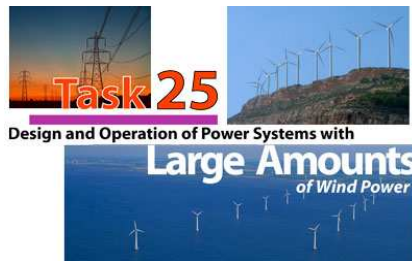


Large Scale Integration of Wind and Solar Energy in Europe Requirements on Transmission and Storage

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- 1) Fraunhofer IWES
- 2) ForWind, 3) SIEMENS AG



Contents

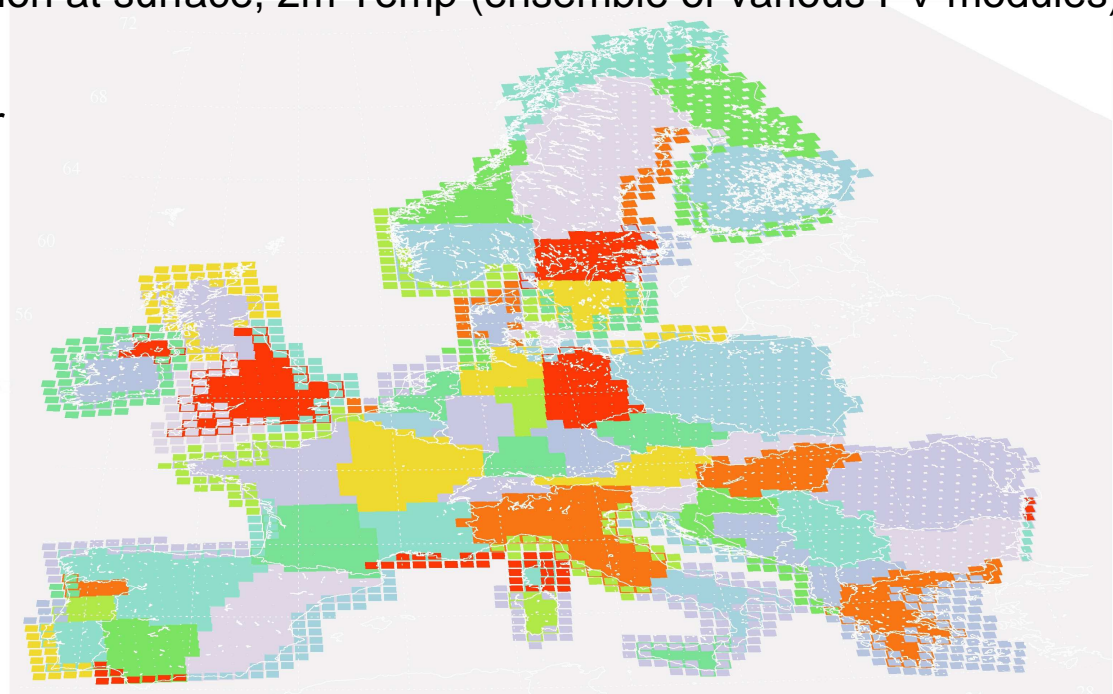
- Requirements on storage and transmission for the:
 - 1) electricity supply of UCTE & Nordel countries by wind and PV
 - 2) electricity supply of UCTE & Nordel , North Africa & Russia by wind, hydro, biomass and solar thermal power plants
- The Combined Power Plant: Coordinating intermittent and dispatchable renewable energy
- a new concept for energy storage: Renewable Power Methane

Spatio temporal patterns of wind and PV generation in the UCTE & Nordel region

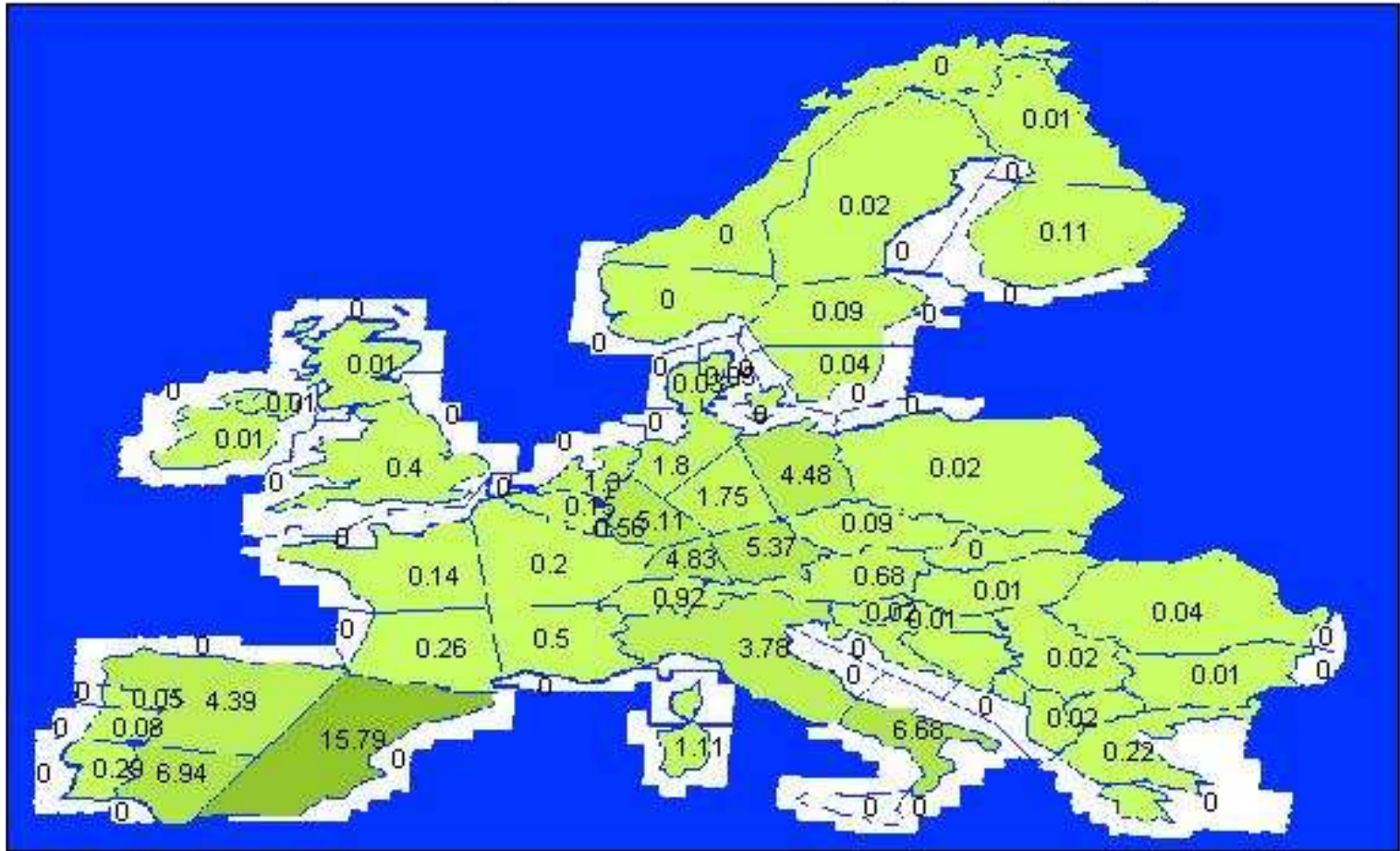
- 100% renewables electricity for Europe by wind and PV
- Fact 1: weather dependent RES (wind, PV) lead to fluctuating generation (storage and high transmission is required)
- Fact 2: Spatial aggregation reduces fluctuations
- Determine required transmission and storage capacities for various shares of wind and PV in Europe (worst case scenario!)
- Comparison of :
 - **Perfect** transport and one European storage
 - **No** transport and only regional storage
- Results with respect to
 - „optimal“ mix/ratio between PV and wind power
 - European vs. regional view

