TECHNISCHE UNIVERSITÄT DRESDEN

The Economics of DESERTEC

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EE²

Chair of Energy Economics and Public Sector Management and Workgroup for Infrastructure Policy (WIP)

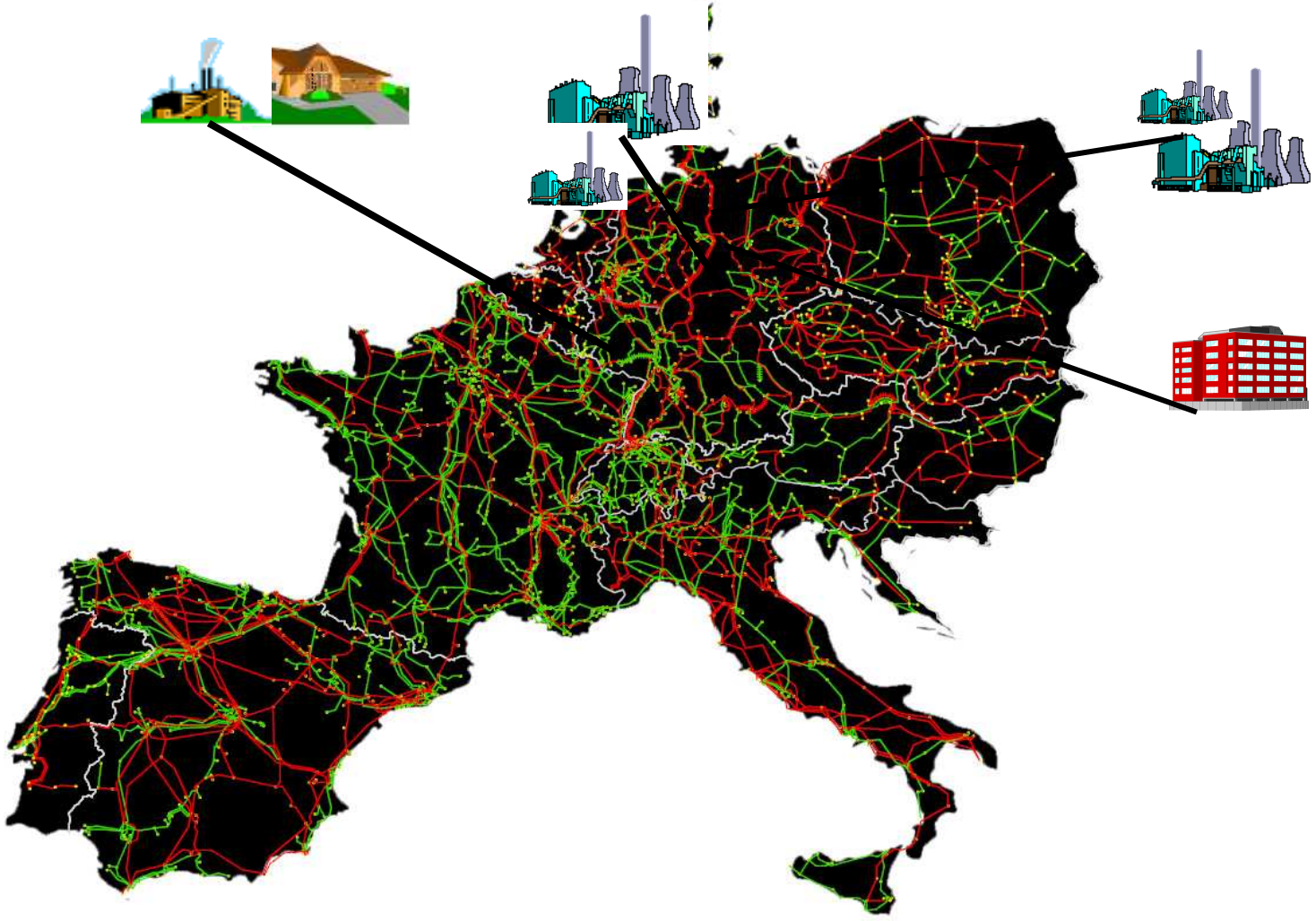
6 Theses

- **The existing AC grid will play an important role in super grid approaches and must not be neglected in the planning**
- **Regional, multi-source Super Grids (combining different studies) are to be considered**
- **A simple welfare maximization approach is not sufficient due to potential institutional obstacles**
- **At present, most of the installed capacities are CCGS (combined cycle), significantly tilted towards natural gas**
- **The current proposal does not sufficiently take into account the initial link between energy generation and water use**
- **The institutional framework for system development of a Desertec or similar project to 2050 are not in place**

Agenda

1. Introduction
2. Adding an Economic-Engineering Approach to Desertec
3. Adding a Integrated European View
4. Winners and Losers: A Game Theoretic Approach
5. Other Issues
6. Conclusion

