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COALMOD-World – The Security of Coal Supplies in Europe and Other Importing Regions Until 2030

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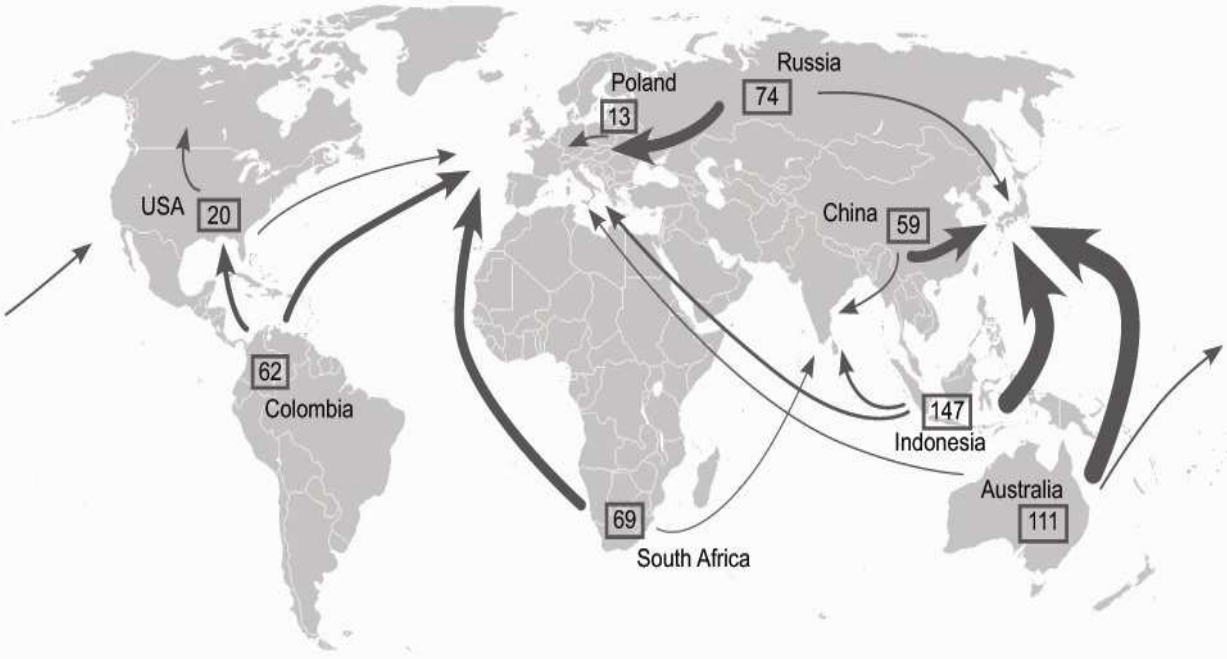
Agenda

1. **Aim and Scope of the Modeling Effort**
2. **Structure of the Model**
3. **COALMOD-World Exemplary Runs**
4. **COALMOD-World: Scenarios**
5. **Conclusions**

Steam Coal Seaborne Trade and Major Exporters

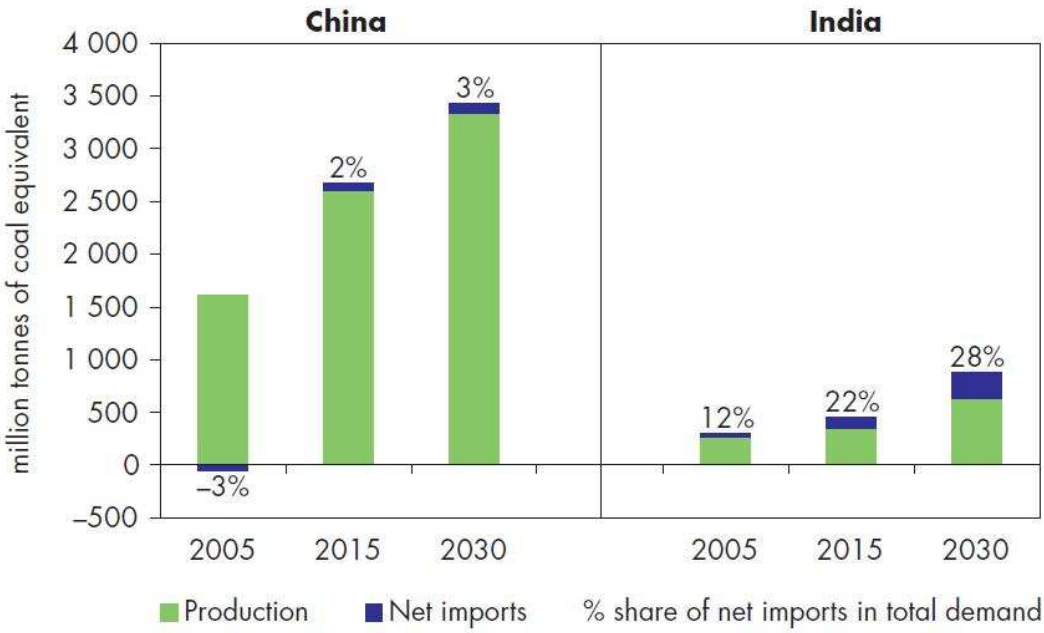
Seaborne traded steam coal 2007: 607 Mio. t