Model and input data

- Domain: UCTE + Nordel + UK/IR
- Study period: 2000-2007
- Data: 1hourly, 50km horizontal resolution
- Wind Power: Wind speed (~100m), standard power curves for on/offshore, losses (wake, availability, el. losses) are considered
- PV: cloud cover, net short wave radiation at surface, 2m Temp (ensemble of various PV modules)
- 83 regions (50 onshore, 33 offshore)
- Hourly time series of consumption for each region (partly reconstructed)



Distribution of PV in 2020 (political targets)



sum of all installed PV- power: 68 GW

Scaling up of planned capacities for the 100% RES scenario

Average power demand in the domain: 357 GW

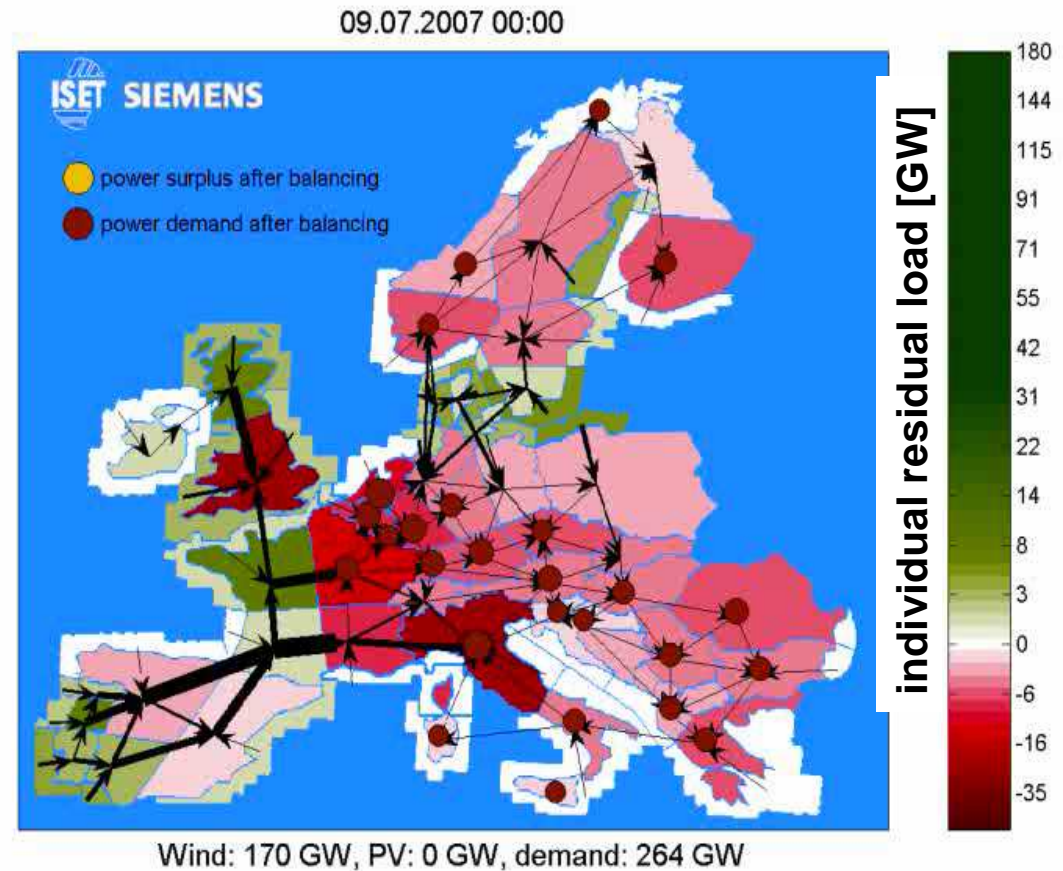
Assuming that demand remains the same as today about 23% of the consumption would be met by wind and PV power if political targets are realised

Therefore: scaling up of wind and PV targets by a factor of ~4
for a 100% scenario