The ELMOD Model I



- **Economic-engineering approach**

The ELMOD Model II

Objective

n,t	node, hour
g_n	generation in n
d_n	demand in n
$p(d_n)$	demand function in n
$c(g_n)$	generation costs in n

$$\max \; W = \sum_{n,t} \int_0^{q_{n,t}^*} p(q_{n,t}) \, \mathrm{d}q_{n,t} - \sum_{n,t} \left(c(g_{n,t}) g_{n,t} \right)$$

Constraints

Line capacities

$P_{i,t}$	load flow on line i

$$\left| P_{i,t} \right| \leq P_i^{\max}$$

Energy balance

PSPup	pump storage hydro (storage)
PSPdown	pump storage hydro (generation)
windtinput	from wind energy
ni	netinput

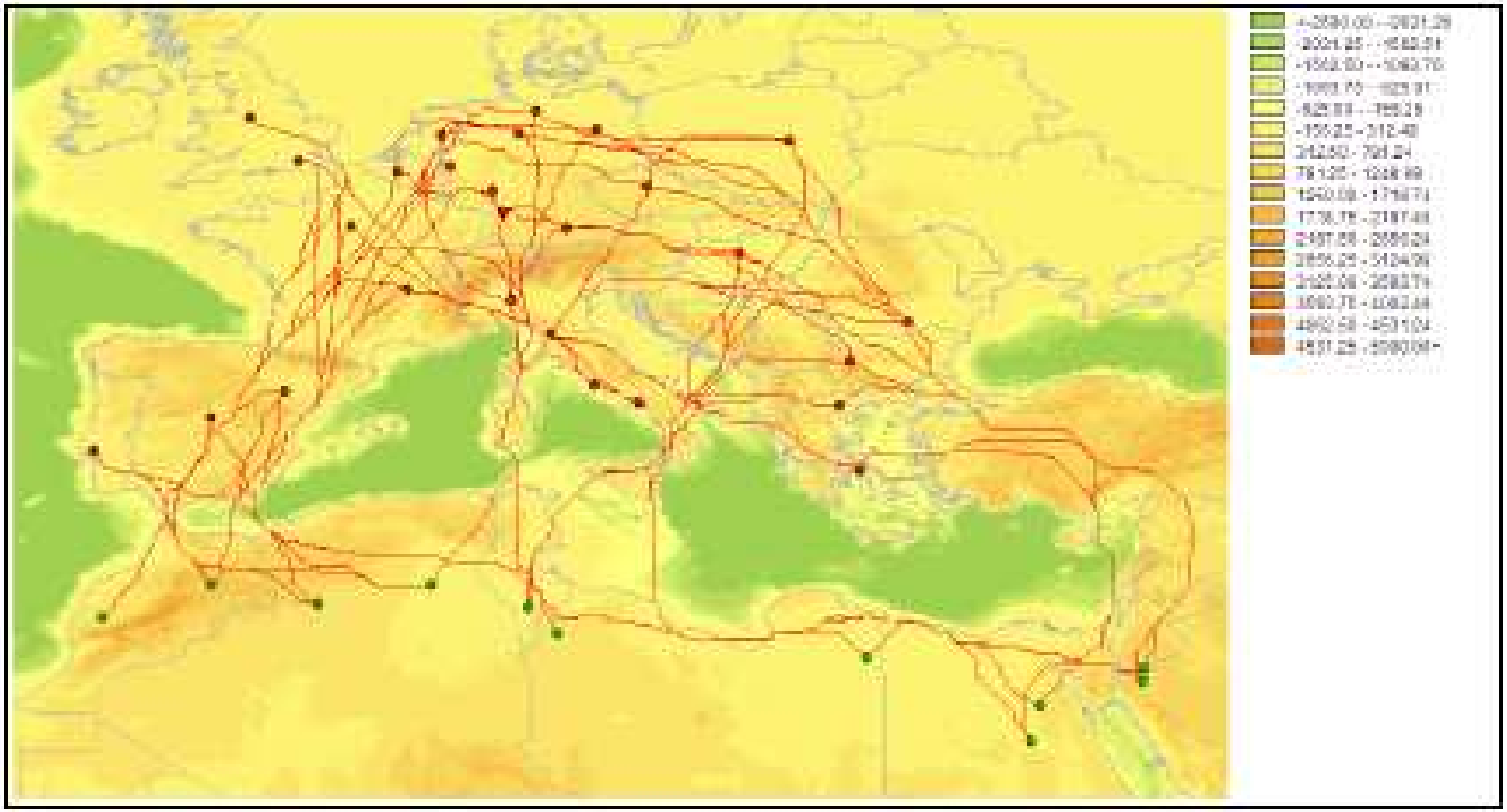
$$g_{n,t} + wi_{n,t} + PSP_{n,t}^{down} - PSP_{n,t}^{up} - q_{n,t} - ni_{n,t} = 0$$