Source: IEA (2008) Coal Information

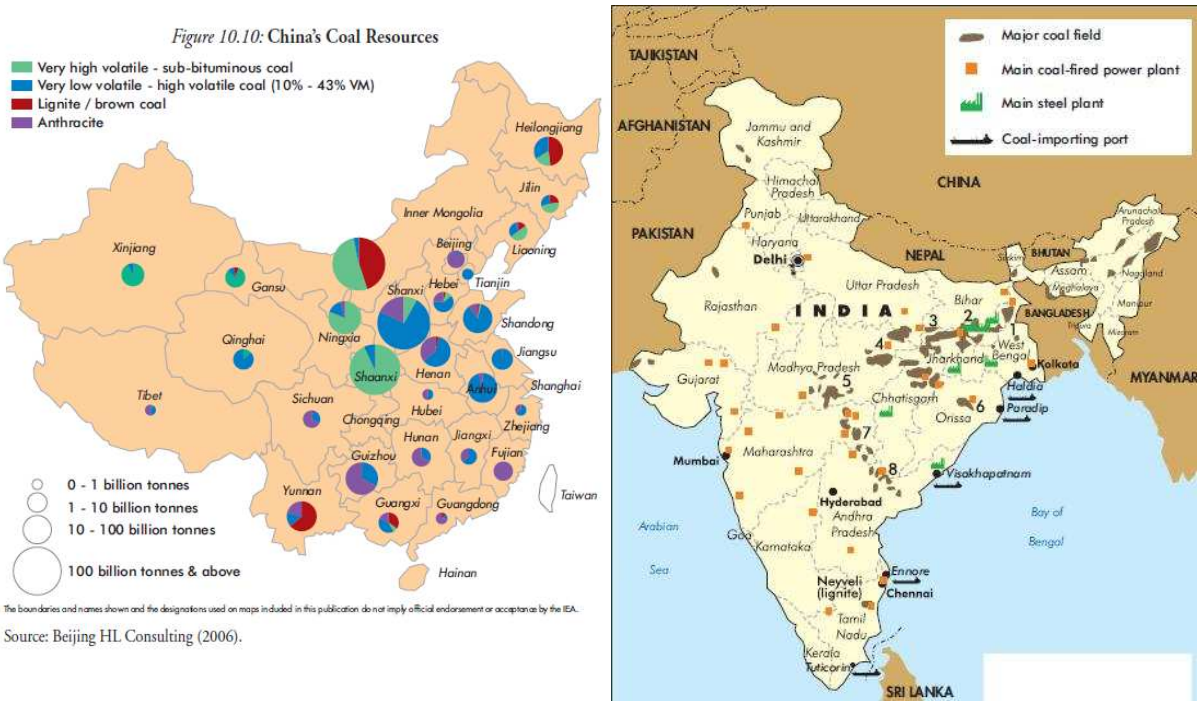
Domestic Developments and Global Trade

Figure 2.6: **Coal Balance in China and India in the Reference Scenario**



Source: IEA World Energy Outlook 2007 „China and India Insights“

Coal in China and India



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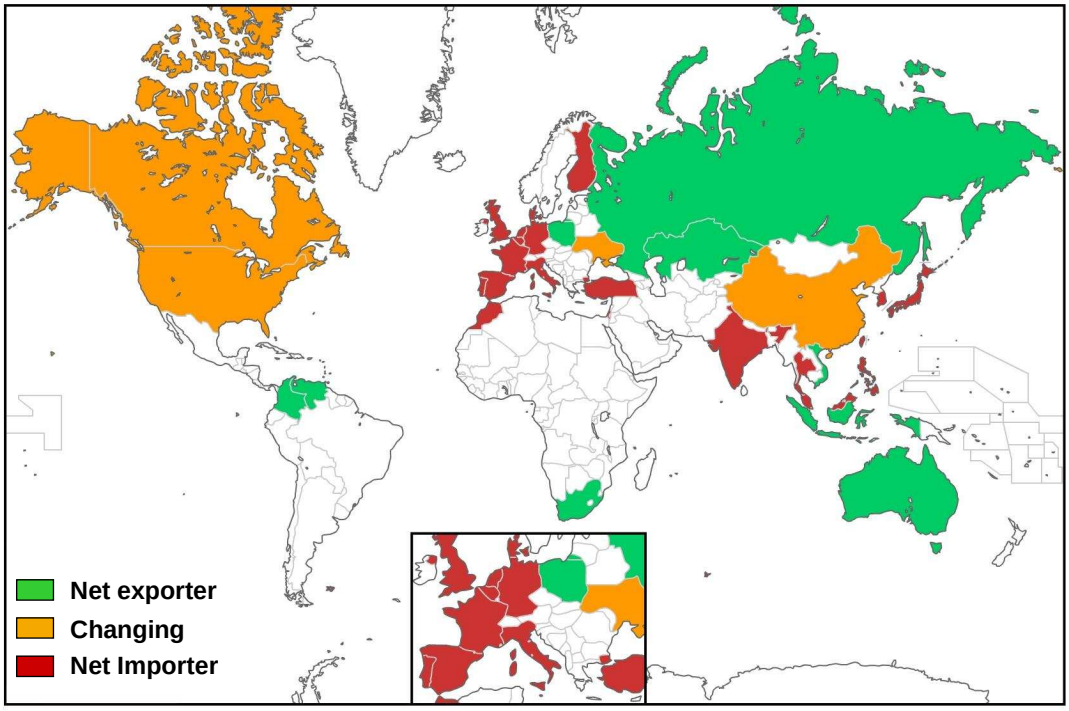
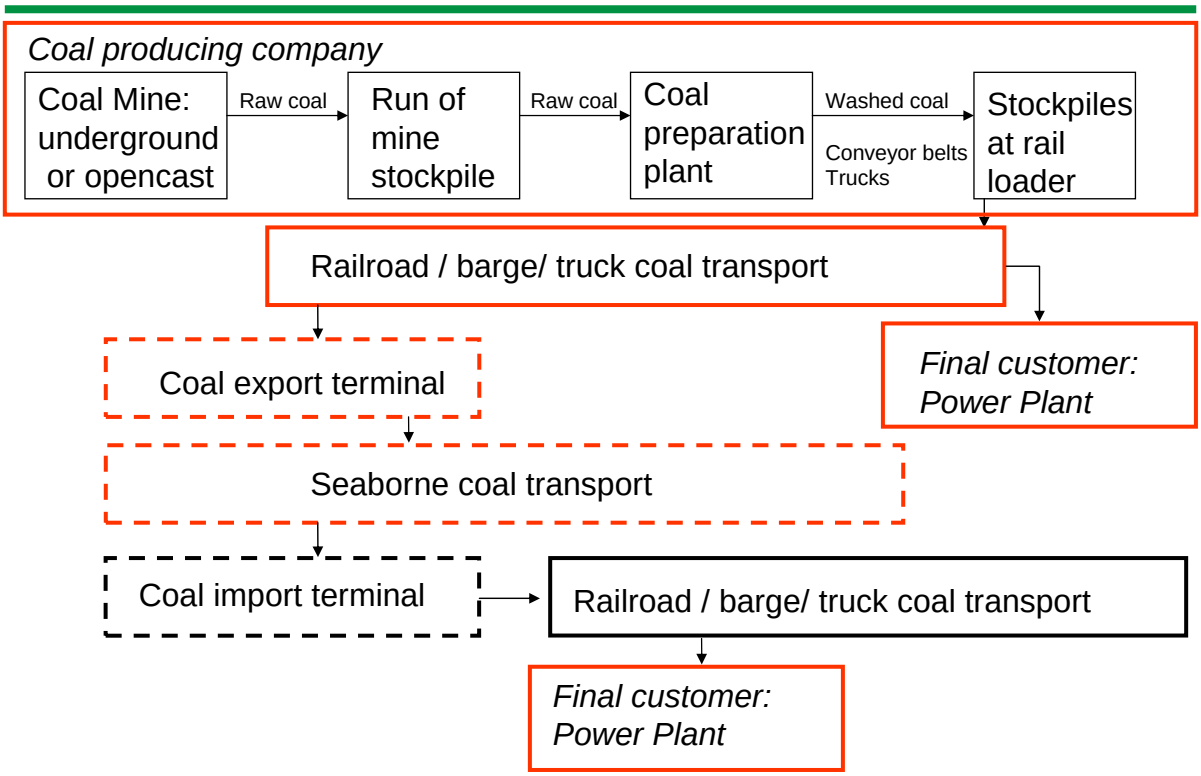
The Countries of the COALMOD-World Model



