

## The Integration of Renewable Energies in the European Electricity grid

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## Outline

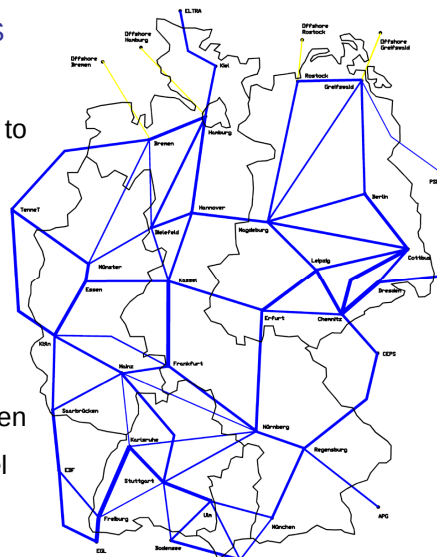
1. Introduction
2. Results from a national model
3. Properties of the load and supply timeseries in the study area
4. Ideal energy fluxes in Europe
5. Outlook and Conclusion

- Intermittency and geographic dispersion of renewable energies make their integration into the energy system challenging.
- In the understanding of the integration of renewable energies a **decentralised view** competes with a vision of dispersed, but **centralised generation** within a powerful electricity grid.
- ➡ Can a European Supergrid facilitate the use of Renewable Energies?
- Previous studies on global, continental and national level:  
Bieberacher, 2004; Rosen 2006; Czisch, 2005; Nitsch, 1998;  
Heitmann and Hamacher, 2008, etc.

## Model of the German electricity system

Model generated with model generator URBS

- Transmission network is simplified to 29 knots in the model
- High time resolution (1h)
- Detailed description of the generation, storage and transport processes
- CO<sub>2</sub> limits and/or costs can be given as boundary condition to the model
- Linear optimisation of total costs (GAMS)

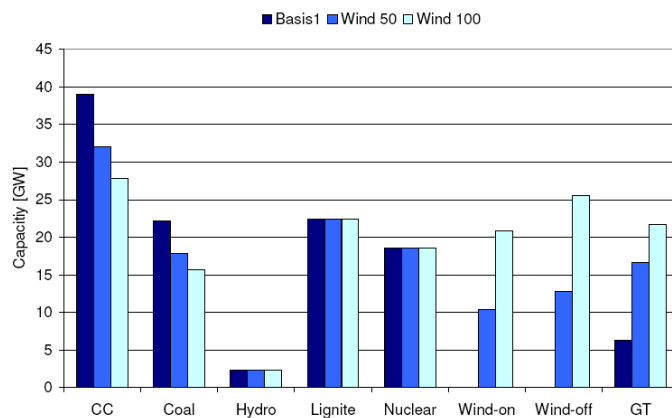


(Haase, 2006; Heitmann and Hamacher 2008)

## Model of the German electricity system

### Capacities

Comparison of baseline scenario (*Basis 1*) and scenarios with windenergy at 50% and 100% of german wind potential (*Wind 50/100*)



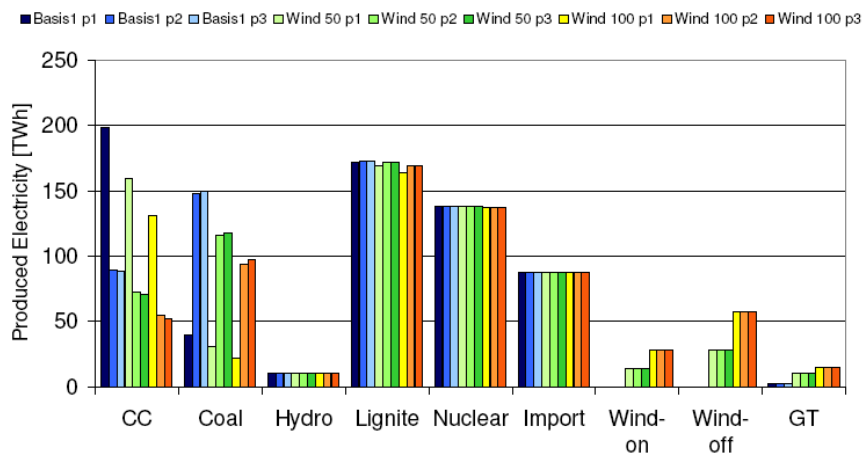
Heitmann and Hamacher 2008

➡ Very little capacity effect for thermal power plants!