Classification of Different Approaches for a Super Grid

		Geographic Approach	
		Continental	**Regional**
Source	**Single**	• Zweibel et al. (2009): *Grand Solar Plan* • *Trieb et al. (2009): Characterisation of Solar Electricity Import Corridors from MENA to Europe*	-
	Multiple	• Trieb et al. (2006): *Trans-Mediterranean Interconnection for Concentrating Solar Power* • AWEA, SEIA (2009) *Green Power Superhighways*	• Krapels et al. (2009): *Integrating 200,000 MW of RES into the US power grid* • *Hirschhausen et al. (2009): EEA- MENA RegGrid 2050 Integration of Large-Scale Renewables*

Solar Electricity Import Corridors from MENA to Europe – A Primer for DESERTEC

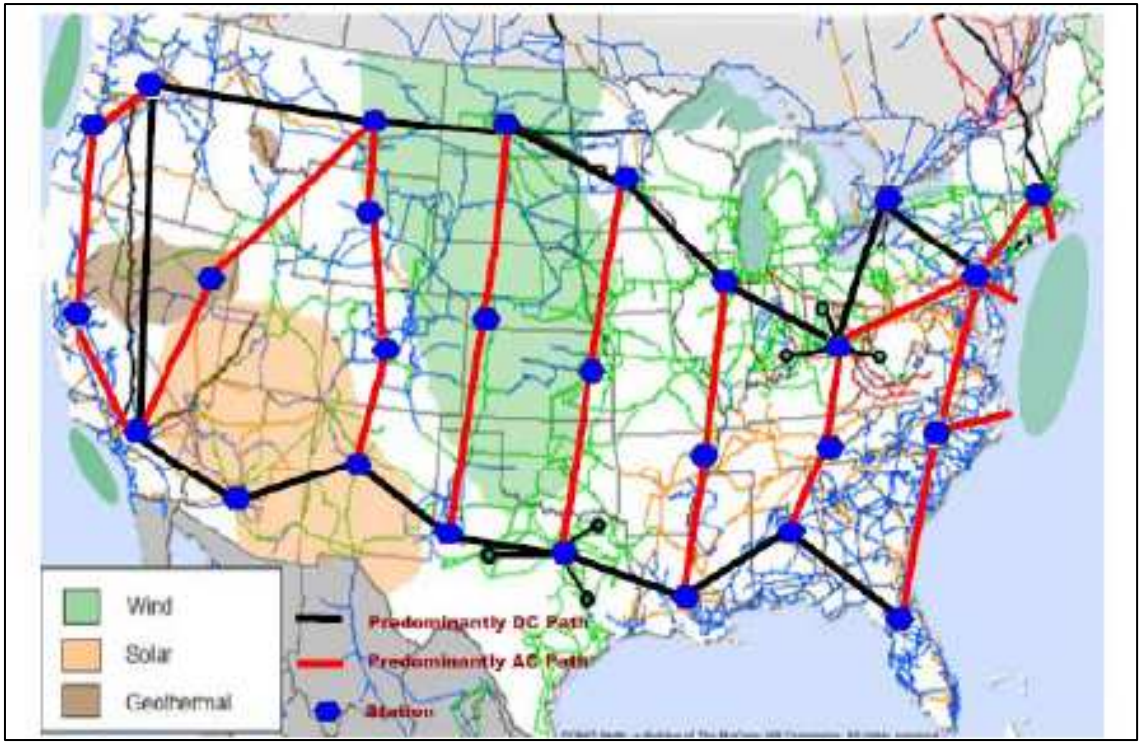
Trieb et al. 2009:



Source: Trieb et al. 2009

Multi-Source High Voltage Grid Project in the U.S.