The Value-Added Chain of Steam Coal



Modeling Approach

COALMOD-World model (equilibrium model) with profit maximizing players with respect to sold quantities and investments.

- Model players:

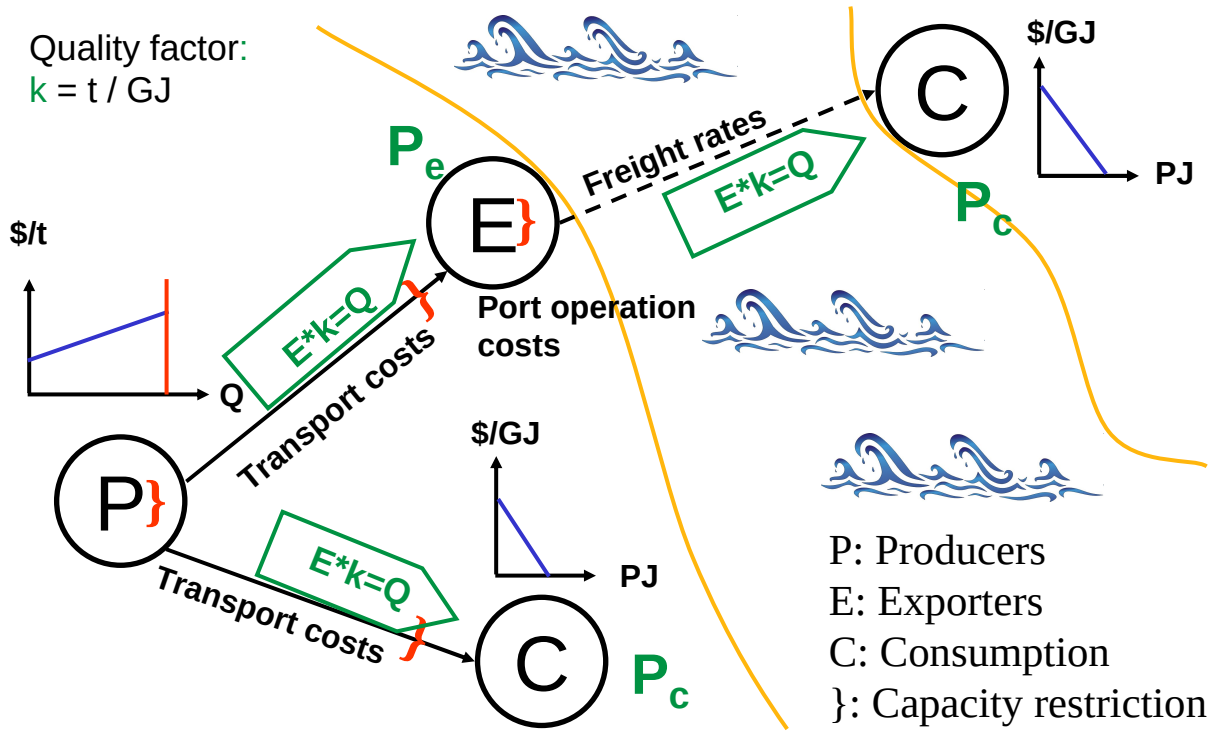
  Producers who produce, transport overland and sell the coal to local demand nodes or to the exporters.

  Exporters operate the export terminal, transport the coal over sea and sell it to demand nodes with import terminal.
- The players can also invest to expand their production, export or transport capacities.
- The model is dynamic and runs till 2040 in 5 years steps.

