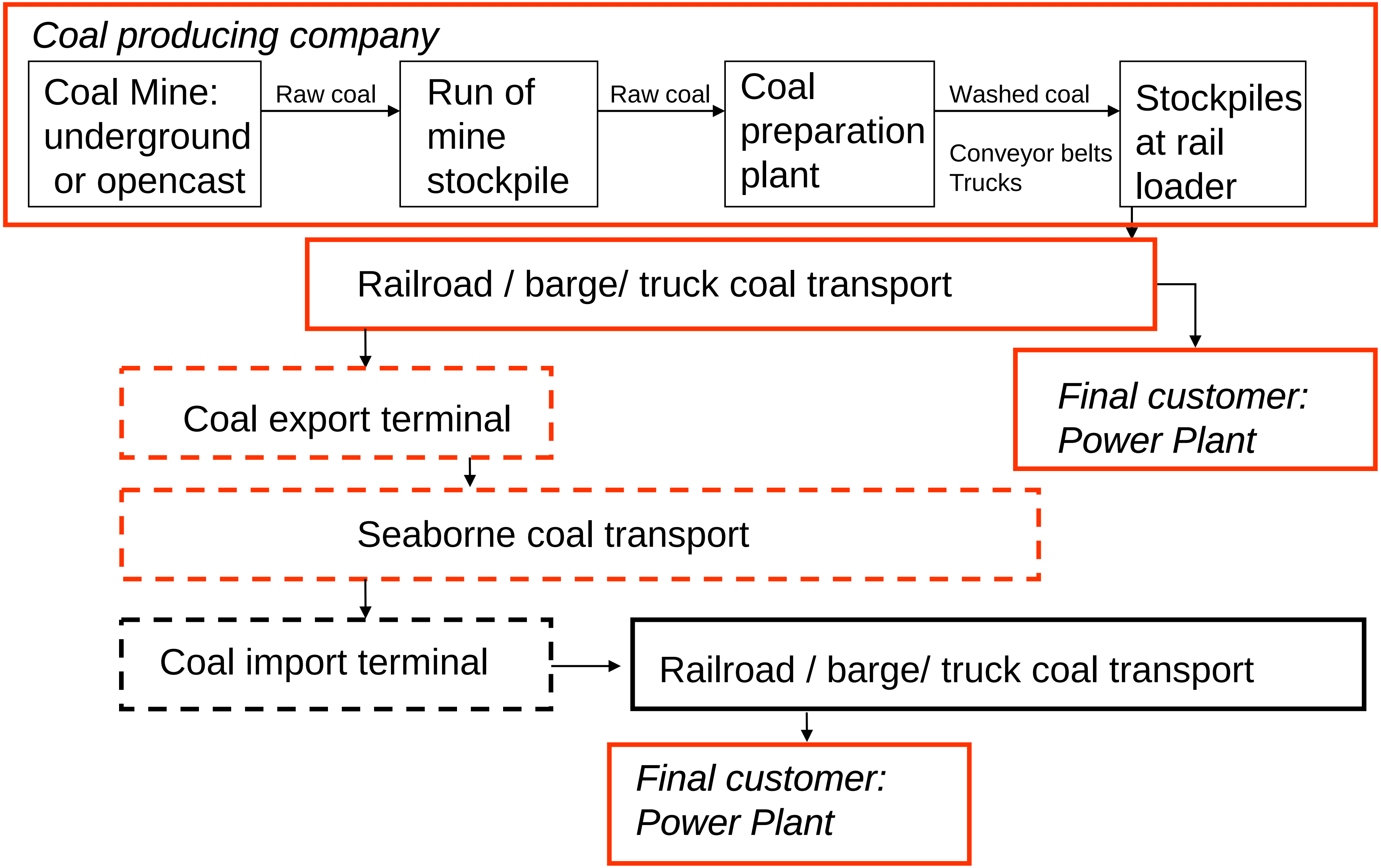
Source: Deliverable 5.3.2

Conclusions Steps 1 & 3: Threats from the International Market

- Coal supplies In the last years have expanded considerably (annual rate of about 50 million t)
- Little (geo-) political risk on coal market
- Diversification indices show that European countries are in a good situation
- Variations of indicators between the years follow the same pattern for almost all importers → increasing globalization of the steam coal market

- Is there an oligopolistic market structure that is a threat to a “reasonable price level” on the import market?
- → COALMOD model: no evidence of oligopolistic behavior can be found
- Step 2: Impact assessment of import market threats: COALMOD model (scenario analysis)
- Step 4: Cost assessment of import market threats: COALMOD model (price, quantity results)

Modeling Approach: The Value-Added Chain of the Steam Coal Sector



Countries Involved in the Steam Coal Trade

2006 values in Mt

Major Exporters:

• **Australia**	110,8
• **Indonesia**	104
• **Russia**	81,7
• **South Africa**	67,7
• **Colombia**	59,7
• **China**	58,9
• **USA**	19,9

Major Importers:

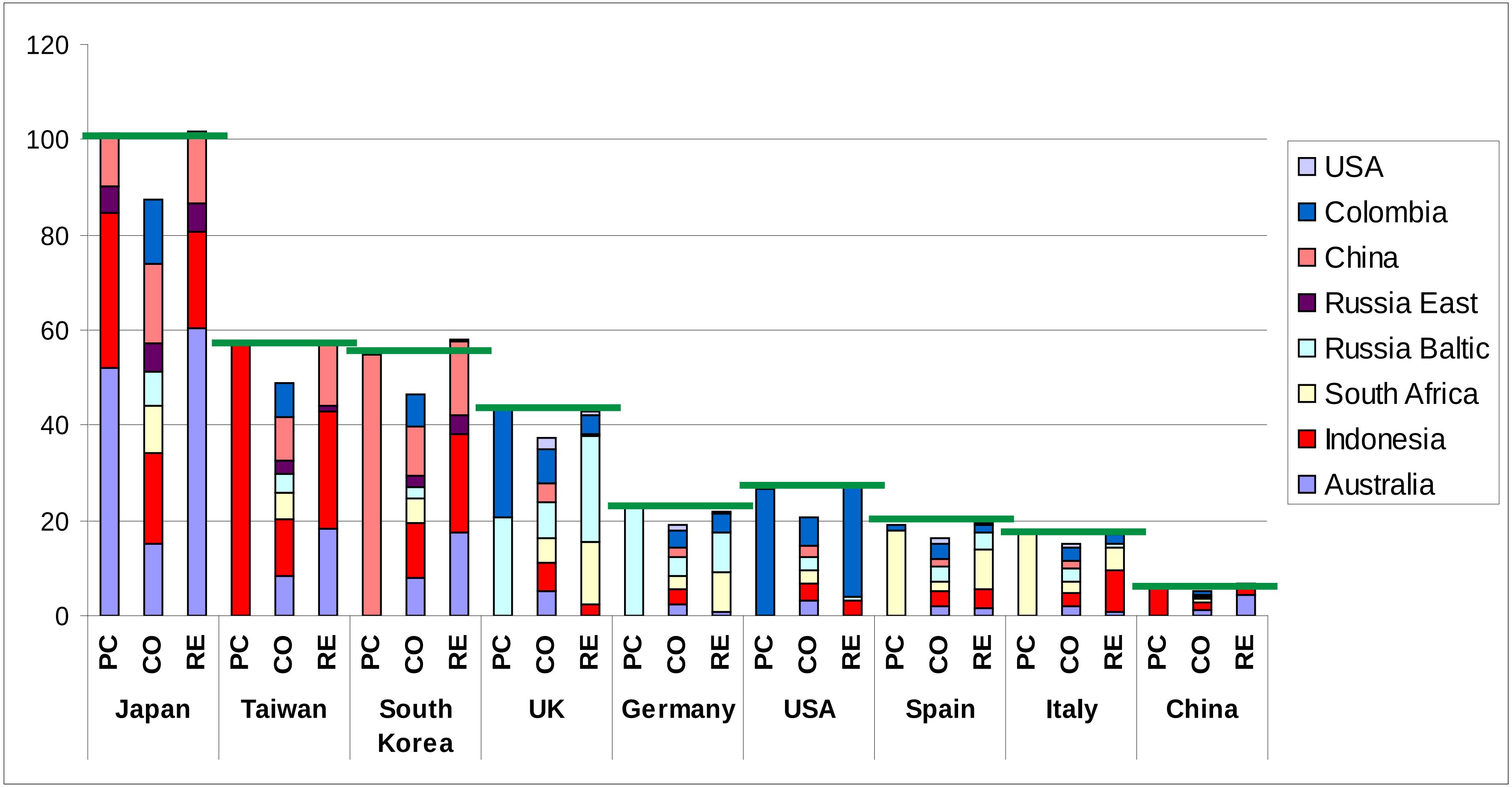
• **Japan**	105
• **Korea**	59,6
• **Taiwan**	57,5
• **UK**	44,4
• **Germany**	32,7
• **USA**	31,2
• **China**	28,8
• **Spain**	20,1
• **Italy**	18,6

India 0,042 / 21,9

Modeling Approach

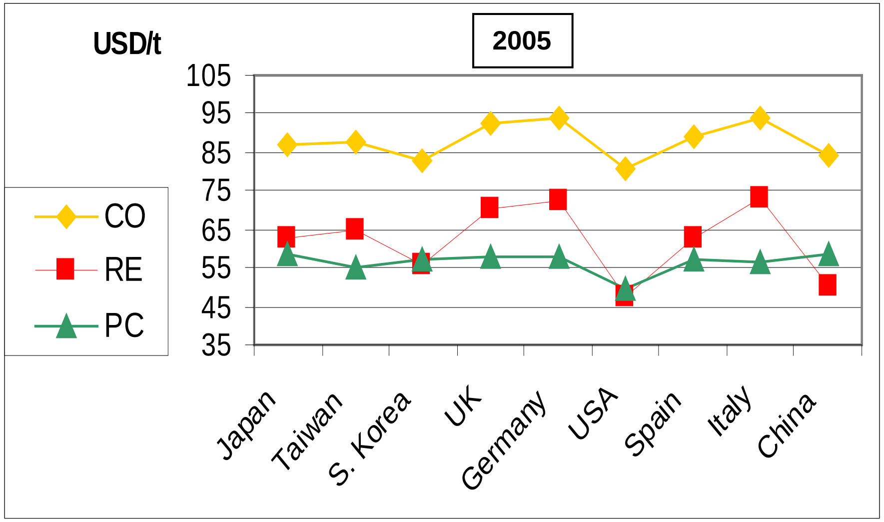
- **Players:** Steam coal exporting countries
  They produce, transport and sell to the importing countries.
- **Model:** Equilibrium model with the possibility to exert market power à la Cournot
- Players maximize their profit by choosing the optimal quantity to sell to each importing country.
- → quantity and price endogenous variables
- Linear demand function defined in a reference point (reference consumption level, reference price and elasticity)
- Production costs and distance-related transport costs
- Constraints: production and export capacity
- The **equilibrium model** is implemented in GAMS and solved using the MCP (mixed complementarity) solver PATH.

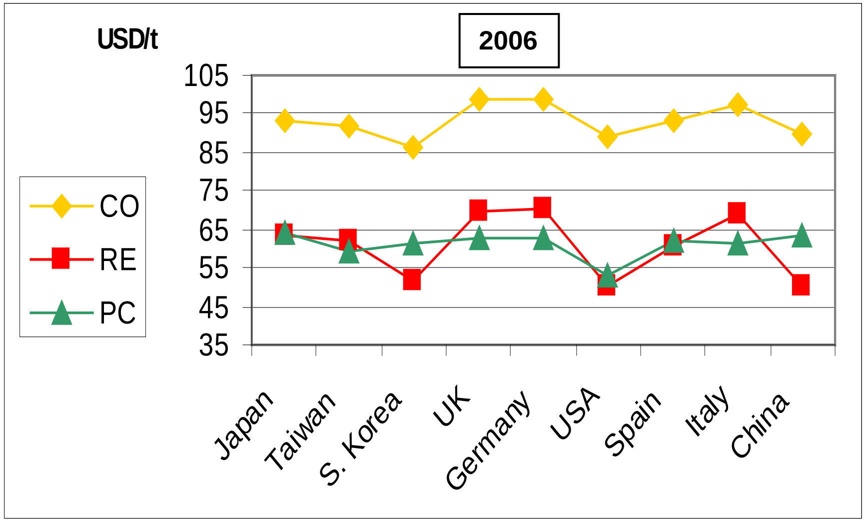
Results 2006: Imported Quantities in Mt
Evidence of Competitive Market



PC: Perfect competition simulation
CO: Cournot competition simulation
RE: Reference quantities 2006

Prices and Market Structure Conclusions





• The real prices are between the modeled price but in 2006 clearly closer to the perfect competition case.