- **DOER (2009)**
- **National approach with HVDC backbone**

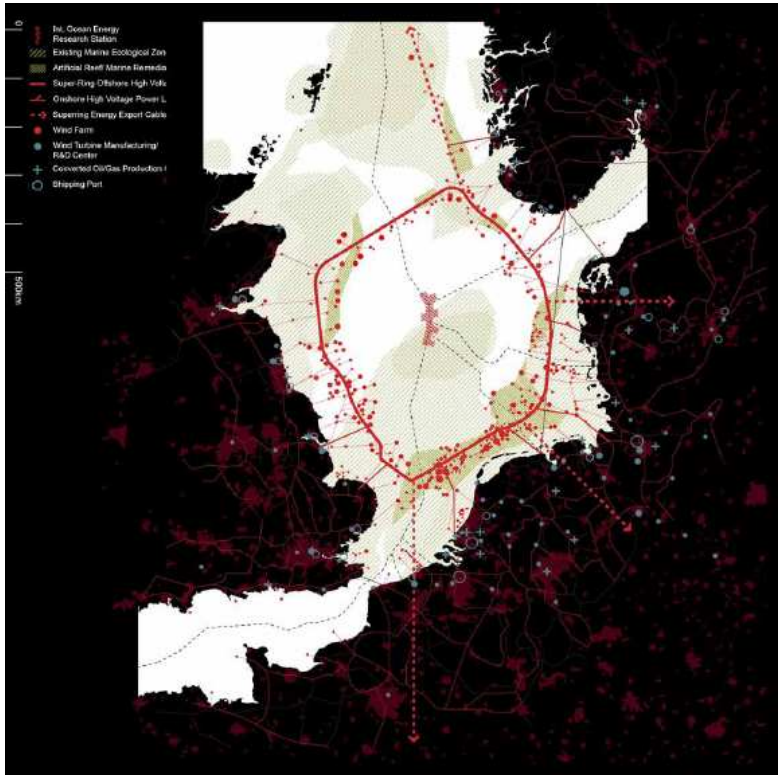


Source: DOER (2009)

The Energy Super Ring (North Sea)

- **OMA (2009)**

- **Integration of offshore wind energy from the North Sea**



Source: OMA (2009)

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Procedure I: Welfare Optimizing HVDC Expansion

- Three export nodes in the MENA region (Morocco, Tunisia and Middle East)
- Possible HVDC connection to 30 demand centers in the EU30+
- Line costs according DLR cost-distance images (DLR 2009) - 4GW cables

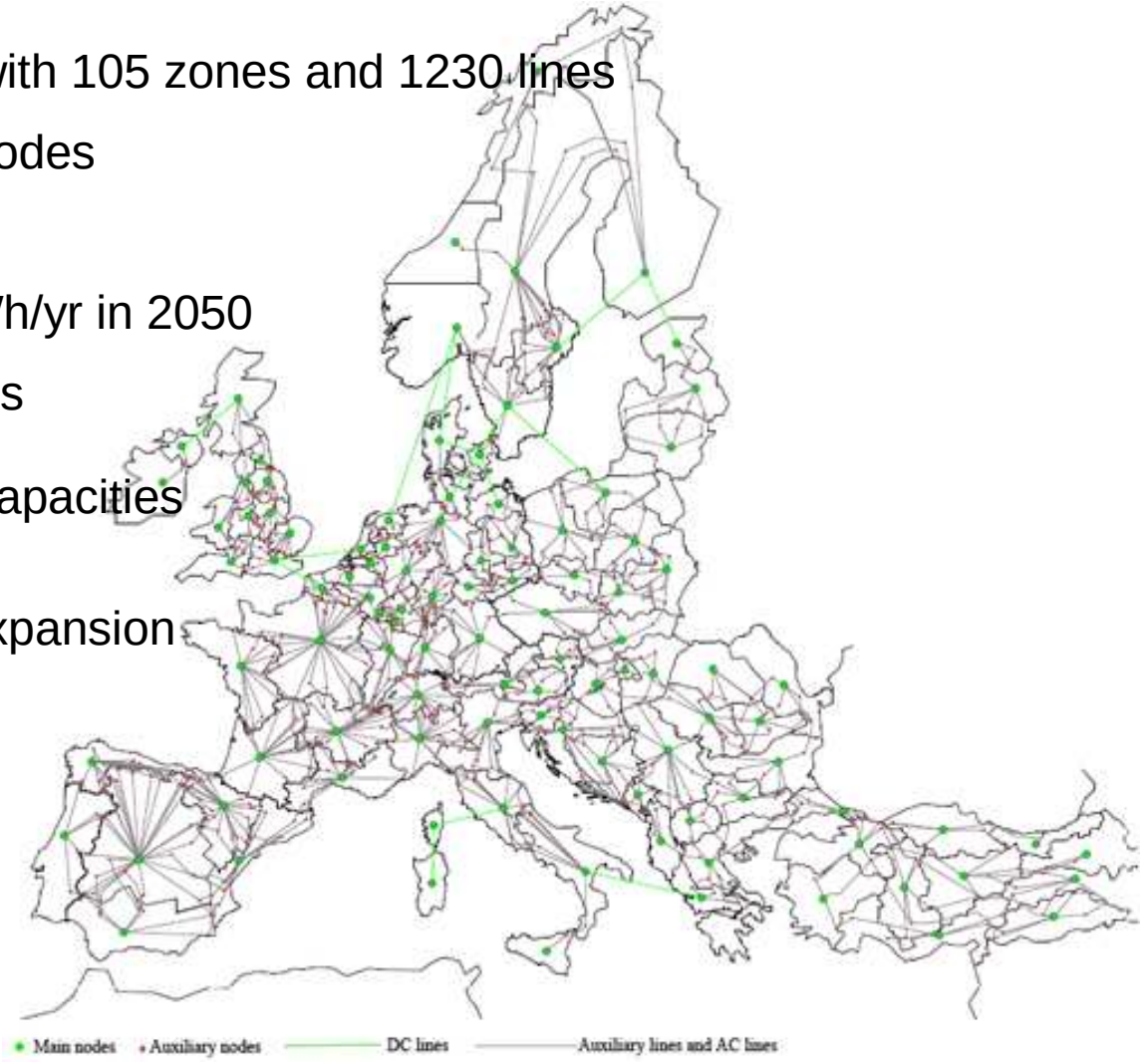
→ Model obtains the optimal HVDC connections for 2020, 2030, 2040 and 2050

Evaluation of the HVDC expansion path for CSP integration.