## Model of the German electricity system

### Produced electricity

for *Basis 1*, *Wind 50* and *Wind 100* scenario,  
 additionally: gasprice variations (low: *p1* - high: *p3*)

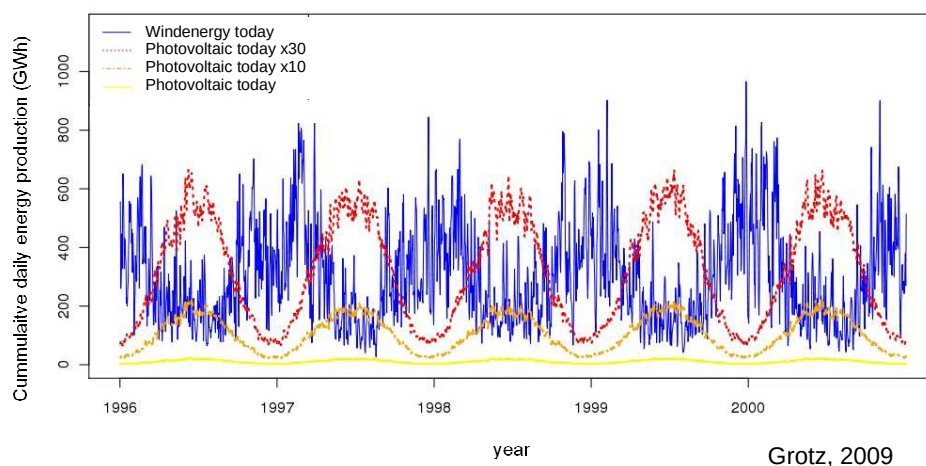


Heitmann and Hamacher 2008

## Load and Supply

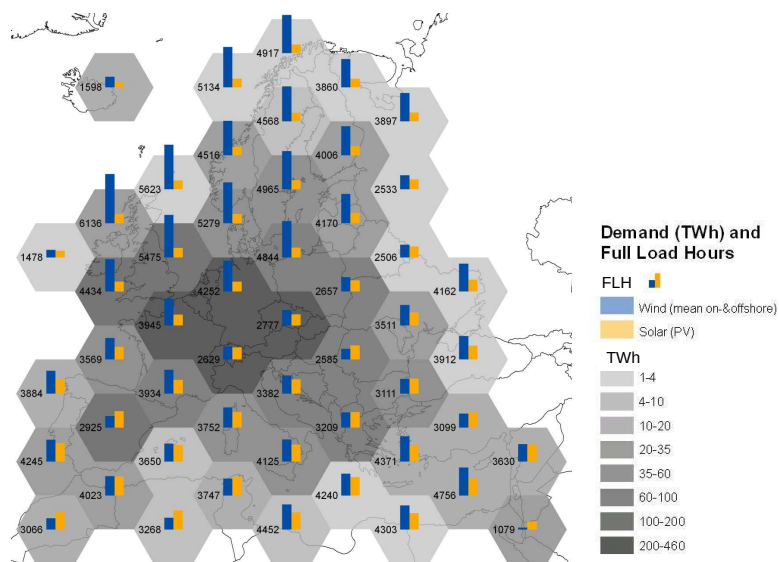
### Intermittency of wind and solar energy from 1996 to 2000

Data: World Wind Atlas (Sander, 2000), Satelight (<http://www.satelight.com>, 2009)