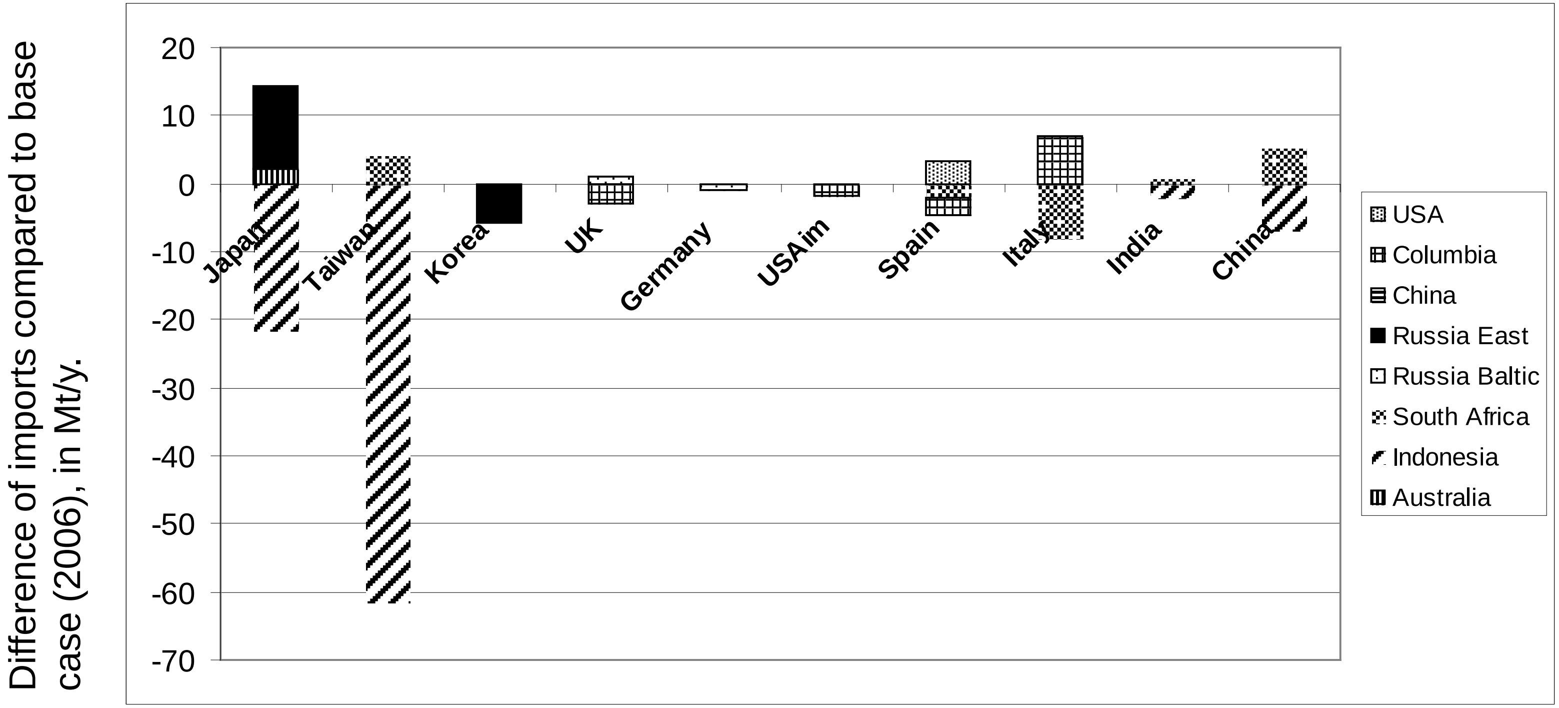
→ The results tend to indicate that the international steam coal market is competitive.

Other (than geo-political) risks in the long-term:
- under-investment, especially in transport infrastructure (railways, export terminals), in large exporting countries, e.g. South Africa → scenario analysis
- No reserve risk foreseeable

Scenario Analysis I

- **A) Disrupted supplies from Indonesia:**

Background: Indonesian government is instable and pondering the introduction of a „Domestic Market Obligation“



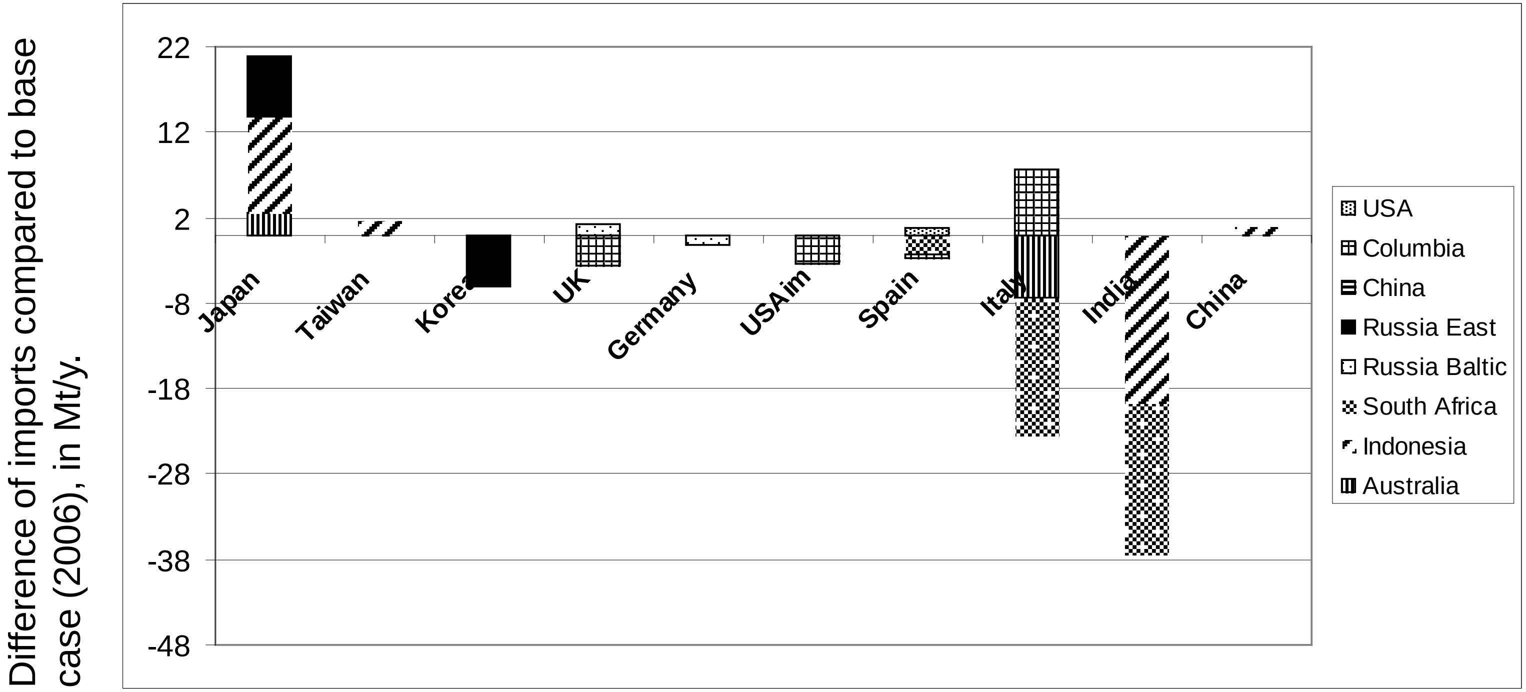
Results: East Asian consumers (Taiwan, Japan) must reduce their coal imports