Procedure II: Assumptions

- Model of the EU30+ network with 105 zones and 1230 lines
- 105 demand and generation nodes
- Simplified AC grid
- Demand increase to 4.200 TWh/yr in 2050
- Gradual decrease of fossil fuels in the electricity sector due to increasing generation capacities of RES
- Exogenous CSP generation expansion
- CO_2-price 2050: 100 €/t-CO_2

- Escalation rates fuel prices:
  - Oil and gas: 2.5 %/yr
  - Coal: 1.0 %/yr

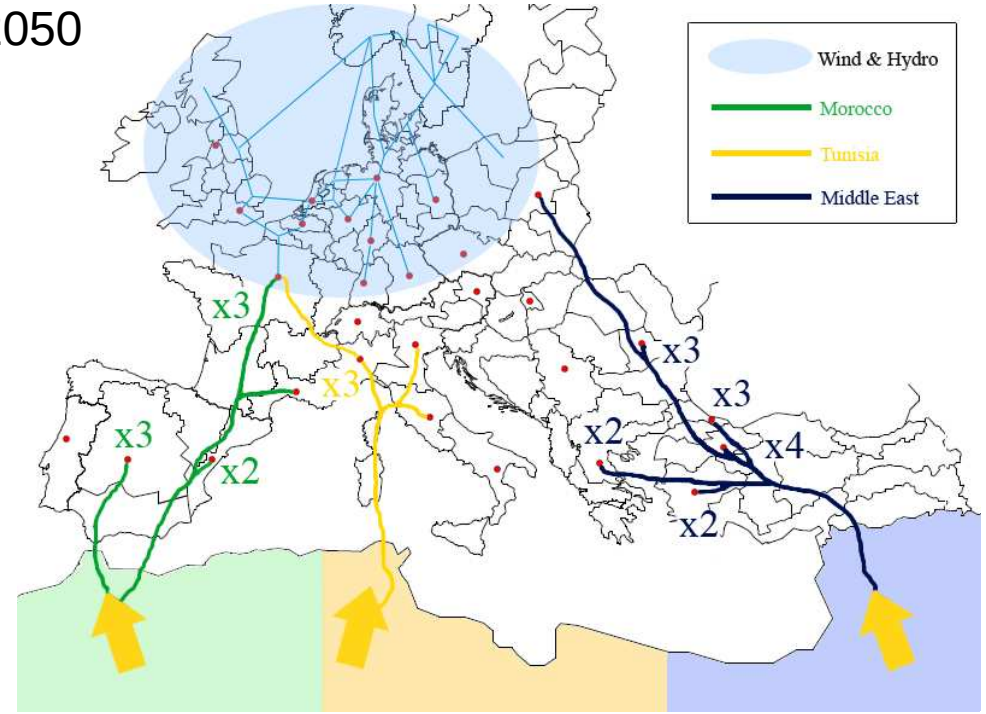


Results I: AC & DC Important for the Integration of LRES

Welfare maximized integration of CSP from MENA to Europe via HVDC transmission:

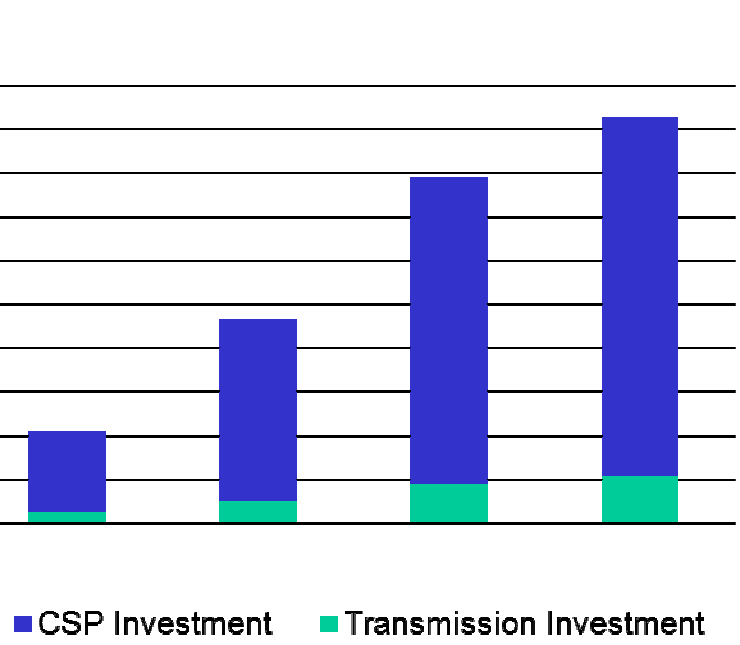
- Achieved by gradually increase of transmission capacity to European demand centers
- Proximity of CSP generation region and supplied node
- No widespread HVDC overlay grid is required
- No direct HVDC connection to Germany for assumed CSP capacity of Trans-CSP report (DLR 2005)