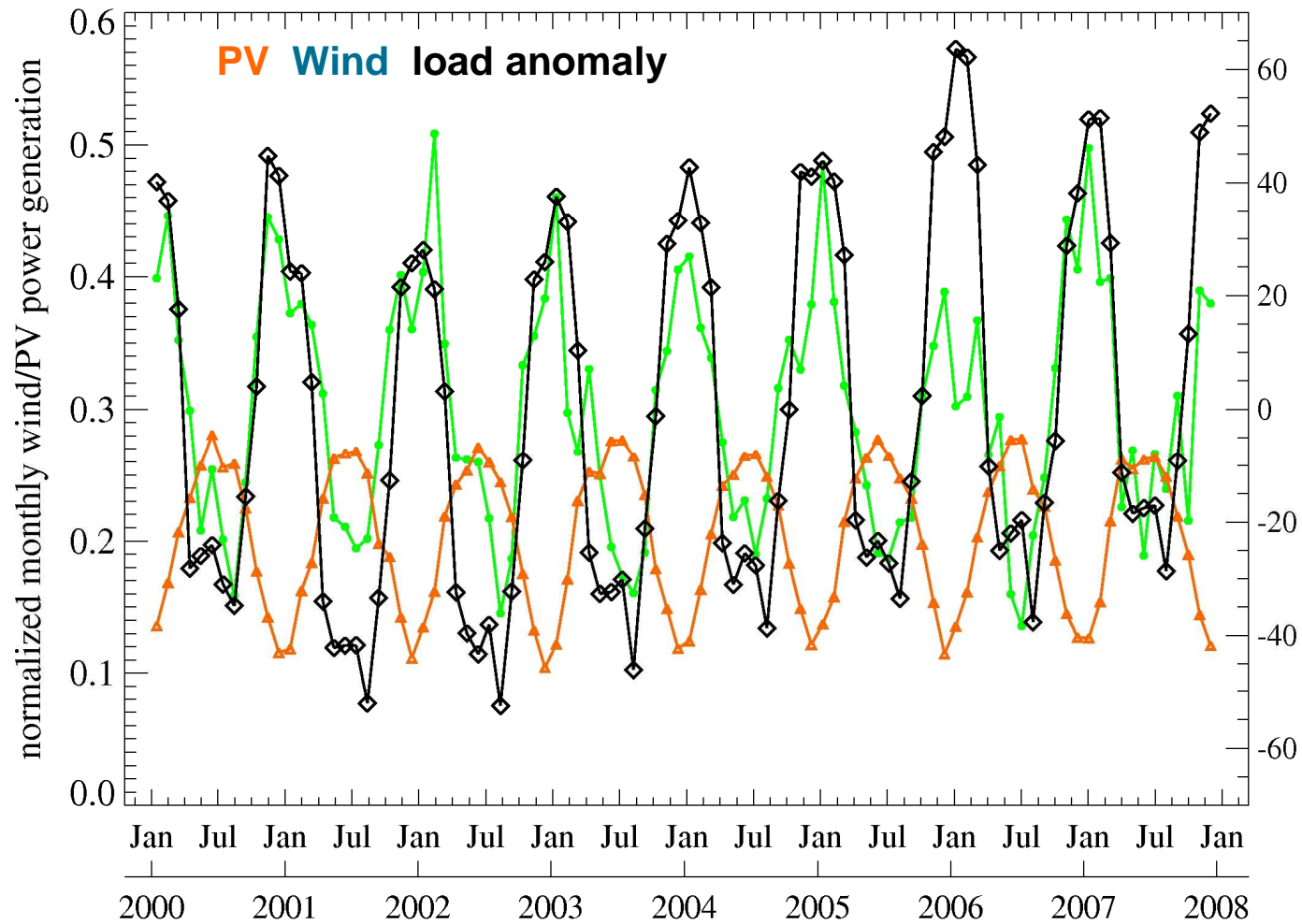
i.e. : 908 GW wind & 272 GW PV

Power flow calculation

- Full interconnection between neighbours
- Offshore regions are only connected to a single onshore region
- no transport limits, no losses
- DC flow equation solved assuming equal resistance on all lines
- single & perfect European power market
- each time step (~70000) is computed individually (no storage)
- after each time step unbalanced regions will remain