European importers can rely on other sources in the Atlantic basin (e.g. USA, Columbia)

Scenario Analysis II

• **B) Disrupted supplies from South Africa:**

Background: Somewhat unstable domestic energy system, in particular electricity system. May require much more coal domestically than currently.



Results: East Asia and Europe are affected, due to South Africa‘s role as swing supplier between the basins

Only Columbia, Indonesia and Australia have spare capacity to compensate → are drawn by East Asia (highest willingness to pay and lowest transport costs)

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   - Input from FEEM and ERSE

Downstream Aspects: CCS
Deliverables 5.3.2 and 5.3.5

- **Two aspects:**
  - **Assessment of current state of deployment and its blockades (technological, regulatory, business models)**
  - **Suggestions for remedies and their funding**

- **Data base construction of existing CCS and CO_2 transport projects**
- **Analysis of possible business models in the CCS value chain: vertical integration vs. contracting vs. hybrid organizational models (LTC, JV, R&D partnerships, …) ?**
- **Regulation of CCS value chain elements, in particular transport (likely to be natural monopoly), incl. funding of infrastructure**

5 Preliminary Hypotheses

- The real issue in European supply security regarding coal is the absence of an economically and politically sustainable use of the coal (for electricity, liquefaction, gasification, etc.)
- Current long-term energy scenarios seem to underestimate the institutional obstacles of implementing CCTS (transportation and storage); the „sustainable infrastructure“ pardigm is limited by the „NIMBY infrastruture“ paradigm associated with CCS
- The successful US-experience with CO_2-pipelines is linked to a profitabe business model: enhanced oil recovery (EOR); it has little to do with either carbon capture neither storage
- Even though considerable asset-specific investments are required along the value-added chain of CCS, vertical integration, i.e. unified ownership, is not necessarily the first-best option
- The conditions for CCS to become a success story (let along „silver bullet“) for a sustainable, energy-secrue future of Europe are not very promising
    1. Economically, the business model of CCS-plants (base-mid load) are incompatible with the dispatch of a largely renewable based electricity system, that values flexibility more than base load
    2. Institutionally, the (few) countries that have followed suit (or even preceeded) European regulation, such as the UK and Germany, are struggling to push CCS forward on the ground

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CCS Value Chain

Storage,
should includes local
pipelines

- **Enhanced Oil/ Gas/ Coal bed methane recovery**
- **Depleted oil and gas fields**
- **Aquifers, saline formations**

Transport,
should includes main
Pipelines

- **Pipelines, economic for large quantities**
- **Ship, e.g. transport of natural gas from the Middle East, taking CO_2 back for EOR, EGR**
- **Road or rail, for pilot plants**

Sequestration/ Capture,
Cleaning Compression,
should includes local
pipelines

- **Post-combustion capture**
- **Pre-combustion capture**
- **Oxy-fuel**

Ongoing and Planned CCS and CO_2 Transport Projects

- **About 34 CCS power plant projects in the world under construction or announced, ranging from 5 MW up to 1 GW**
- **However, only a few CCS pilot plants started operation by now (Germany, France)**
- **World-wide storage projects < 100 running or planned, no technical barriers expected as EOR operates in the USA since 1972**
- **In the US, about 3600 miles of CO_2 pipelines operating, technology comparable to oil or gas pipelines (15 existing projects plus 6 planned), mostly for EOR from geological CO_2 sources**
- **Elsewhere in the world: 5 existing projects (usually EOR) plus 11 planned (often CCS)**

CO_2 Transport and Storage Database

Database of 40 CO_2 Transport and Storage Projects (existing and planned) of which

- 25 are located within the US/Canada
- 1 located in Brazil (operating)
- 2 are located in Australia (planned)
- 1 located in Turkey (operating)
- 1 located in Algeria (operating
- 10 located within Europe (2 operating)

Analysis of ownership structure and contract structure between sources, sinks and pipeline owners if possible

Focus on the US sector, in which most of the existing pipelines are located and CO_2 is profitably used in EOR operation