2050



Results II: Investment Figures CSP MENA

- Generation: 425 billion €
- Transmission: 55 billion €
- **Total Investment: 480 billion €**



- Starting in the early 2030th, CSP from the MENA region becomes competitive on the European electricity market.
  - Investments in pilot projects and large scale CSP in MENA before 2030 has to be financially supported
  - In addition to export capacity, capacity building for MENA domestic markets is of high importance

Results III: Supportive Instruments

- **Generation:**
  - Implementation of CDM mechanism
  - Feed in tariffs
  - Avoidance of physical trade of electricity → natural gas as currency
  - Support of energy intensive industries in MENA with green energy
  - Integration of MENA into EU carbon trade

- **Transmission:**
  - Regulation of transmission fees
  - Problem of transit countries

Enable diffusion of CSP technology before 2030 to reach large scale integration into the European electricity market after 2030.

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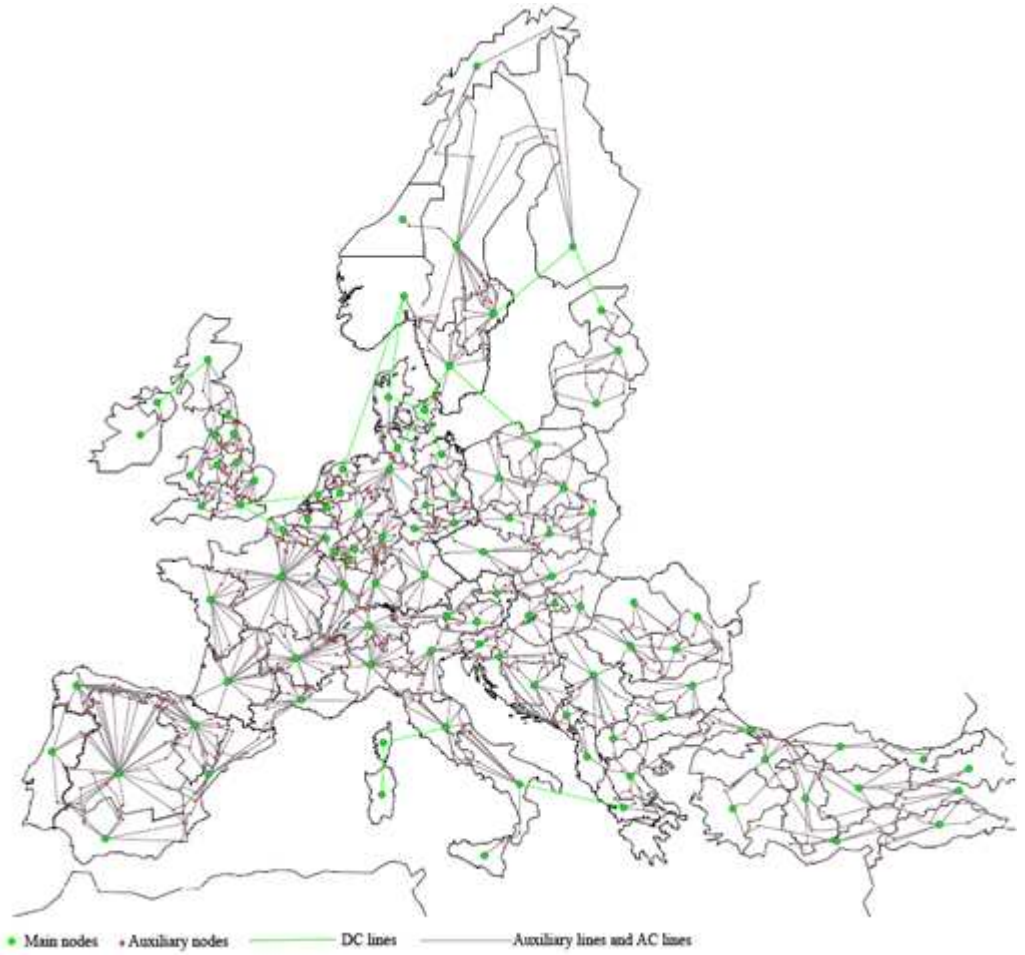
Procedure I: Model Adjustments

- Reference year with 24 states
  - Season
  - Daytime
  - Demand
  - Wind generation
- Seasonal storage (reservoirs)