Specificities**:**

- Constraints on production, transport and export capacities and on investments.
- Energy and mass model: It is the energy in the coal that is traded but for the costs of producing and transporting and for the constraints it is the mass of the coal that is considered.

CMW-Energy Basic Model Structure and Data



Producer's Problem

Objective function: Profit max:

- Revenue
- Costs (production and transport)
- Investments (in production and transport)

Constraints:

- Production capacity
- Max. investments in production capacity per period
- Reserves
- Transport capacities
- Max. investments in transport capacities per period

$$\max_{x_{afc};\, y_{afe};\, Pinv_{af};\, Tinv\_c_{afc};\, Tinv\_e_{afe}} \Pi_f^P(x_{afc}; y_{afe};\, Pinv_{af};\, Tinv\_c_{afc};\, Tinv\_e_{afe})$$

$$= \sum_{a\in A}\left(\frac{1}{1+r_f}\right)^a \cdot \Big[\sum_c p_{ac}\cdot x_{afc} + \sum_e p_{ae}\cdot y_{afe}$$

$$- C_{af}^P\left(\sum_c x_{afc}\cdot\kappa_{af} + \sum_e y_{afe}\cdot\kappa_{af}\right)$$

$$- \sum_c trans\_c_{afc}\cdot x_{afc}\cdot\kappa_{af} - \sum_e trans\_e_{afe}\cdot y_{afe}\cdot\kappa_{af}$$

$$- Pinv_{af}\cdot CPinv_{af}$$

$$- Tinv\_c_{afc}\cdot CTinv\_c_{afc} - Tinv\_e_{afe}\cdot CTinv\_e_{afe}\Big] \qquad (1)$$

s.t.

$$cap_f^P + \sum_{a'<a} Pinv_{af} - \left(\sum_c x_{afc}\cdot\kappa_{af} + \sum_e y_{afe}\cdot\kappa_{af}\right) \geq 0 \qquad (\alpha_{af}^P) \qquad (2)$$

$$Pmaxinv_{af} - Pinv_{af} \geq 0 \qquad (\alpha_{af}^{Pinv}) \qquad (3)$$

$$Res_f - \sum_{a\in A}\Big[\Big(\sum_c x_{afc}\cdot\kappa_{af} + \sum_e y_{afe}\cdot\kappa_{af}$$

$$+ \sum_c x_{a-1fc}\cdot\kappa_{a-1f} + \sum_e y_{a-1fe}\cdot\kappa_{a-1f}\Big) * \frac{5}{2}\Big] \geq 0 \qquad (\alpha_f^{Res}) \qquad (4)$$

$$Tcap\_c_{fc} + \sum_{a'<a} Tinv\_c_{afc} - x_{afc}\cdot\kappa_{af} \geq 0 \qquad \left(\alpha_{afc}^{Tcap\_c}\right) \qquad (5)$$

$$Tcap\_e_{fe} + \sum_{a'<a} Tinv\_e_{efc} - y_{afe}\cdot\kappa_{af} \geq 0 \qquad \left(\alpha_{afe}^{Tcape}\right) \qquad (6)$$

$$Tmaxinv\_c_{afc} - Tinv\_c_{afc} \geq 0 \qquad (\alpha_{afc}^{Tinv\_c}) \qquad (7)$$

$$Tmaxinv\_e_{afe} - Tinv\_e_{afe} \geq 0 \qquad (\alpha_{afe}^{Tinv\_e}) \qquad (8)$$

$$x_{afc} \geq 0;\; y_{afe} \geq 0;\; Pinv_{af} \geq 0;\; Tinv\_c_{afc} \geq 0;\; Tinv\_e_{afe} \geq 0 \qquad (9)$$

Exporter's Problem

Objective function: Profit maximization

- Revenue
- Costs
- Investments

Constraints:

- Export capacity
- Max. investments in export capacity per 5 years
- Max. possible investments in export capacity over total time

$$\max_{z_{aec};\, Einv_{ae}} \quad \Pi_e^E(z_{aec};\, Einv_{ae}) = \sum_{a \in A} \left(\frac{1}{1+r_e}\right)^a \cdot \left(\sum_c p_{ac} \cdot z_{aec} - \sum_c p_{ae} \cdot z_{aec} - \sum_c z_{aec} \cdot Cport_{ae} \cdot \kappa_{ae} - \sum_c z_{aec} \cdot searate_{aec} \cdot \kappa_{ae} - Einv_{ae} \cdot CEinv_{ae} \right) \quad (10)$$

s.t.

$$Ecap_e + \sum_{a'<a} Einv_{ae} \quad \sum_c z_{aec} \cdot \kappa_{ae} \geq 0 \quad (\mu_{ae}^E) \quad (11)$$

$$Emaxinv_{ae} - Einv_{ae} \geq 0 \quad (\mu_{ae}^{Einv}) \quad (12)$$

$$Emaxcap_e - Ecap_e - \sum_a Einv_{ae} \geq 0 \quad (\mu_e^{Emax}) \quad (13)$$

$$z_{ec} \geq 0;\; Einv_{ae} \geq 0 \quad (14)$$

Quality and Market Clearing Constraint

Coal quality equations:

Producers Quality factor:

$$\kappa_{af} = \kappa_f + \delta_f \cdot \sum_{a' \leq a} \left(\sum_c x_{afc} + \sum_e y_{afe} \right)$$