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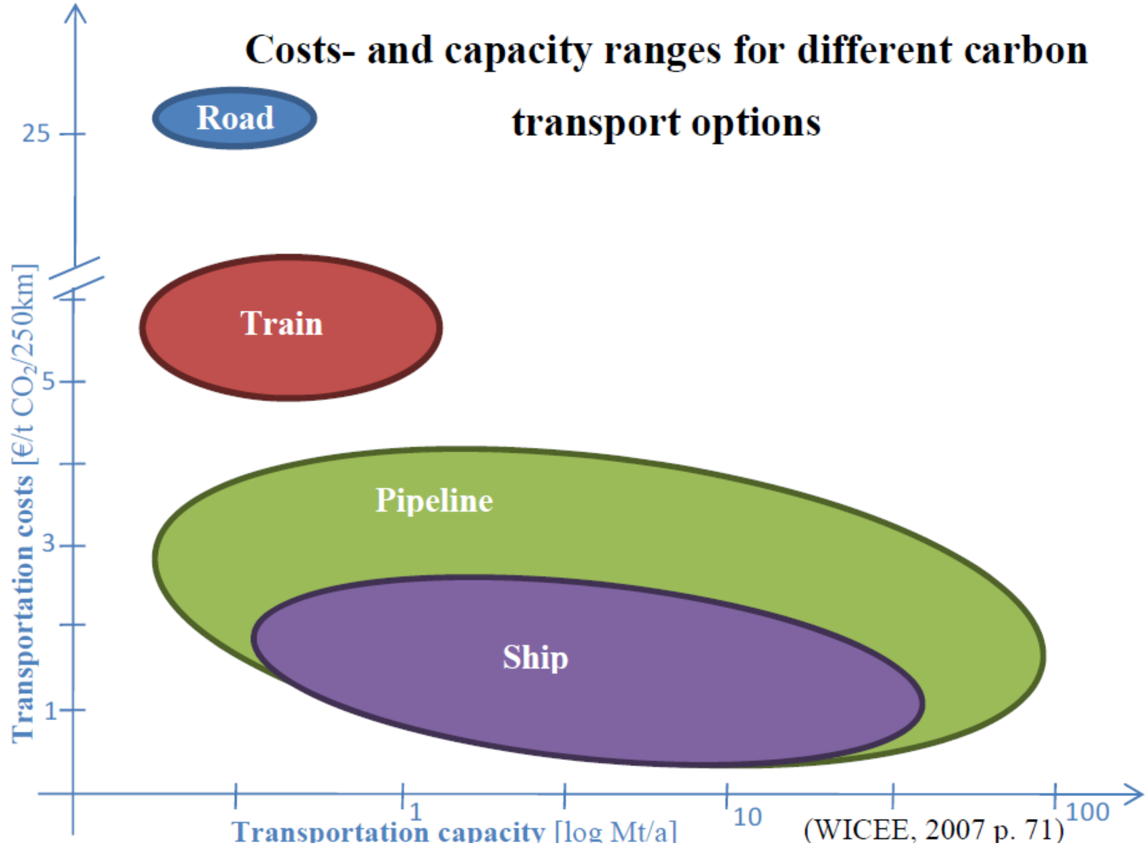
CO_2 Transport Options and Costs

Transport of CO_2 via pipelines as the only option capable of conveying the volumes involved when looking at fossil fueled power plant.

According to Valentin (2007), CO_2 emission of a large scale lignite power plant > 10,000 tCO2/d



Pipeline Networks and Cost Structure

- High capital-intensity and "sunk" costs character
- High fixed costs (the pipeline, compressor stations, metering) compared to low operational costs (maintenance, variable fuel costs of compressor stations)
- Construction costs are derived from a pipeline's length, diameter and maximum operational pressure
- Variable costs increase in the flow
- → Total costs are optimized with respect to the relation between pipeline diameter and the number of compressor stations
- Economies of scale from extending capacity from one to several pipes in a trunkline (investment costs of a second pipeline within a given corridor are about 80% of the costs of the first string; the second pipeline costs about 70% of the first pipeline)

Carbon Highway Masterplan for Europe?
Estimated European Carbon Sources and Sinks

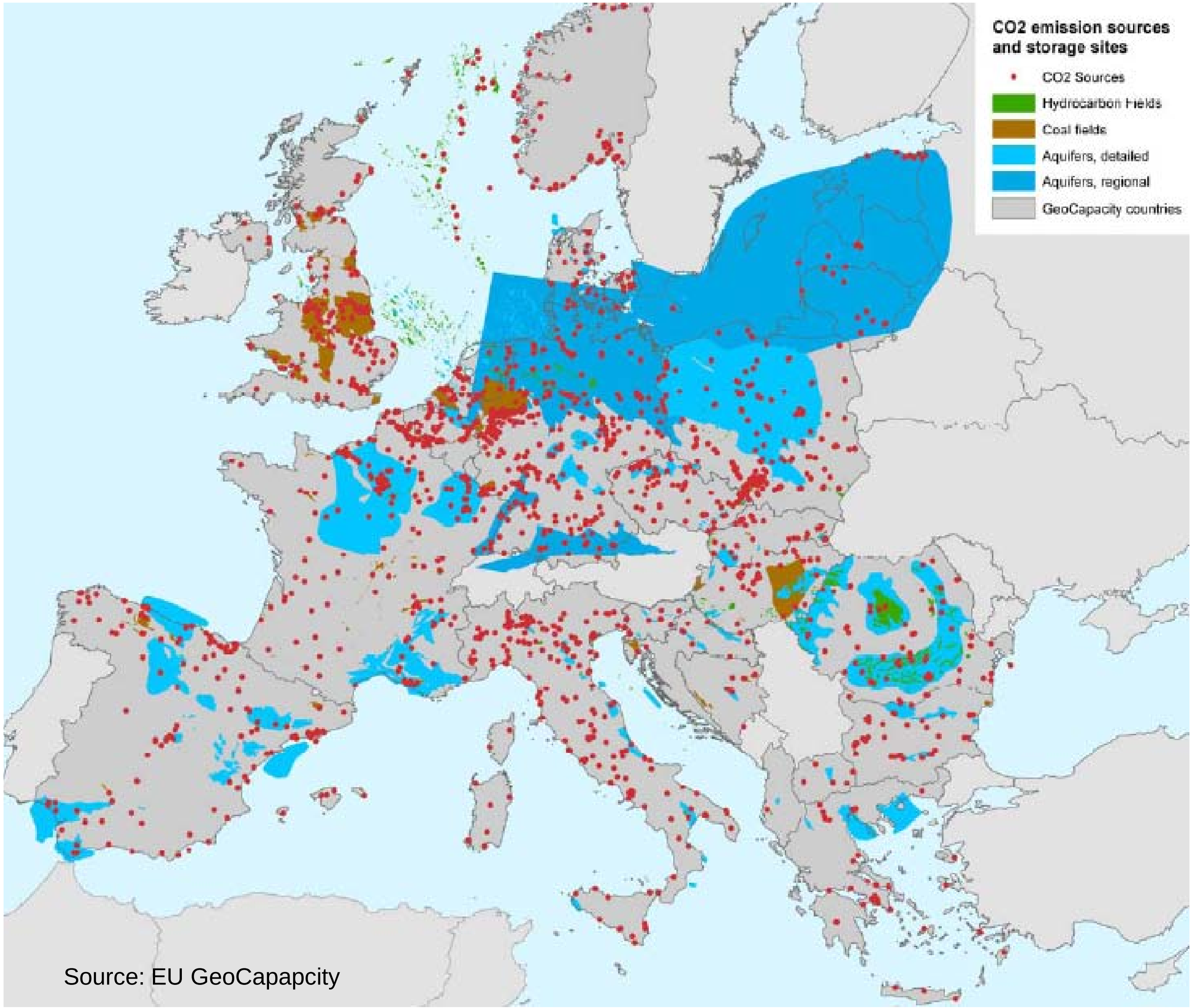
For **storage** suitable gas fields located in the **North,** Aquifers mainly located in **North-East Europe**

→ **Disconnection of major CO_2 sources and sinks, scarce low cost storage potential**

Pipeline costs should be carried by a **large consumer basis** and low-cost, long-term **access to alternative storage sites** should be given.