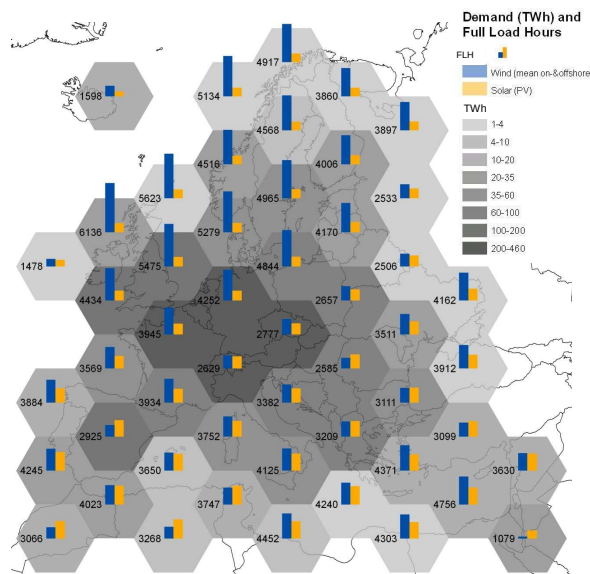
## Load and Supply

### Geographic distribution of load and wind and solar Ressources



## Load and Supply

### Geographic distribution of load and wind and solar Ressources



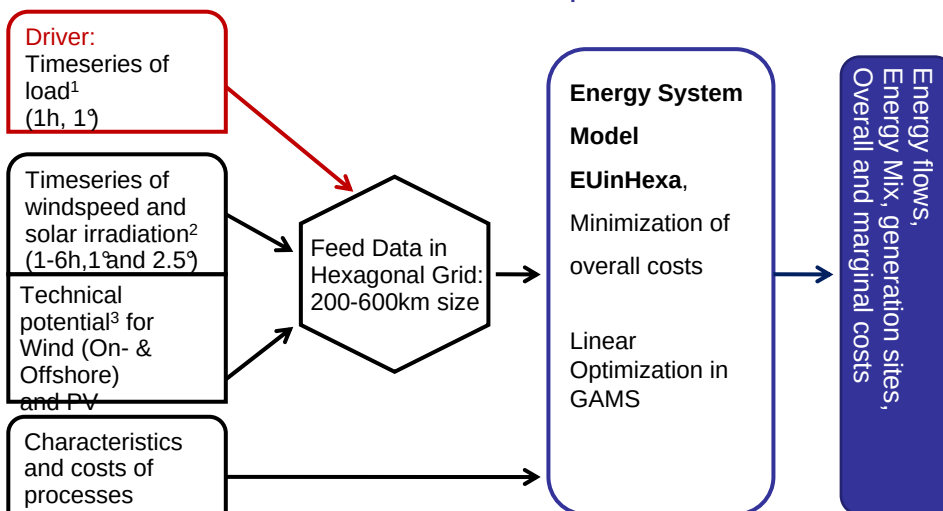
- Barplots represent Full Load Hours of wind and solar power (World Wind Atlas 2000, Satellight 2009, Helioclim 2009)
- colourscale shows the level of annual cumulative demand in TWh (UCTE 2008, Nordhaus 2006)
- Load and renewable supply show low geographical correlation

### Model Setup

Aim: Determine energy flows in Europe for an ideal case of high renewable energy supply

- **source:** renewable energy supply: timeseries of windspeed and solar irradiation
- **drain:** hourly load curves for each cell: UCTE Data from 2008 scaled with population (Nordhaus, 2006)
- timespan: one year as showcase
- hexagonal grid to map flows

## Model Setup



<sup>1</sup> UCTE, Population: Nordhaus, 2006

<sup>2</sup> World Wind Atlas, Satellight and Helioclim <sup>3</sup> Hoogwijk, 2004; Brückl, 2005; Tzscheutschler, 2005; Giebel, 2000