Exporters Quality factor:

$$\kappa_{ae} = \frac{\sum_f \kappa_{af} \cdot y_{afe}}{\sum_f y_{afe}}$$

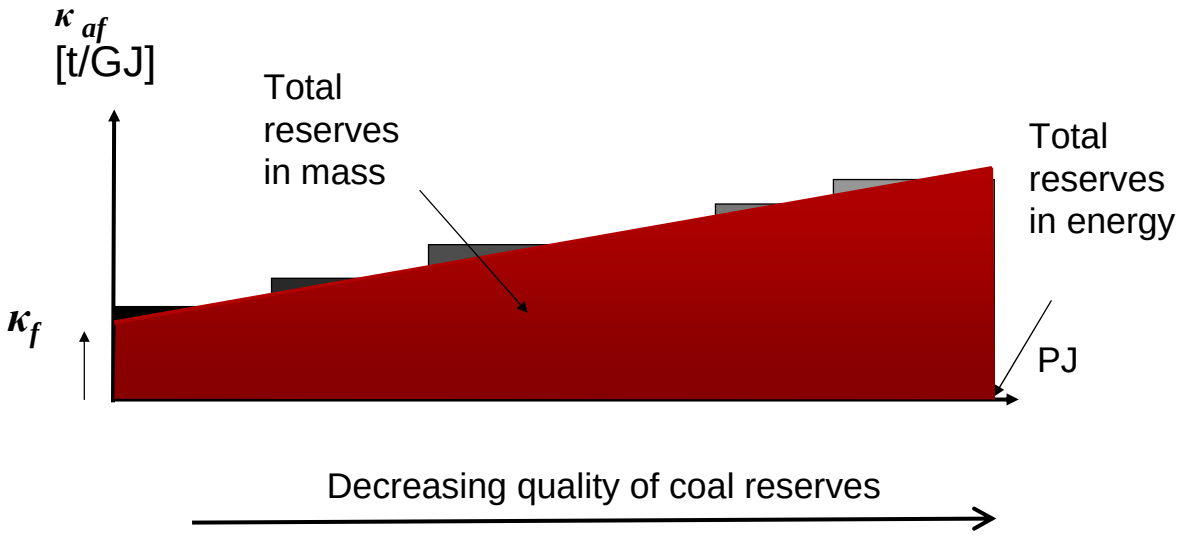
Demand and market clearing condition:

$$p_{ac} - p_{ac} \left(\sum_f x_{afc}, \sum_e z_{aec} \right) = 0 \quad , p_{ac}(\text{free})$$

$$0 = \sum_f y_{afe} - \sum_c z_{aec} \quad , p_{ae}(\text{free})$$

Reserves and Quality in COALMOD-World

$$\kappa_{af} = \kappa_f + \delta_f \cdot \sum_{a' \leq a} \left(\sum_c x_{afc} + \sum_e y_{afe} \right)$$



Summary Energy Model

Achievements of an energy based model:

- Allows to handle a different coal quality for each producer
- Can be consistently used with all the data expressed in tonnage
- Allows for the degradation of coal quality reserves (κ_f would get higher over time as the reserves are mined)
- Gives a better picture of reality

Possible extensions:

- Possibility to bind demand to certain coal types (E/Q > Value)
- Include coal washing facilities (lowers κ_f) for flows to the exporters.

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Provisional Assumptions

- **Status of data: more and more precise data inputs are needed**

- **For the following run:**
  - **Costs increase in accordance with price developments shown below**
  - **Inland transport costs do not vary over time**
  - **Freight rate do not vary over time**
  - **There is no restriction on investments**
  - **There is no variation of quality over time**

- **This may lead do various types of distortions**
- **The following results are illustrative!**

Provisional Data Until 2030

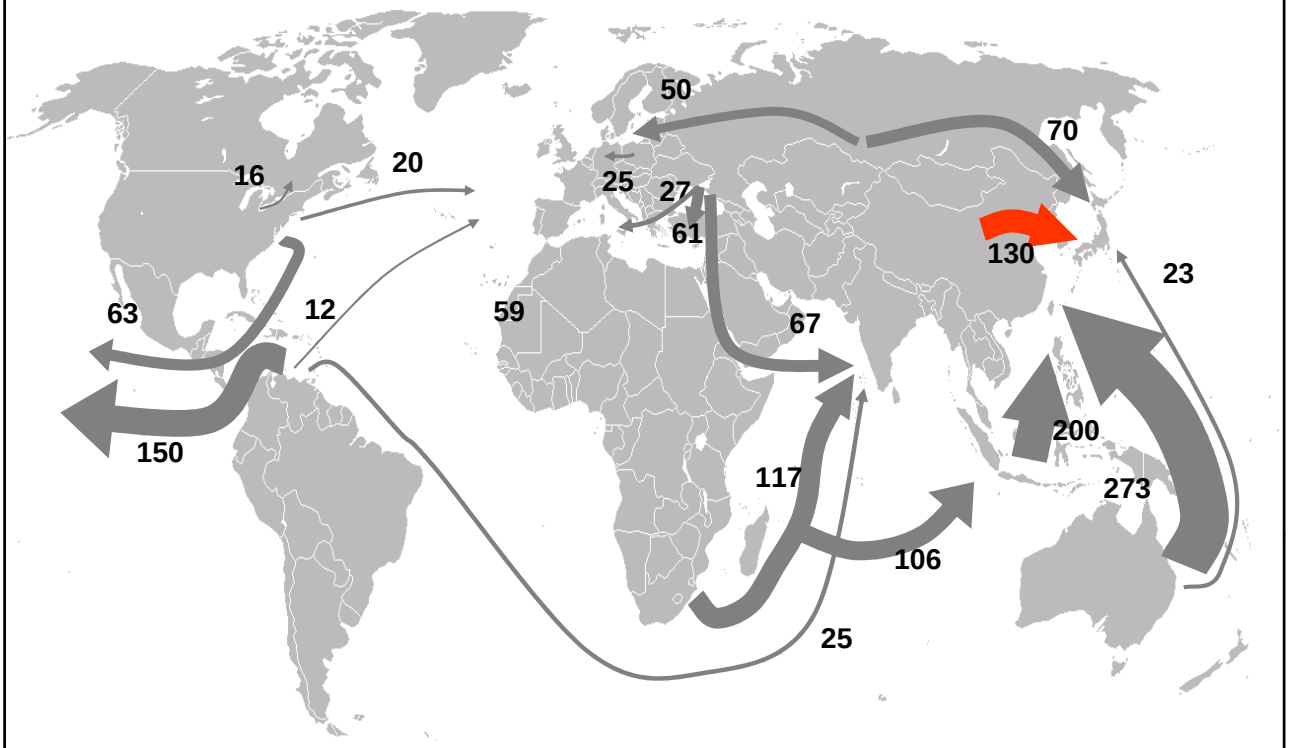
- **Demand projection from IEA World Energy Outlook 2008: Reference Scenario**