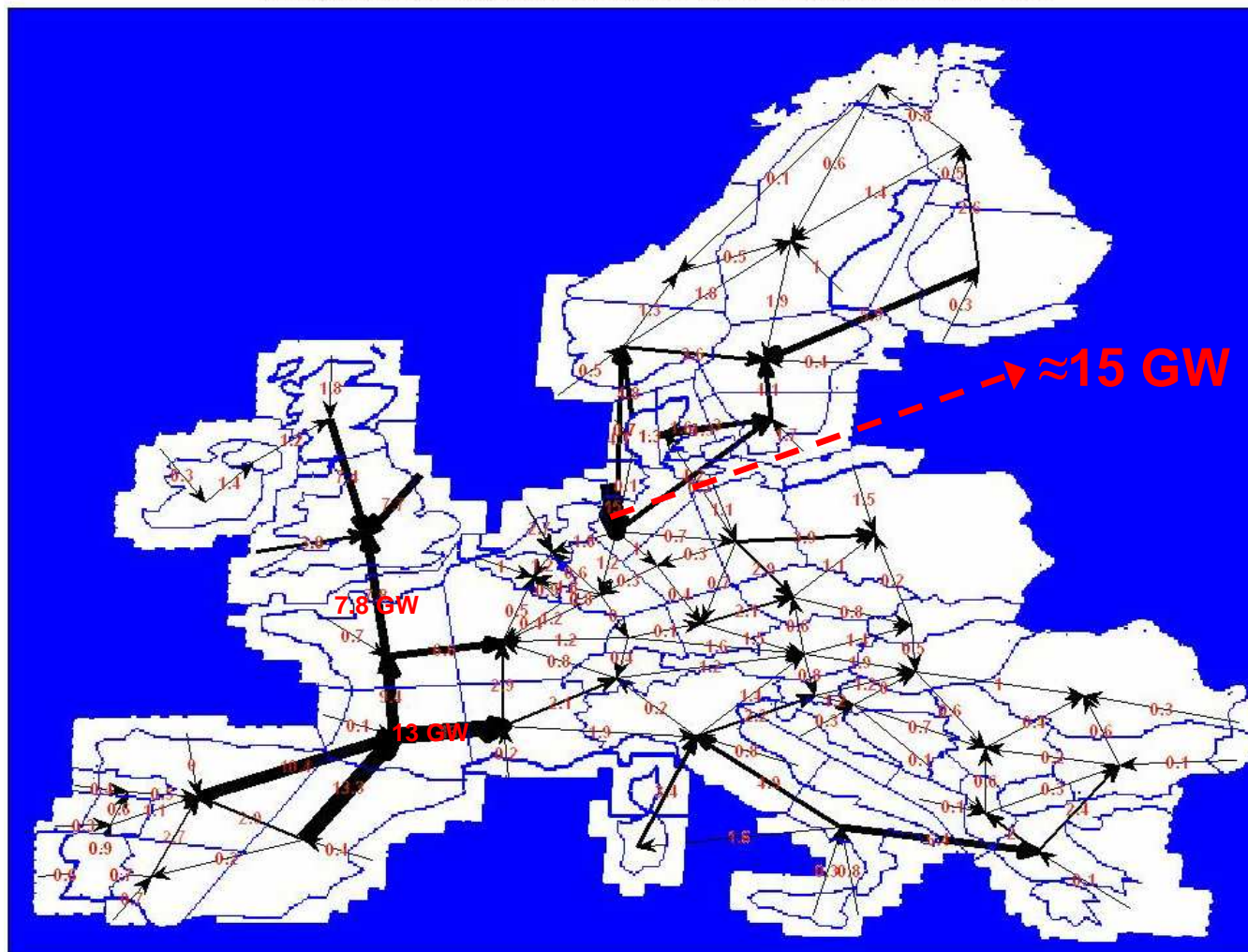


Monthly PV, Wind generation and consumption anomalies



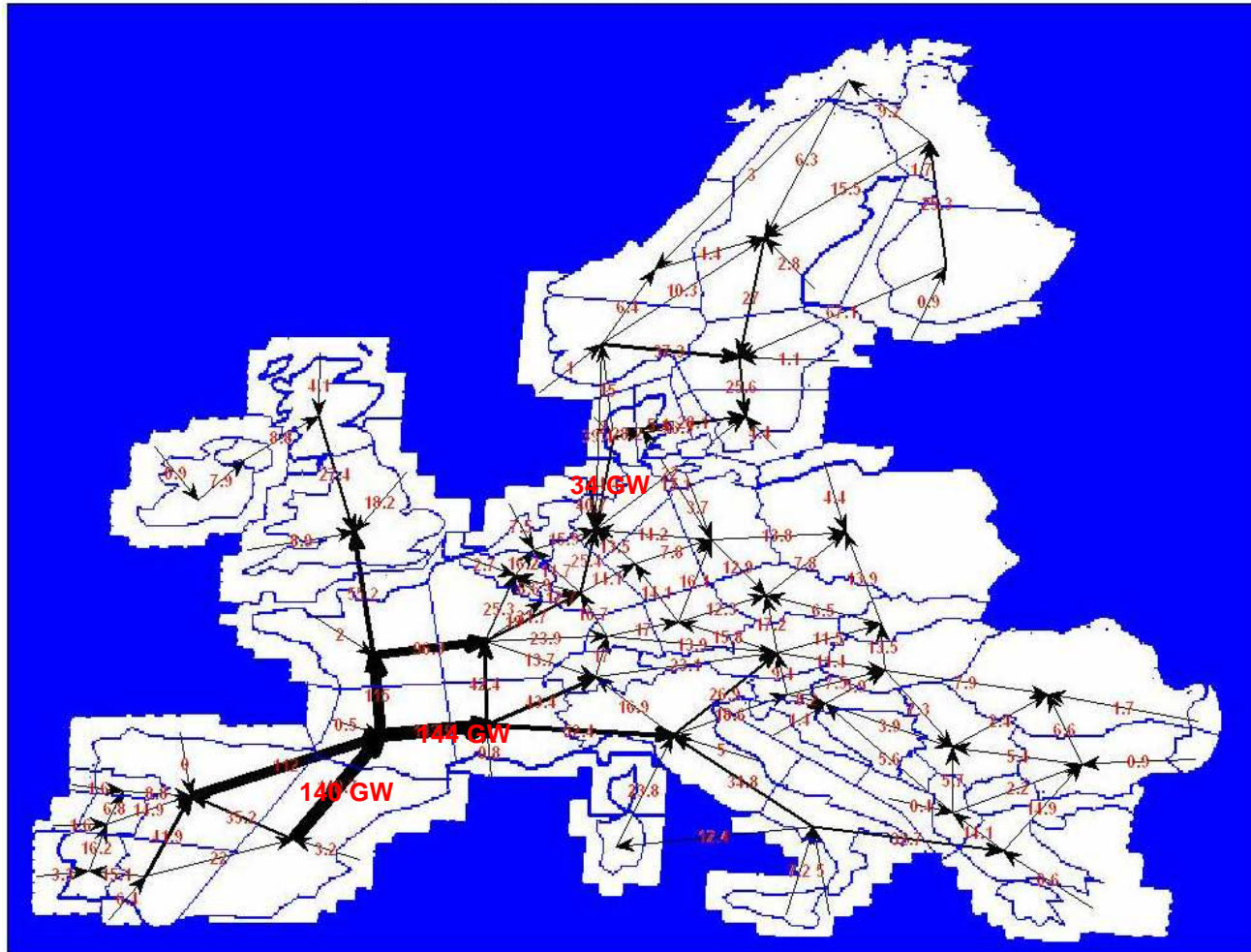
Average Transports in 100% supply scenario

averaged power transport for share of RES=1 and share of PV=0.55



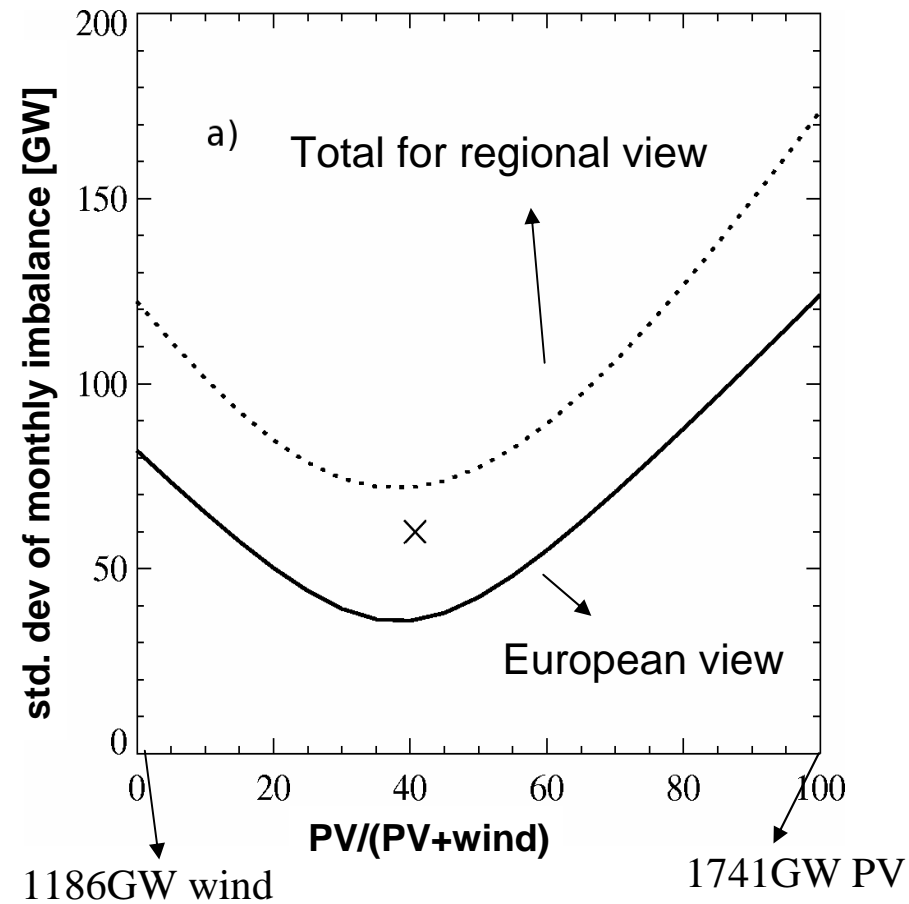
Maximum power transports in the 100% scenario