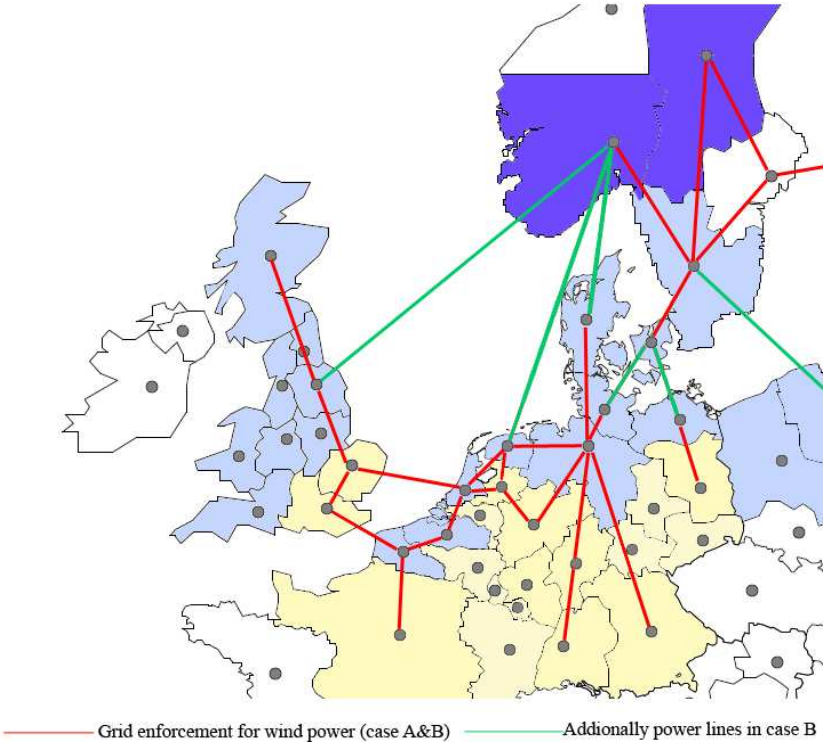
- Objective: Welfare maximization
  for the entire system



Procedure II: Solar and its “Friends” Wind and Hydro Power

Different developments of large scale renewable generation and integration projects have to be considered

- CSP is not the only promising source for large scale renewable energy
- The vast amount of wind capacity in Northern Europe has a rather low capacity credit
- Bringing together the fluctuating character of wind power and large reservoir capacities in Scandinavia influences the market conditions for CSP integration
- Investments in HVDC connections are required



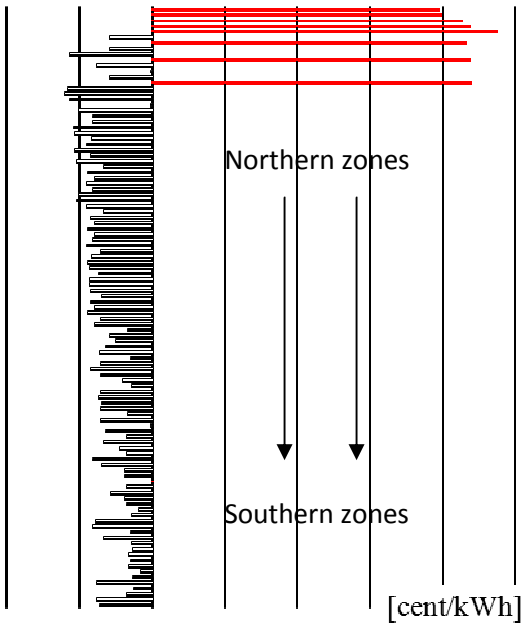
Results: Influence of Scandinavian Hydro

Model results including the integration of Scandinavian reservoirs to the continental electricity market conclude lower returns for CSP

- **Expanded inter-connection of the markets shifts prices**
  - Price increase for Scandinavia of 4 cent/kWh
  - Price decrease for rest of Europe 0.5 - 1.0 cent/kWh
- **No influence on HVDC corridors before 2050**
- **CSP profitability delayed due to lower prices**

  also in southern Europe
- **Welfare increase outweighs costs of transmission investment in inter-connections for assumed expansion scenario**

Price difference through better market integration:



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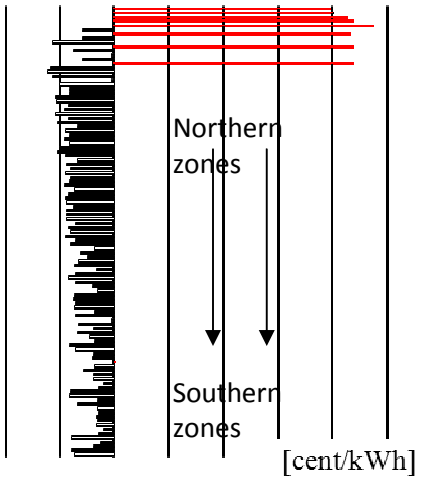
A Problem I: Rent Shifting

What do Scandinavian consumers think about a price increase for electricity of about 50 percent ?