Table 5.1 • World primary coal* demand in the Reference Scenario
(million tonnes of coal equivalent)

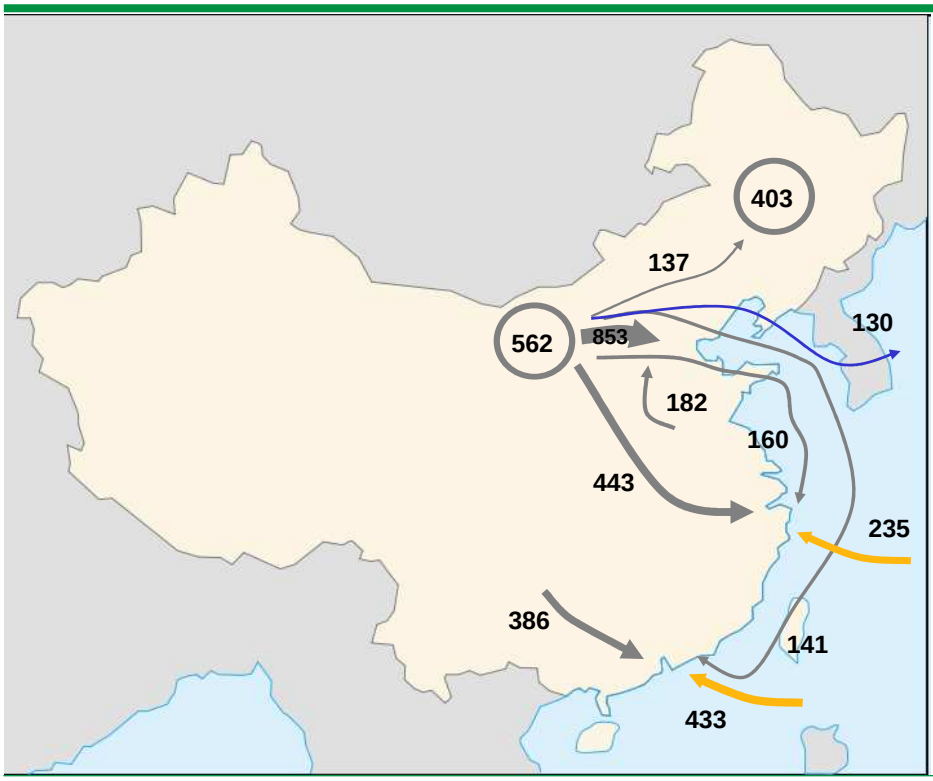
	1980	2000	2006	2015	2030	2006-2030**
OECD	1 373	1 566	1 627	1 728	1 703	0.2%
North America	571	832	839	895	959	0.6%
United States	*537*	*777*	*787*	*829*	*905*	*0.6%*
Europe	657	467	472	491	418	-0.5%
Pacific	145	267	316	342	326	0.1%
Japan	*85*	*140*	*161*	*164*	*153*	*-0.2%*
Non-OECD	1 181	1 714	2 735	4 019	5 308	2.8%
E. Europe/Eurasia	517	295	307	356	386	1.0%
Russia	*n.a.*	*158*	*152*	*201*	*233*	*1.8%*
Asia	572	1 249	2 238	3 415	4 634	3.1%
China	*446*	*899*	*1 734*	*2 712*	*3 487*	*3.0%*
India	*75*	*235*	*318*	*451*	*827*	*4.1%*
Middle East	2	12	13	20	36	4.4%
Africa	74	129	147	174	175	0.8%
Latin America	16	29	31	55	77	3.8%
World***	2 554	3 279	4 362	5 746	7 011	2.0%
European Union	*n.a.*	*459*	*463*	*460*	*372*	*-0.9%*

- **Prices from Primes (**EC: European Energy and Transport trends to 2030 - 2007 Update): 2005:**14.8**, 2010: **13.7**, 2015: **14.3**, 2020: **14.7**, 2025: **14.8**, 2030 **14.9** in **USD(2005)/boe**

Base Case Results 2030: Seaborne Flows (in Mt)



China Results 2030 (in Mt)