maximum power transport for share of RES=1 and share of PV=0.55



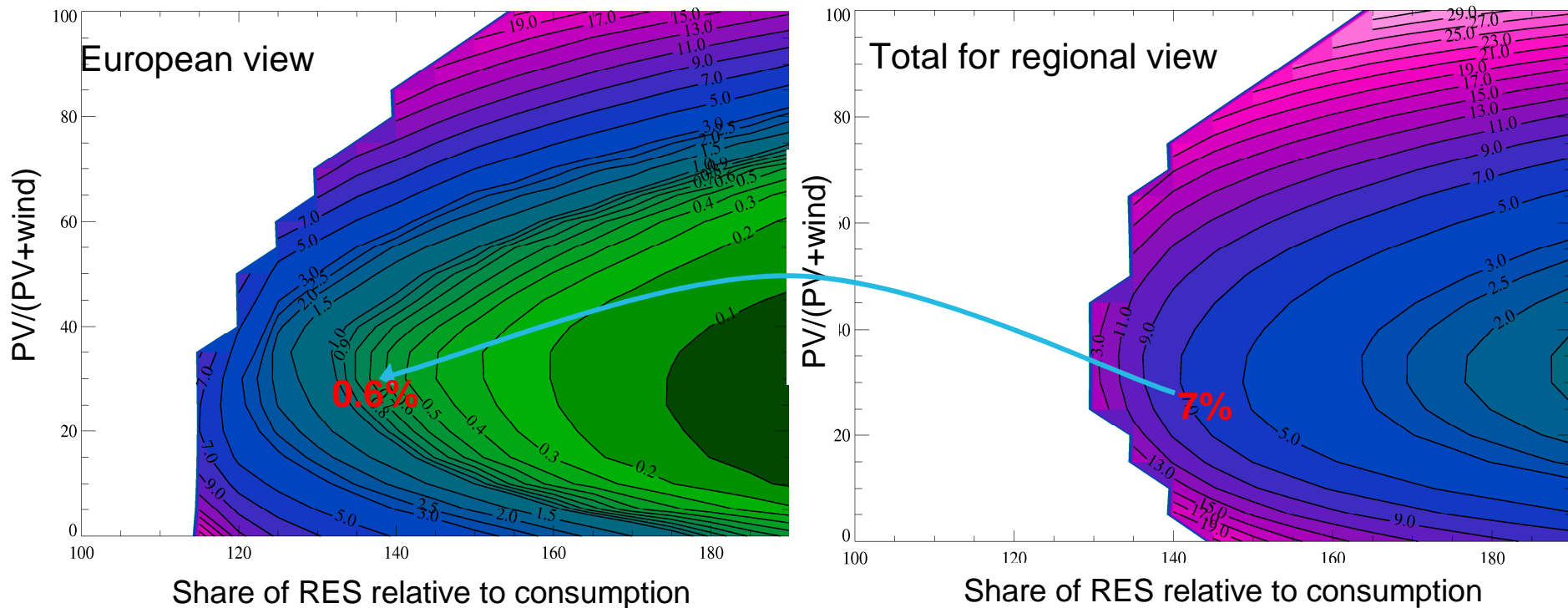
Finding the optimal ratio between PV and wind power via minimal fluctuations

- Fluctuation of monthly residual load (RES-consumption) in a 100% renewables scenario



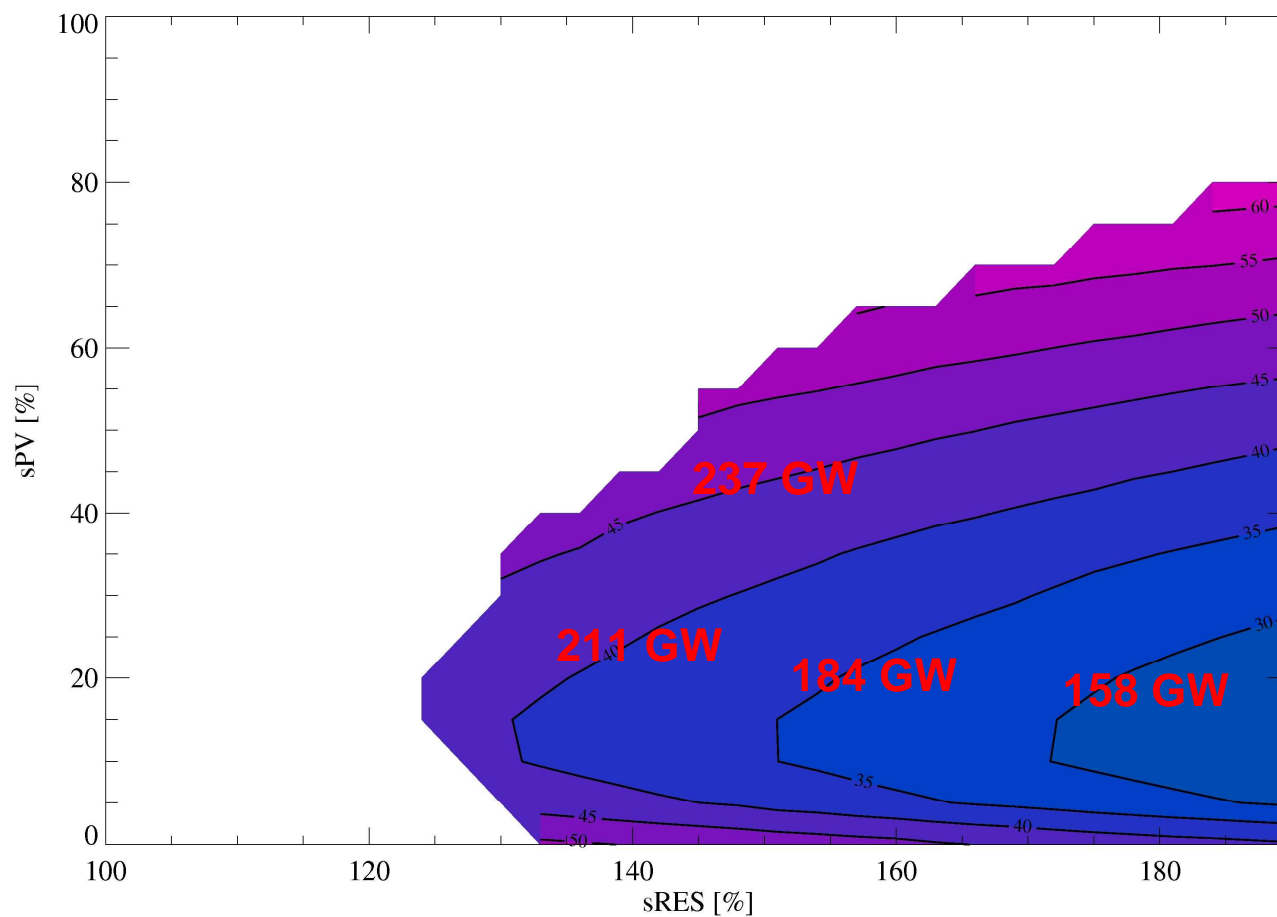
Finding the optimal ratio between PV and wind power via required storage capacity

➤ Storage capacity relative to annual consumption (=3127TWh) (in %)



- Example: 140% RES, PV=30% → required storage capacity = 2.2 days of avg. consumption
- European balancing reduces storage capacity by factor of 11!