### Minimization of overall costs

#### Objective Function

$$C = \sum_x \left[ \sum_{ieProcessinHexa} (K_i^{Inv} c_i^N(x) + K_i^{Fix} c_i(x) + \sum_t K_i^{Var} E_i^o(t, x)) \right] \\ + \sum_x \left[ \sum_{ieTransport} \frac{1}{2} \sum_y (z(x, y) (K_i^{Inv} c_i^N(x, y) + K_i^{Fix} c_i(x, y)) + \sum_t K_i^{Var} E_i^o(x, t)) \right]$$

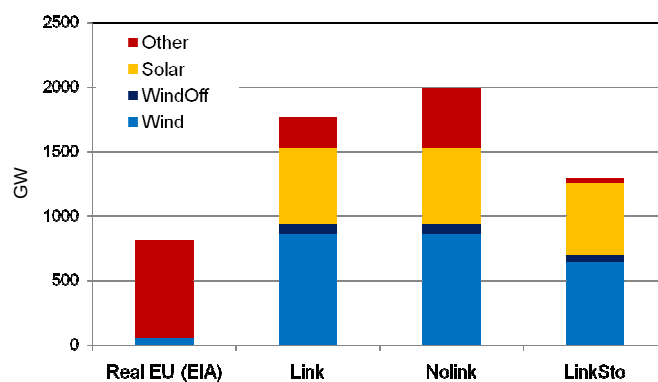
timsteps  $t$  and hexagons  $x / y$

- Annuity of investment costs, fix and variable costs are taken into account for each process
- Geometry matrix  $z(x,y)$  describes neighbourhood of the gridcells

### 3 Scenarios:

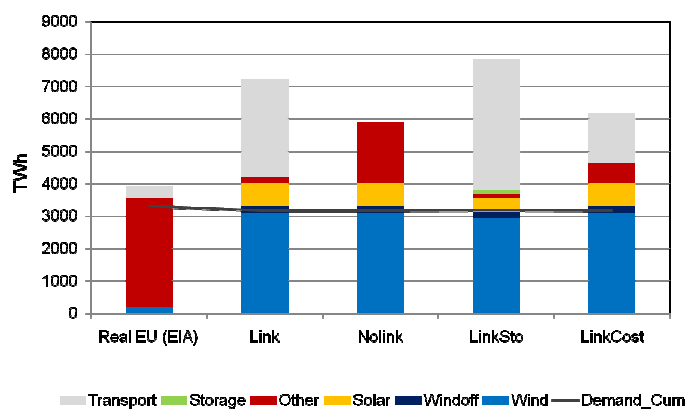
- Link: No Transport costs and –losses  
relatively low RE prices  
high prices for other
- Nolink: No Transport possibility  
relatively low RE prices  
high prices for other
- LinkSto: No Transport costs and –losses  
relatively low RE prices  
high prices for other  
possibility of storage (1,7 TW Storage capacity)

## Installed capacity for the scenarios



- Powerful grid facilitates the use of intermittent resources: backup is reduced by 50%
- storage supports the use of solar energy rather than wind energy, due to its interdiurnal variation