Common, **shared CO_2 transport network,** ensuring **non-discriminating access to the pipeline and storage sites.**

Connecting different storage sites, allows **switching between reservoirs.**



Source: EU GeoCapapcity

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US CO_2 Pipeline Network

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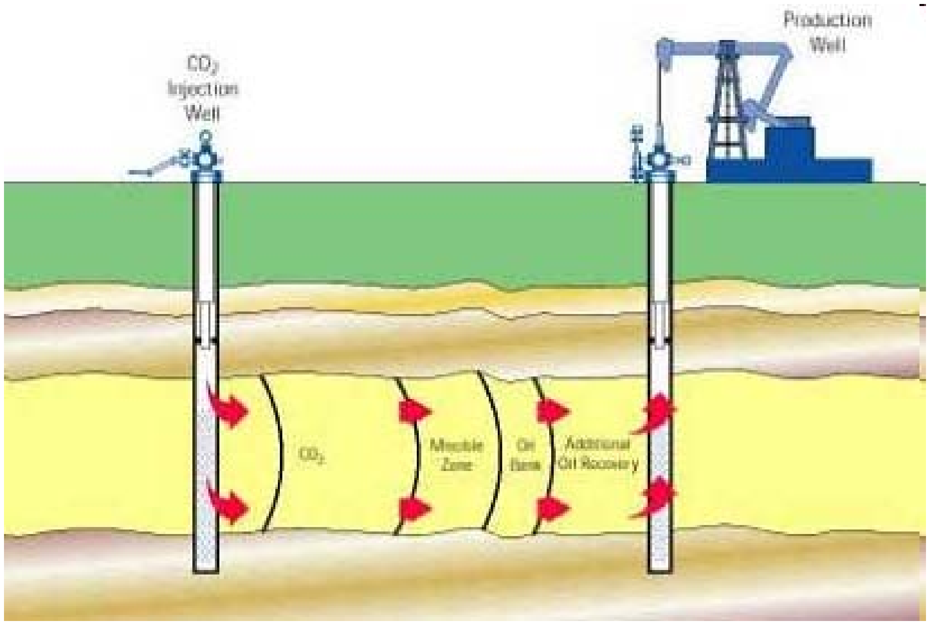
Existing CO_2 "Storage": Enhanced Oil Recovery (EOR)

Conventional oil production yields only a fraction of the original oil in place.

- When this method is exhausted, water (secondary recovery) and CO_2 floods (tertiary recovery) may be used to increase production.
- The pressurized CO_2 expands in the field, thereby pushing additional oil to a production wellborn and decreasing viscosity of the oil.
- 6-10 Mcf of CO_2 are needed to produce 1 incremental bl. of oil, so the cost of CO_2 in EOR operation constitutes about 20 to 35 % of the sales revenue and is the most expensive part of operating a CO_2 flood.
- The increase in total recovery can lead to additional monetary benefits of 50% for an average field.



Development of the US EOR CO_2 Transport Sector

The first project utilizing CO_2 was the SACROC unit in the Permian Basin in Texas. Starting in 1972, it uses CO_2 from four gas processing plants which was delivered via the Common Reef Carriers pipeline.

Natural reservoirs of CO_2 , namely McElmo Dome in Colorado and Bravo Dome in New Mexico where tapped and their CO_2 transported to the Permian Basin via the Cortez (808 km) and Bravo (351 km) pipelines, respectively.

The main CO_2 sources for the Permian Basin today are the McElmo Dome and Doe Canyon (966 MMcfd), Bravo Dome (290 MMcfd) and Sheep Mountain (40 MMcfd) fields in Colorado and New Mexico, and several natural gas processing plants to the south of the basin, connected via the Val Verde Pipeline (75 MMcfd), totalling a capacity of 1,371 MMcfd or 26.6 Mt/a (Moritis, 2008. "Worldwide EOR Survey", *OGJ*).

Low cost CO_2 availability is the limiting factor to the expansion of EOR operations in the basin and several companies seek to increase it with new reservoirs and pipelines.

US CO_2 Pipeline Network

Ownership Structure in the US CO_2 Network

- **25 transport and storage projects: 18 operating, 7 planned or under construction)**
  - 2 located in Canada,
  - 2 connect Canada with the US
  - 21 state/interstate US pipelines
- **Contract data only available for a very limited number of projects**
- **Pipeline length ranges between 15 to 890 km, and capacities up to 21 Mt/a (Cortez pipeline)**
- **So far, only low costs sources like natural CO_2 reservoirs or industrial sources are used**

Table: Typical costs of CO2 capture for industrial plants

Facility	€/tCO_2	Facility	€/tCO_2
Cement plants	28	Refineries	29-42
Iron and steel plants	29	Hydrogen (pure CO_2)	3
Ammonia plants (pure CO_2)	3	Petrochemical plants	32-36

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Vertical Structure of the CCS Value Added Chain

- A Discussion from an Institutional Economics Perspective -

Idiosyncratic investments in uncertain environments should lead to a motivation to choose more hierarchical governance forms

Objective = minimization of the sum of production and transaction costs:

Governance forms:

Market = „Classical contract“

- Identity of the trading partners is irrelevant
- Short-term relationship without any longer-term dependency
- Good in autonomous adaptation to changing conditions

Hierarchy = „Vertical integration“

- Good in coordinated adaptation to changing conditions

Spectrum of hybrids, e.g.:

- Long-term contract (identity of the trading partners matters, bilateral dependency, safeguards may be implemented, trade-off between flexibility and security)
- Relational contract (incomplete contract where reputational aspects are relevant)
- Joint ventures, R&D partnerships, …

Players along the CO_2 Value Chain

- **Participants in CO_2 market face risks similar to those in natural gas market:**
  - **High capital expenditures**
  - **Sunk costs (development of CO_2 fields and pipeline construction)**
  - **Requirement of continuous cash flows from EOR and pipeline operation to pay back high capital costs**
- **EOR operators depend on a steady supply of CO_2:**
  - **Supply may be interrupted for technical reasons or because the seller chooses to sell his product to a third party**
- **Producers of natural CO_2 cannot sell their gas to a random buyer:**
  - **Limited number of oil fields are connected to CO_2 sources by pipeline**
- **All parties are tied to one another technically due to the physical structure of the pipeline network**
  - **This is less of a constraint for EOR operations in the Permian Basin (Texas) where the bulk of EOR operations is located, as the network of different CO_2 pipelines with different owners and operators may allow for a change of the source or sink of CO_2.**

Conclusions from Existing CO_2 Transportation Experience

Pipeline network emerged as CO_2 is profitably used in EOR operations and low cost natural CO_2 sources are used as supply.