Required storage power



Peak load: 527 GW

Candidates for needed large scale storage technologies

Needed storage capacity in TWh for different technologies

| Technology | Capacity in TWh for 2% | Capacity in TWh for 8% |
|------------|------------------------|------------------------|
| Hydrogen | 100 | 400 |
| Pump hydro | 67 | 267 |
| AA-CAES | 80 | 320 |

Needed storage power: ~ 190 GW

Hydro storage plants in Nordel

| | Norway | Sweden | Finland | Sum |
|----------------|--------|--------|---------|------------|
| Storage plants | | | | |
| Capacity [TWh] | 81,7 | 33,8 | 5,5 | 121 |
| Power [GW] | 29 | 16 | 3 | 48 |

Conclusions

- very high transport capacities occur in a 100% scenario
- demand for storage decreases on the European level (factor of 9!!)
- required storage capacities can be <5 days
- required storage power is extremely high
- optimal mix between PV and wind power exists to reduce fluctuations, power transports and storage capacity
- wind and PV do not care about national interest → aim for unified European integration
- deployment of different renewables must be coordinated in Europe, otherwise unnecessary losses and investments (storage, etc) might happen

Other studies

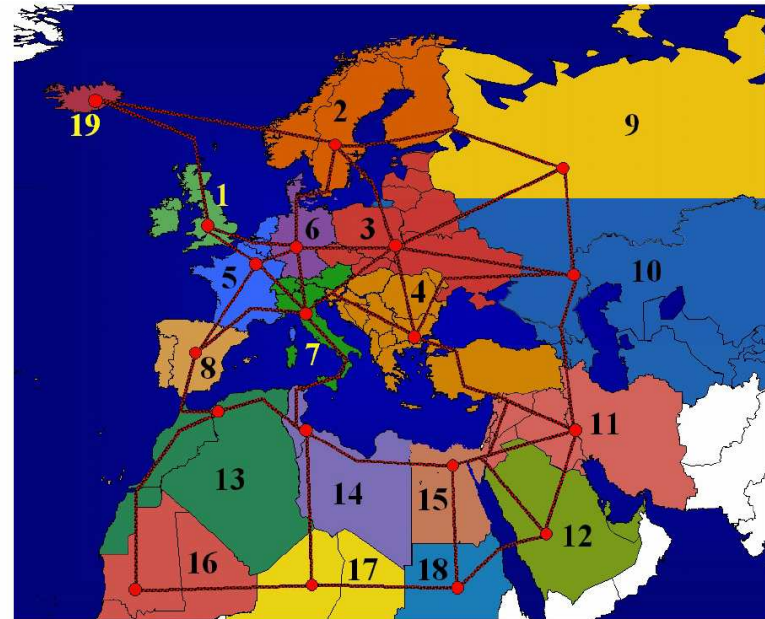
PhD Thesis by Gregor Czisch:

cost-optimised European - North African electricity supply by renewable energy

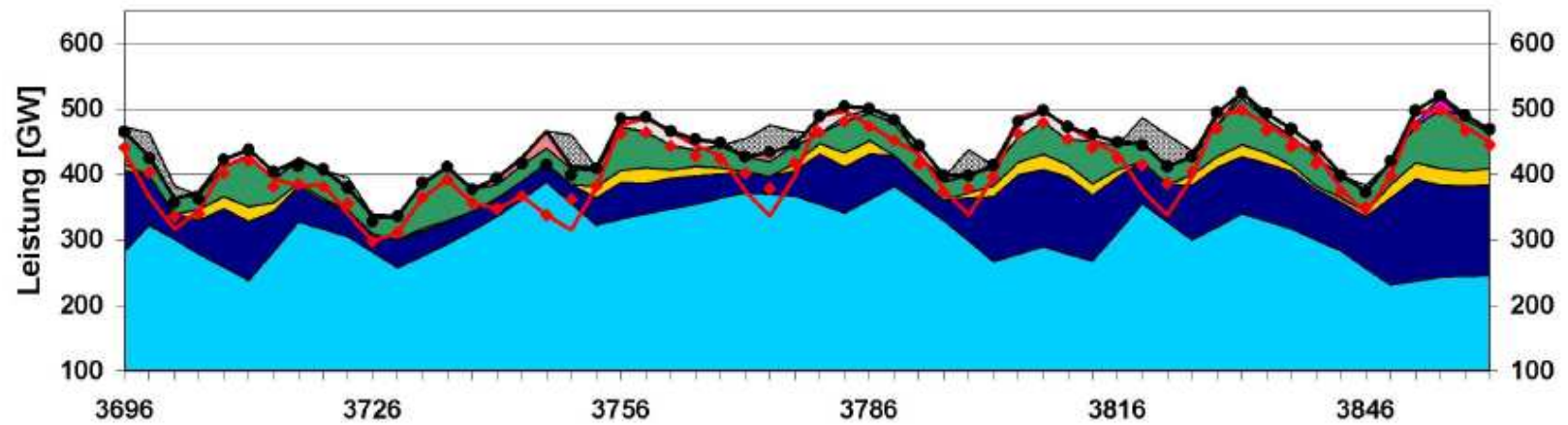
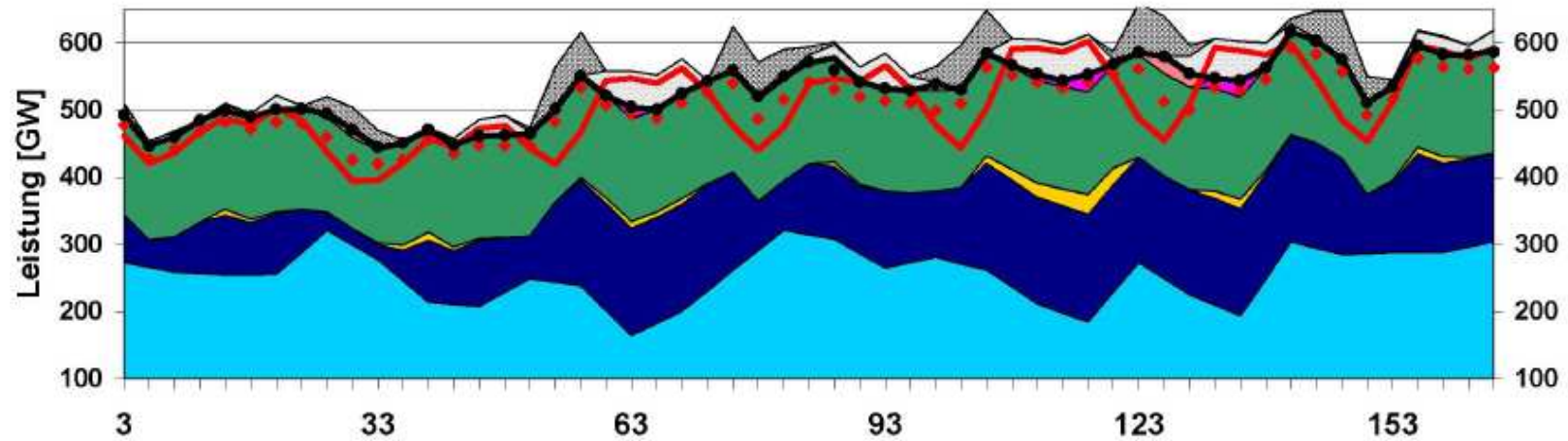
Installed capacities in the „main“ scenario:

- ca.1034 GW onshore wind energy
- 0 GW PV
- 162 GW biomass (with storage)
- 30 GW CSP with thermal storage of 335 GWh
- 133 GW storage hydro power plants
- 68 GW run of the river hydro power plants

Peak load: 650 GW



Temporal pattern of load and generation



Relation of summer to winter wind conditions

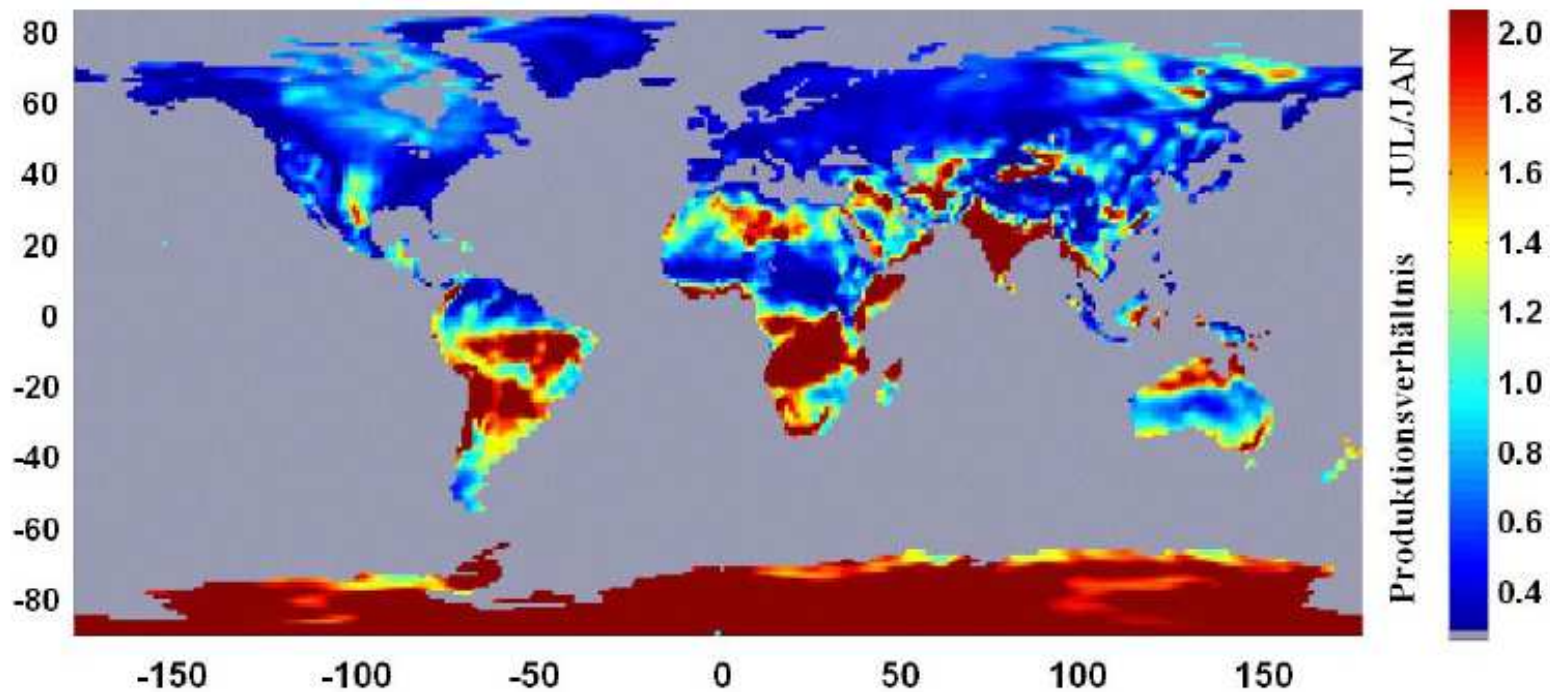
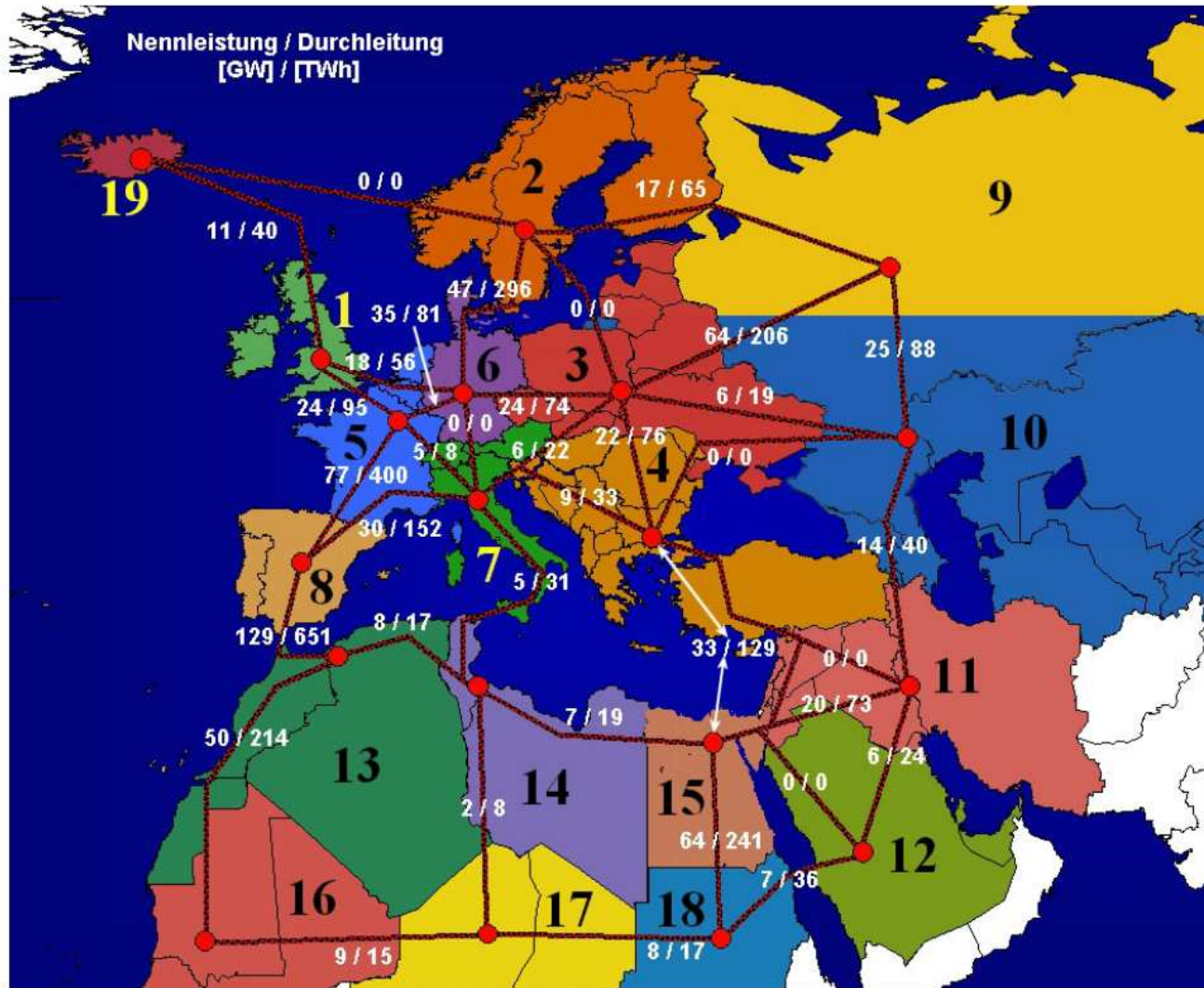