## Produced energy

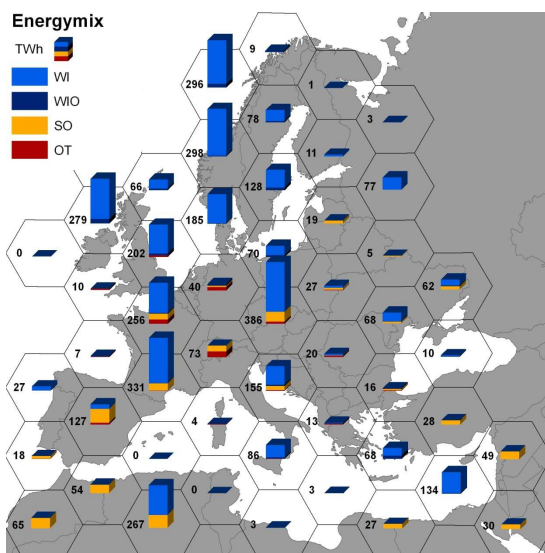


## Overproduction (%)

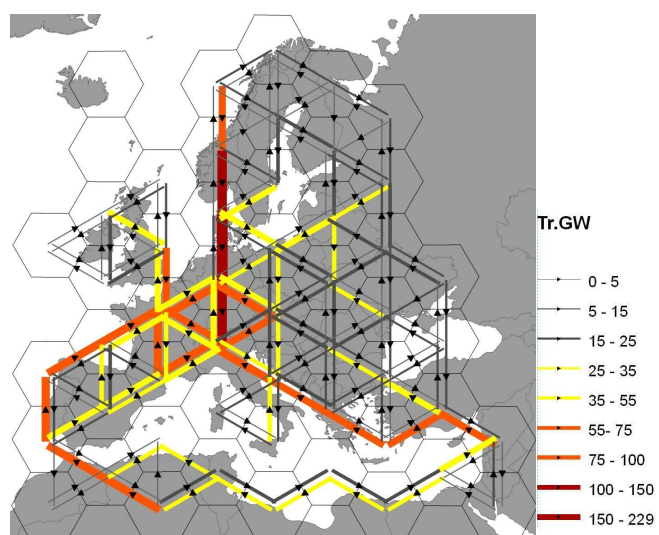
|          |        |
|----------|--------|
| Real EU  | 7.82%  |
| Link     | 32.47% |
| Nolink   | 86.31% |
| LinkSto  | 14.98% |
| LinkCost | 46.02% |