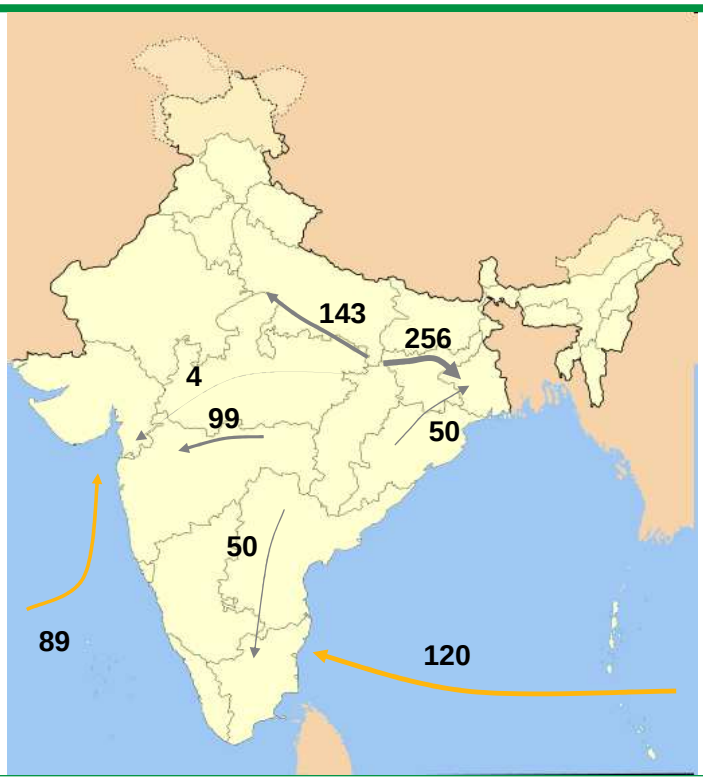
Export licenses: 130 Mt

Exports to:
- Korea
- Japan
- Taiwan

Imports from:
- Colombia
- South Africa
- Russia
- Indonesia
- Australia

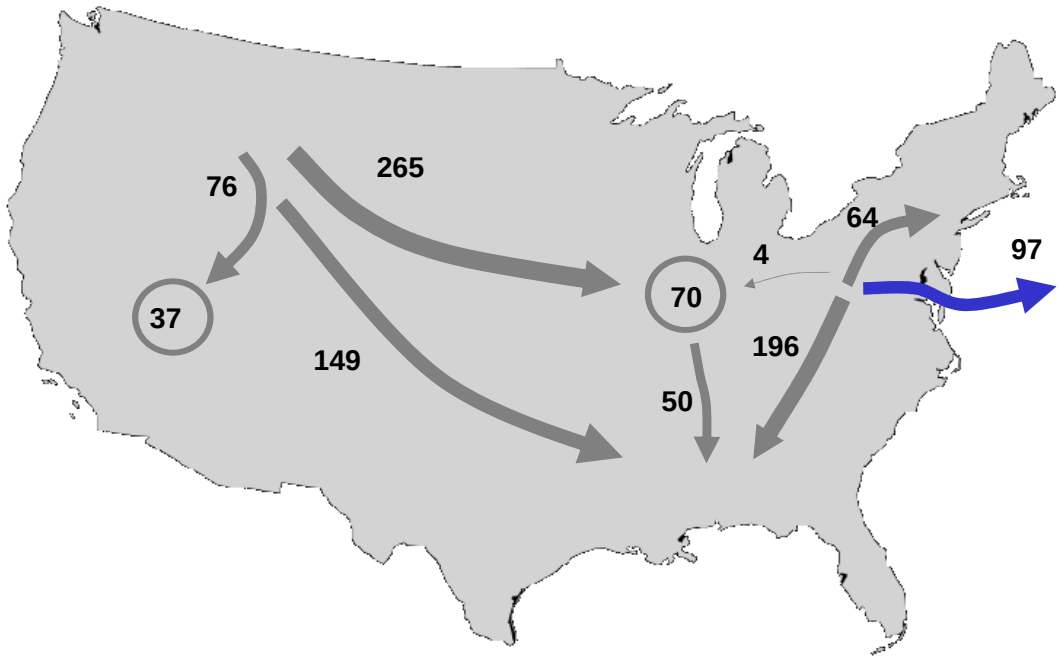
India Results 2030 (in Mt)

Imports from:
- Colombia
- South Africa
- Russia



Imports from:
- Colombia
- South Africa
- Russia

USA Results 2030 (in Mt)



Exports to:
- Canada
- Europe

Marginal supplier to:
- India
- China

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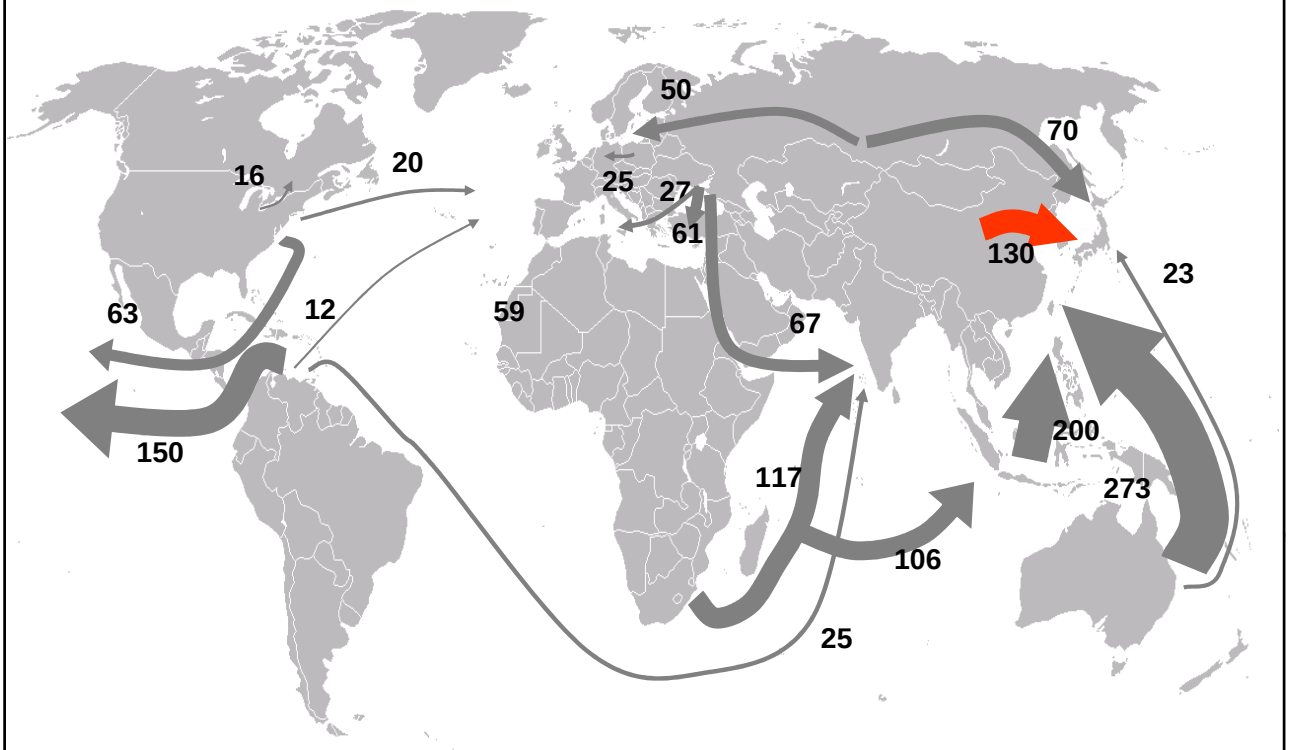
China: (Political) Export Restrictions