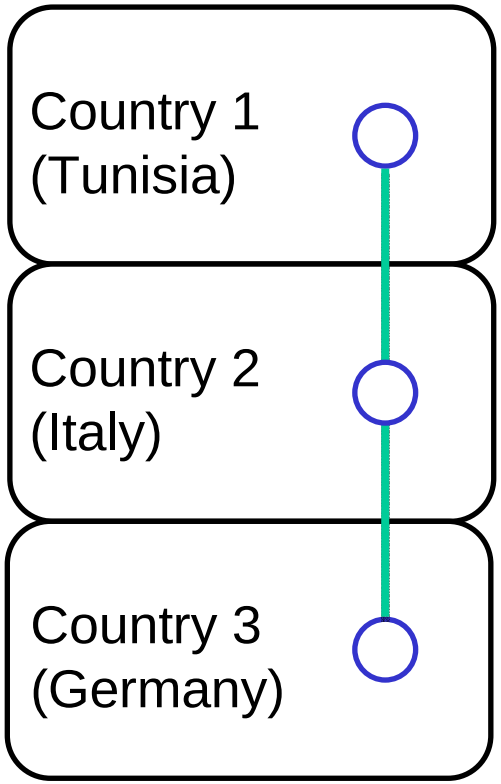
- Shift in prices due to transmission expansion creates winners and losers
- This rent shifting could cause an opposition of certain players against the welfare optimal planning
- Simple welfare assessment omits those issues and is therefore not sufficient
- Game theoretic approaches are required



A Problem II: Implications for Transmission Expansion

How do rents shift between consumers and producers and what is the impact of transmission expansion on the entire welfare of one country?

- Example:
  - CSP generation in Tunisia
  - Transmission to Italy causes higher marginal prices in Morocco and lower prices in Italy (rent shifting)
  - Discussion of welfare effects required (export or domestic)
  - Transit to Germany needs cooperation of Italy as well
  - How to achieve cooperation or what incentives for Italy to cooperate?



Possible Solution I: Game Theoretic Approach

- **Game theoretic approach raises questions**
  - Cooperative vs. non-cooperative
  - Who are the players and who could be co-operating

- **Problems for Modeling:**
  - Lumpy/discrete investments → assumptions (simplified model) to integrate game theory
  - Questions: Who are the players, who to integrate discrete expansion, how to find Nash equilibrium

- **Modeling Approach:**
  1. Step: Different countries play an extension game for own welfare maximization → non-cooperative
  2. Step: Possibility for players to form coalitions → cooperative

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- A simple welfare maximization approach is not sufficient due to potential institutional obstacles
- At present, most of the installed capacities are CCGS (combined cycle), significantly tilted towards natural gas
- The current proposal does not sufficiently take into account the initial link between energy generation and water use
- The institutional framework for system development of a Desertec or similar project to 2050 are not in place

At present, most of the installed and announced capacities are ISCC (combined cycle), significantly tilted towards natural gas

Country	Name	Plant type	Solar thermal capacity	Total capacity	Client / Owner
Algeria	Hassi-R'mel	ISCC/trough	20 MWe	150 MWe	Sonatrach (Algerian State Corporation)
	N.E.A.L.	ISCC/trough	2 x 70 MW	2 x 400 MW	New Energy Algeria
Morocco	Ain-Ben-Mathar	ISCC/trough	20 MW	470 MW	Office National de l'Electricité / Abengoa
	Morocco ISCC Plant 2	ISCC/trough	6 MW	n.a.	n.a.
Egypt	Kuramayat	ISCC/trough	25 MW	150 MW	NREA (New and Renewable Energy Authority)

Source: Greenpeace et al. (2009), NREL (2010)

Water: The Forgotten Resource

- **Aqua-CSP included a significant value of water (desalination, etc.)**

- **Since, it seems that the water factor has been „forgotten“:**

  Power plants in Algeria moving South (into the desert)

  No concrete linking with desalination processes

Possible Solution II: Integrated Energy Infrastructure Planning?

- **10-year non-binding forecasts not sufficient, given the long lead times of natural gas infrastructure**
  - Creation of new ENTSO-E and -G end
  - Non-binding Ten Year Network Development Plan

- **Integrated planning necessary, not only sector-specific calculations of requirements; coordination with**
  - Electricity networks, natural gas pipelines, CO_2-pipelines

- **Idea: Separate the decision on „allocation“ of infrastructure from the decision of production („carrying out“)**
  - „Allocation“ should be decided at a fairly central level, with more competences to ACER-Entso-G and the European level
  - Production can be tendered to (private) firms

- **„European Integrated Energy Infrastructure Planning“ does not imply to be „back in the USSR“, but a reasonable and welfare-oriented policy with an institutional design that addresses uncertainty and information asymmetries**

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Thank you very much
for your attention!
Any questions or comments?

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