➡ Efficiency of the system increases with grid and storage

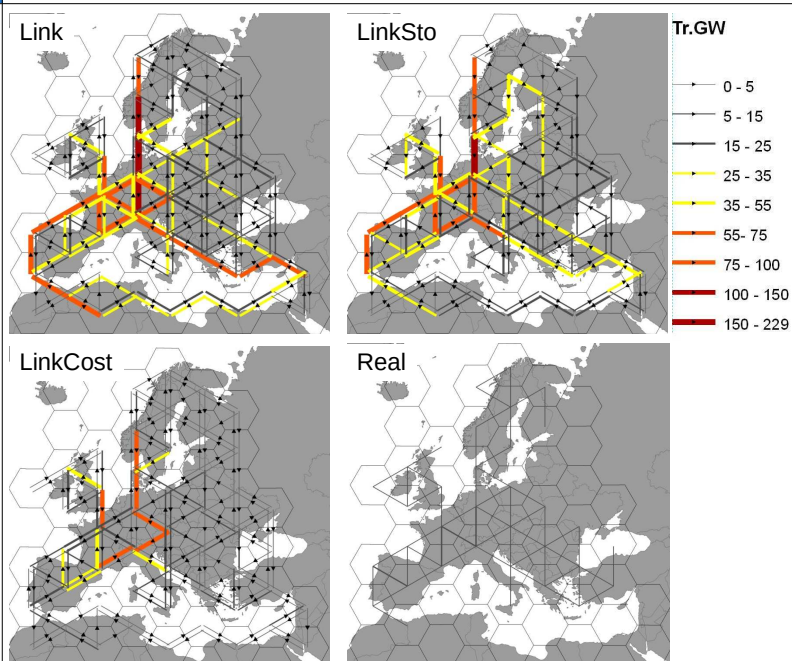
### Energymix scenario *Link*



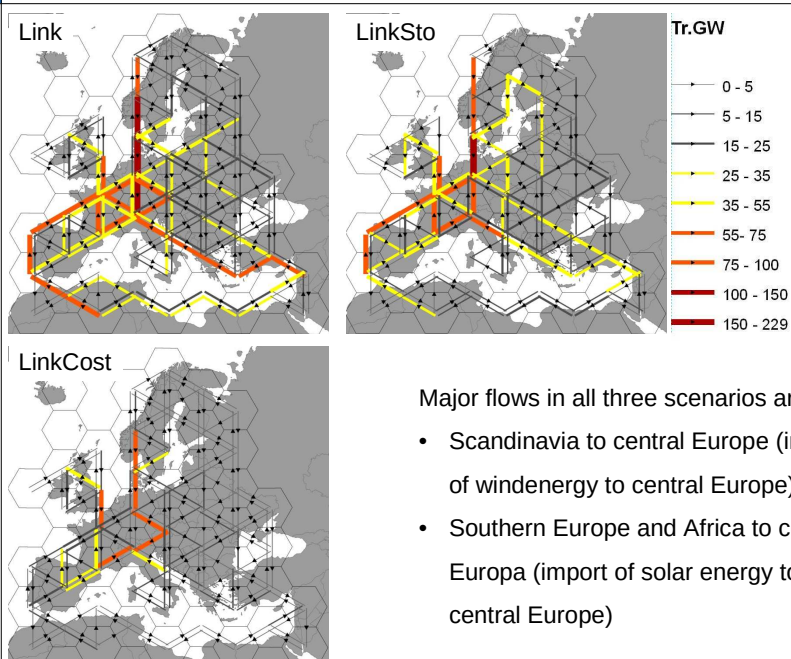
- Ideal generation sites can be determined with this scenario
- High solar potential in northern Africa, south-western Europe
- High wind energy potential in Scandinavia, Denmark