Vertical integration is common on the US market:

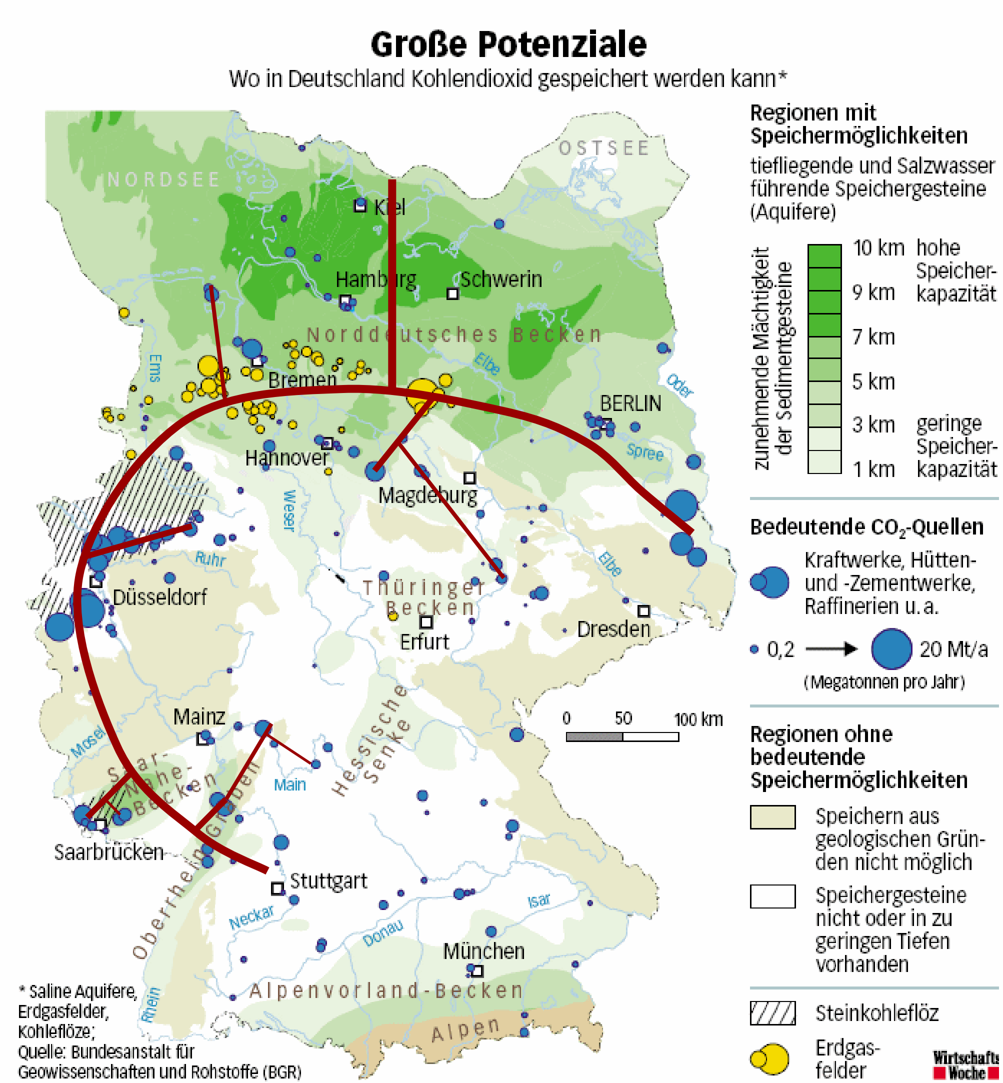
Most participants have an ownership interest and/or operate at least two of the three segments of the value chain (companies own and/or operate the CO_2 source and the pipeline, or the pipeline and the oil field where the CO_2 is used or they are active on all three levels).

The considered projects outside North America (Snøhvit in Norway and Bati Raman in Turkey) are fully integrated and all links of the value chain are owned by the same company.

Long-term take-or-pay contracts are common:

In all cases where contract or pricing information was accessible, the price of CO_2 is linked to an index of the oil price, contracts last several years and obligate the seller to purchase a certain minimum quantity of CO_2.

Carbon Highway Masterplan for Germany?



Source: Wirtschaftswoche

- Pipeline costs should be carried by a large consumer basis and low-cost, long-term access to alternative storage sites should be given.
- Common, shared CO_2 transport network, ensuring non-discriminating access to the pipeline and storage sites.
- Connecting different storage sites, allows switching between reservoirs.
- Taking into account technical, economic, environmental and social restrictions.