2005:	**80 Mt**
2010:	**110 Mt**
2015:	**115 Mt**
2020:	**120 Mt**
2025:	**125 Mt**
2030:	**130 Mt**
2035:	**135 Mt**
2040:	**140 Mt**

Comparison of two model runs:
- one with the restriction of Chinese exports as shown above
- one without any restriction on Chinese exports for all model periods

Base Case Results 2030: Seaborne Flows (in Mt)



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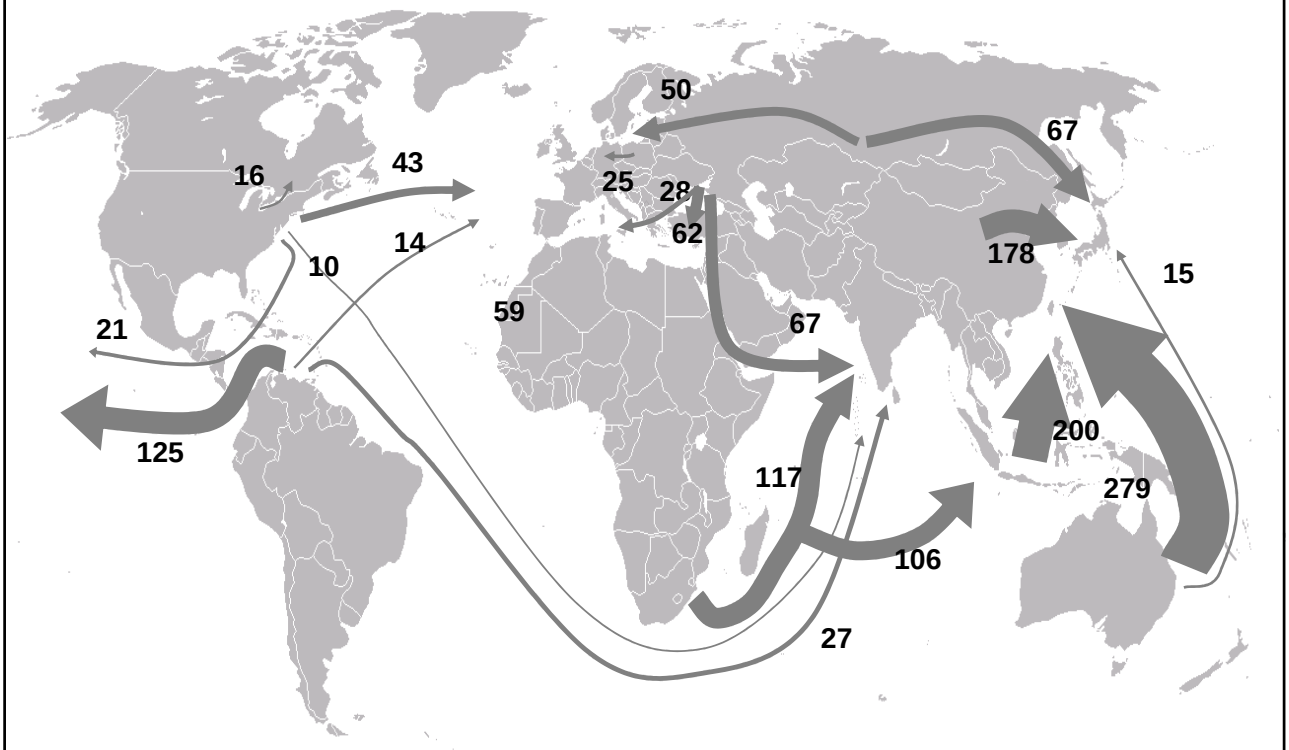
China Case Results 2030: Seaborne Flows (in Mt)



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Possible Scenarios

Scenarios	Meaning	Implementation
Global Scenarios		
i) Carbon constraint case	Reduce demand for coal due to increased CO2 and implicit coal price	Add a “tax” on delivered price of coal, differentiated by consuming country (Kyoto countries; plus US, AUS, RSA; all incl. China and India); Possibly cap demand determined by CO2 content of coal
ii) CCS case	Increase of demand for coal due to lower carbon emissions, based on PESD CCS database and categorization	Shift of demand function, with data input from POLES model
iii) Low natural gas prices	Natural gas prices are low over time and along with CO_2 prices make gas more competitive than coal.	Lower demand for coal in certain regions where natural gas use is high (Europe, US, Japan …)
iv) 2050	POLES scenarios: -protectionism: national approaches -liberalized, technology-push	POLES data input, adapted to the “coal only” Coalmod dynamic model

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Conclusions

- **International (seaborne) trade flows of steam coal will double until 2030, to approx. 1600 Mt/y**
- **Some exporters will reach their resource constraint, in particular Indonesia**
- **Continued rise of importance of the Asian market: China and India will increase their imports and draw a major part of the internationally traded coal**
- **Significant data base improvements necessary to benefit from the richness of the model**

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Thank you very much for your attention!

Any questions or comments?

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