Flows in scenario *Link*

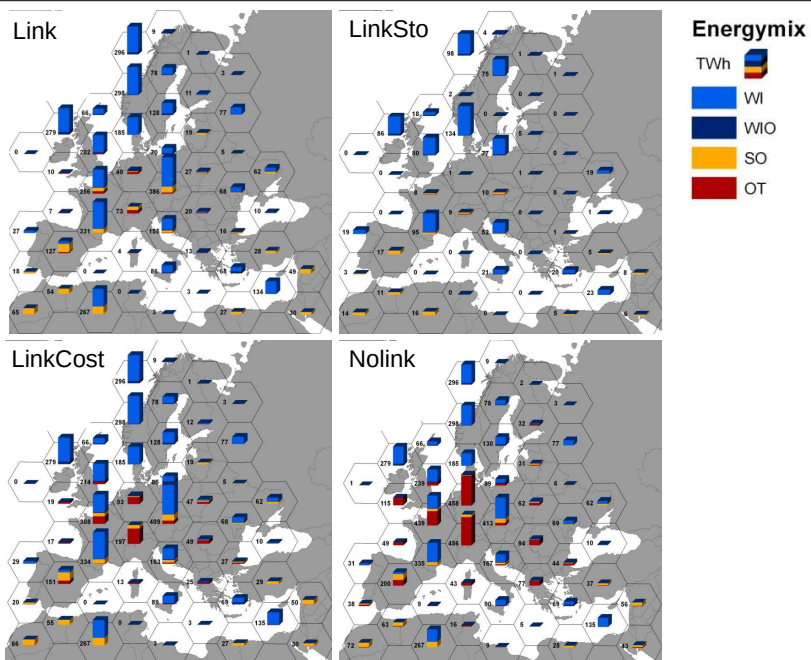
## Comparison of flows



## Comparison of flows



## Europe in Hexagons



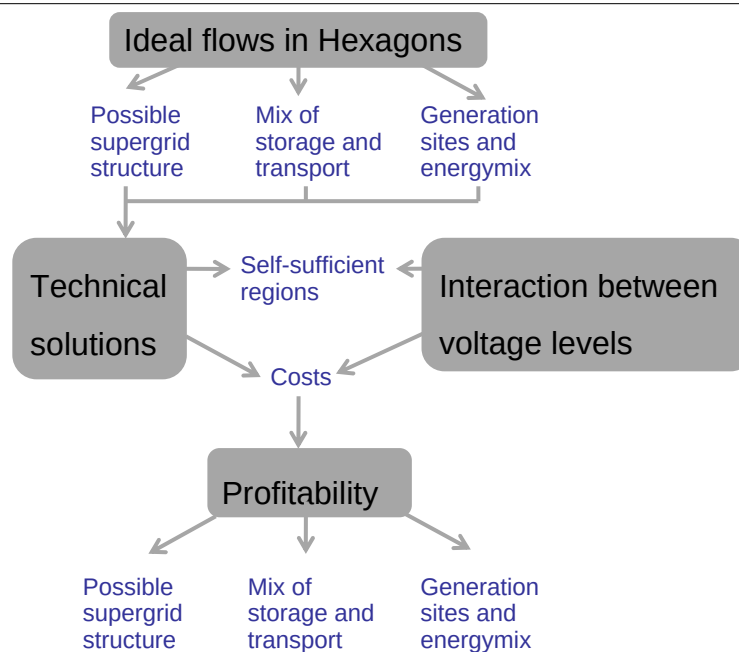


Role of  
supergrid?

Feasibility of  
a supergrid?

Decentralised  
vs.  
centralized  
generation?

Economic  
limits and  
boundary  
conditions



### Ideal flows in Hexagons

#### Further steps

Vary gridcell size  
Integrate other technologies  
(Solarthermal, renewables as backup)  
More realistic technical constraints  
Improvement of data, ...

### Technical solutions

Investigation of different Technologies (HVDC, HVAC, SC)  
Topology of a european grid?  
Mapping of lower level structures

### Interaction between voltage levels

Study of low voltage generation vs. today's cascade like structure  
Network theoretical analysis of the supergrid and its subsidiary connections  
Security of supply

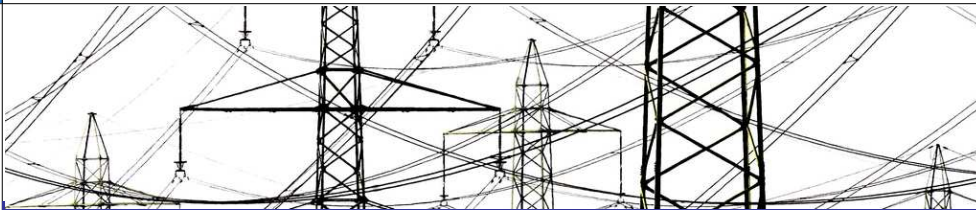
### Profitability

Power plant scheduling  
Market constraints  
...



Role and structure of electricity grid for the integration of renewables in Europe

- National model shows the need for high backup capacities in the case of high renewable supply without increase of crossborder transmission capacities.
- In Europe centers of high load and high potential for wind- and solarpower generation have low geographical correlation.
- First results from energy flow model show, that high share of renewable energies is feasible
  - a powerful grid diminishes the need for backup capacities by 50%
  - major flows are from Scandinavia/Denmark and from Spain/Portugal/Africa to western central europe
  - storage increases system efficiency due to increased solar energy usage.



Thank You!

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## Benefits of distributed wind energy generation