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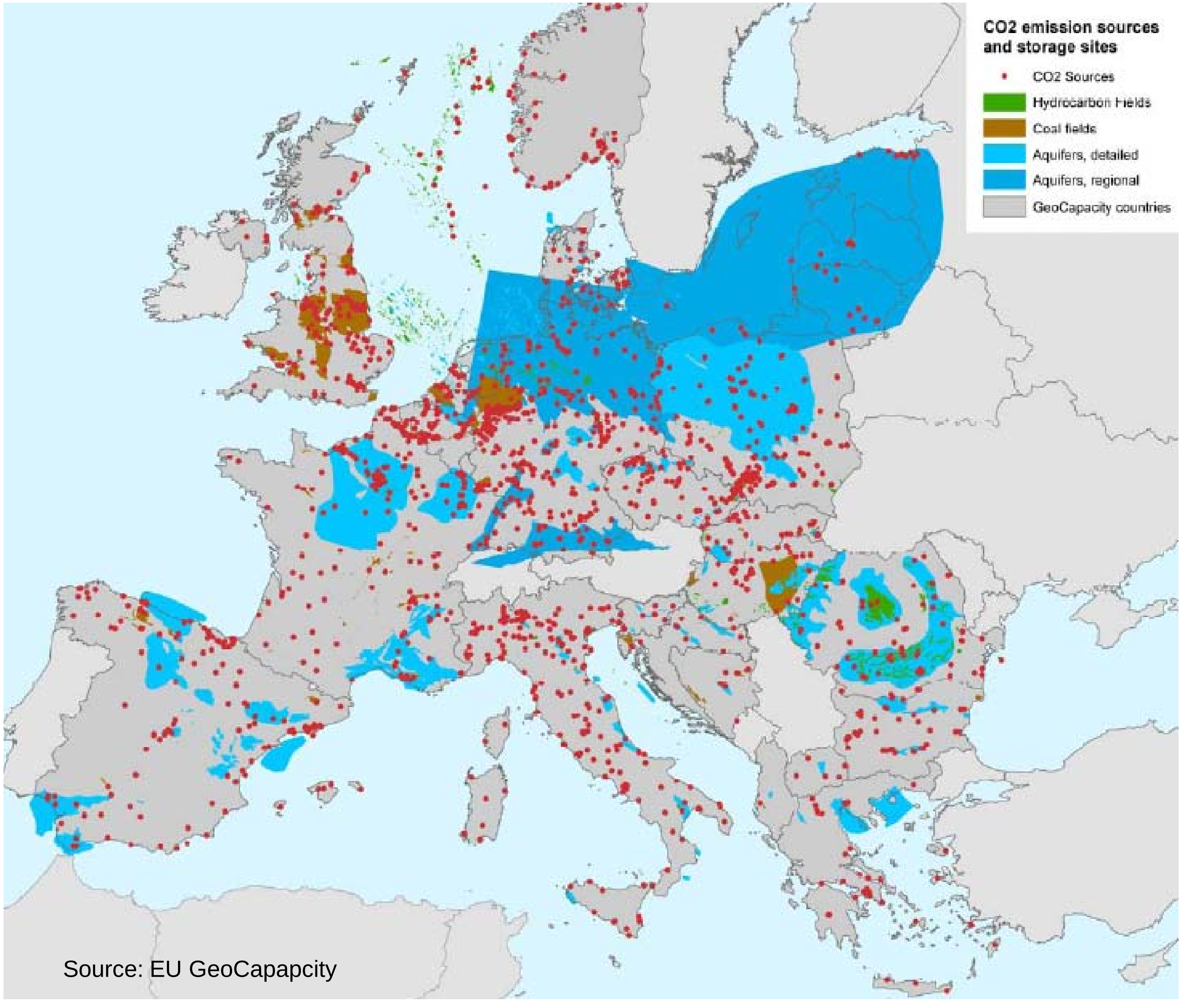

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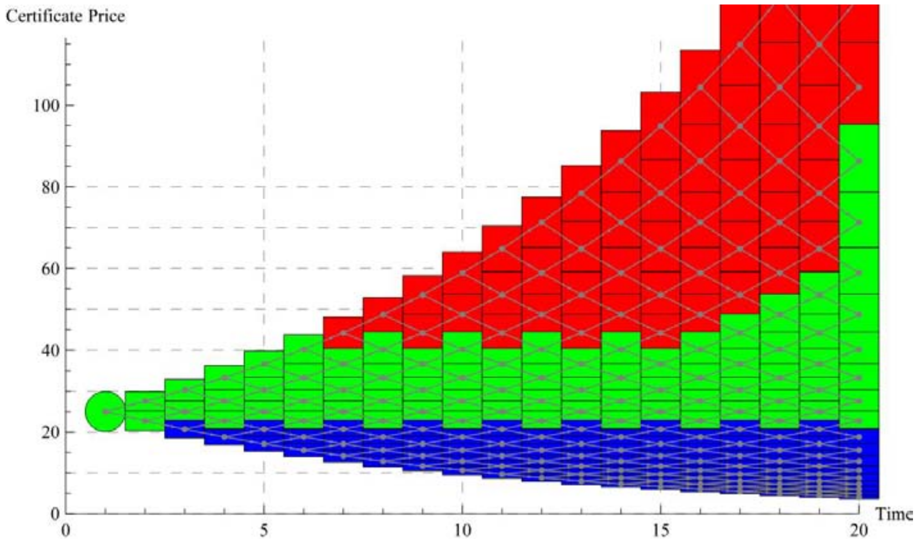
2. Institutionally, the (few) countries that have followed suit (or even preceeded) European regulation, such as the UK and Germany, are struggling to push CCS forward on the ground

Two Different Perspectives: EOR vs. CO_2 from Power Plants

In EOR operations, all player aim at a continuous CO_2 stream, although very low oil prices might stop feeding CO_2 into the fields (due to reduced oil production).

Power plant operators might prefer the option to switch between using a CCS unit or releasing CO_2 into the atmosphere as shown by Geske and Herold (2009, forthcoming).

Low cost storage operators might, according to the Hoteling rule, also have incentive to shift utilization of scarce storage capacity to later periods.



Red: invest and operate
Green: operate but do not invest
Blue: do not invest or operate a prior installed CCS unit
→ in case of low CO2 prices, efficiency penalty of CCS units outweighs sunk investment costs

Source: J. Geske and J. Herold (2009): Carbon Capture and Storage Investment and Management in an Environment of Technological and CO_2 Price Uncertainty. mimeo.

CCS: Regulation of CO_2 Transport (and Storage)

Wide-spread deployment of CCS requires the build up of large scale transportation infrastructure

High uncertainty about the size and configuration of the pipeline network

This uncertainty stems, in part, from uncertainty about the suitability of geological formations to sequester captured CO_2 and the proximity of suitable formations to specific sources

Ownership of storage sites is likely to determine the organizational form of the pipeline network

Legal and regulatory issues are the main barrier towards development of the network and thus to the CCS technology

Harmonization of activities on EU level indispensable and implementation in national law

5 Preliminary Hypotheses

The real issue in European supply security regarding coal is the absence of an economically and politically sustainable use of the coal (for electricity, liquefaction, gasification, etc.)

Current long-term energy scenarios seem to underestimate the institutional obstacles of implementing CCTS (transportation and storage); the „sustainable infrastructure" pardigm is limited by the „NIMBY infrastruture" paradigm associated with CCS

The successful US-experience with CO_2-pipelines is linked to a profitabe business model: enhanced oil recovery (EOR); it has little to do with either carbon capture neither storage

Even though considerable asset-specific investments are required along the value-added chain of CCS, vertical integration, i.e. unified ownership, is not necessarily the first-best option

The conditions for CCS to become a success story (let along „silver bullet") for a sustainable, energy-secrue future of Europe are not very promising

1. Economically, the business model of CCS-plants (base-mid load) are incompatible with the dispatch of a largely renewable based electricity system, that values flexibility more than base load
2. Institutionally, the (few) countries that have followed suit (or even preceeded) European regulation, such as the UK and Germany, are struggling to push CCS forward on the ground

Thank you very much for your attention!

SECURE Meeting Geneva
September 15 – 16, 2009

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