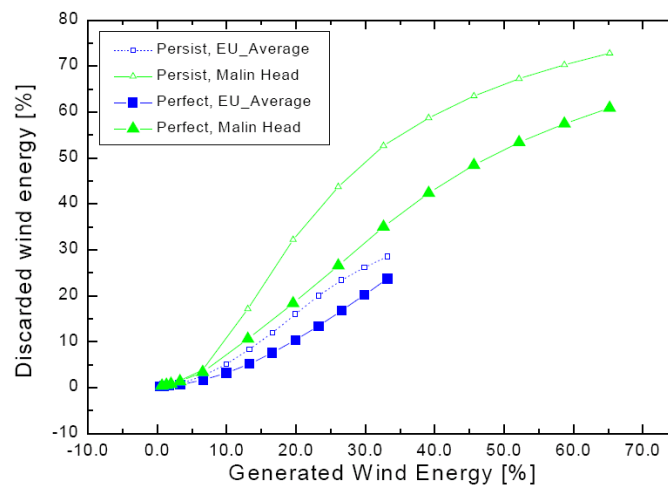


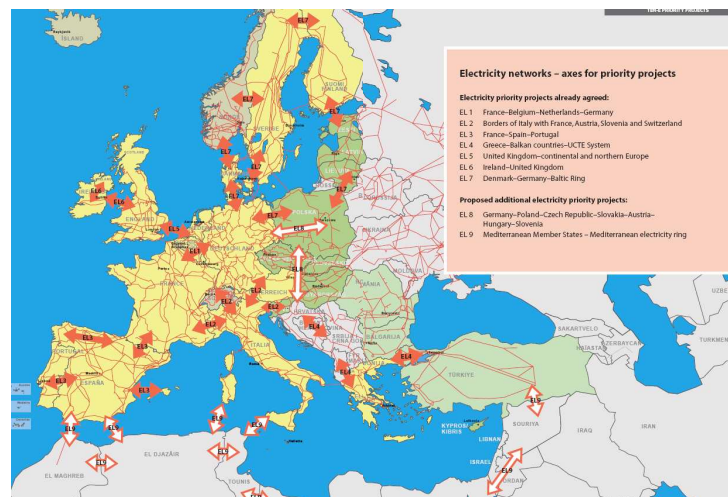
**Figure 34: Discarded wind energy production.** This figure shows the percentage of wind energy that is not accepted into the grid, as a function of the generated wind energy, which is scaled as a percentage of the total demand. Persistence and Perfect are the two forecasting options. The Selection series was omitted; it behaves mainly like the Average series, though it is longer.

Giebel, 2000

## Costs (K9)

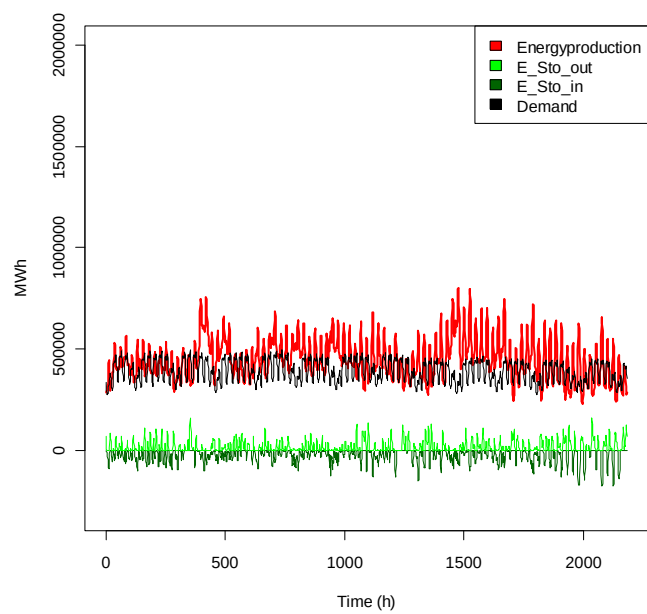
|     |            | [€/kWh] | [€/kWh] | [€/kWh] | [€/kWh]    | [€/kWh]               |
|-----|------------|---------|---------|---------|------------|-----------------------|
| K9  | Vollaststd | Inv     | Fix     | Var     | Annuität   | Stromgestehungskosten |
| Wi  | 2883       | 1000    | 25      | 0.11    | 117.459625 | 0.50627458            |
| Wio | 1969       | 680     | 25      | 0.1     | 79.8725448 | 0.4986148             |
| So  | 1324       | 200     | 25      | 0.01    | 23.491925  | 0.19768272            |
| Ot  | 6000       | 10      | 50      | 0.7     | 1.17459625 | 0.71019577            |
| Tr  |            |         | 5       | 0,1     | 5          |                       |

## TEN (Priority corridors for Energy Transmission=



Ramboll Oil & Gas, TEN, 2008





## Capacity