Abbildung 5.9: Saisonaler Vergleich der mittleren Stromproduktion aus Windenergie, Quotient aus langjährigen Monatsmittelwerten der Juli- und Januarerzeugung der Jahre 1979–1992; met. Daten: EZMW. Quelle der verwendeten meteorologischen Daten: [EZM]



Czisch 2005

Transmission power / transmitted energy

Results

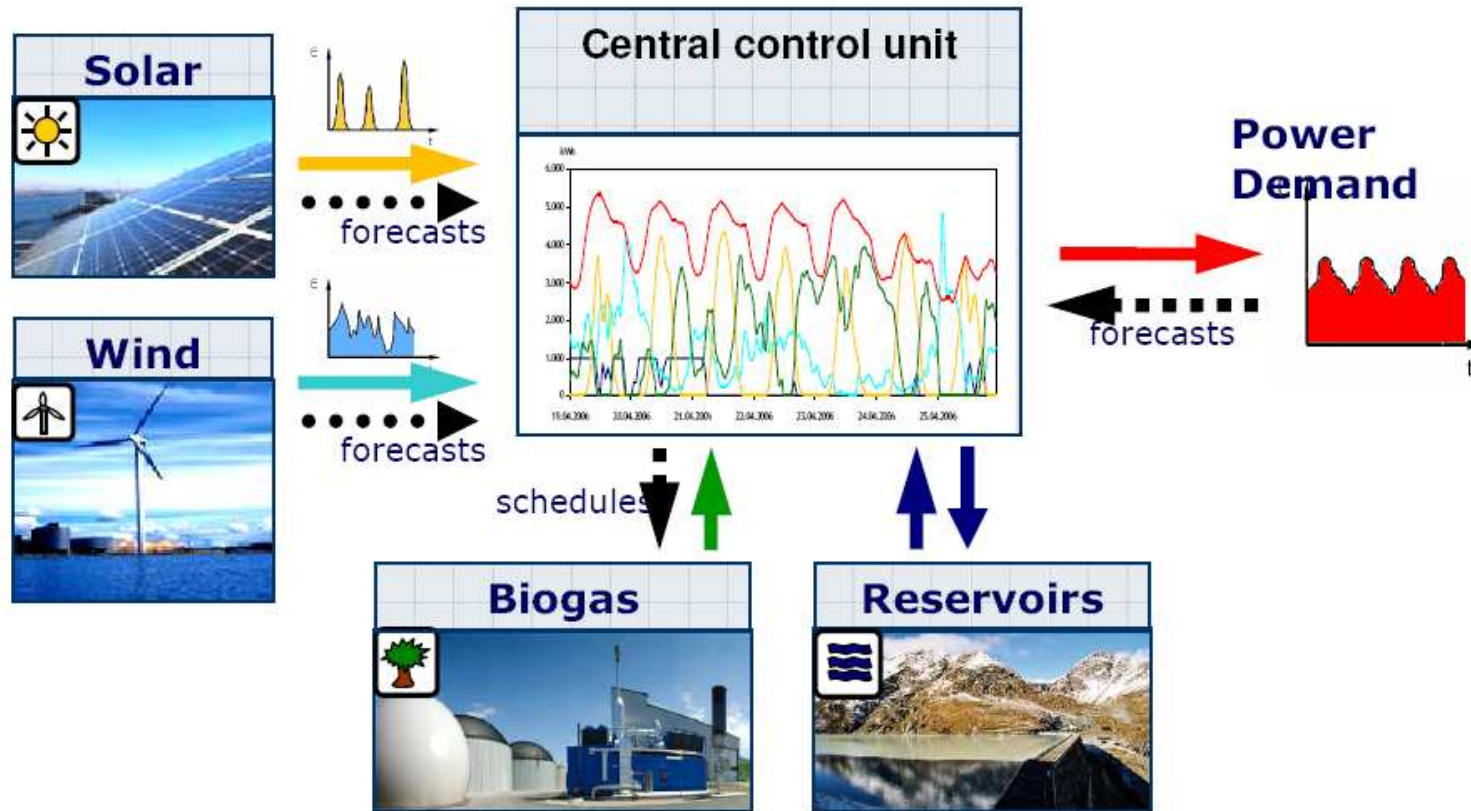
-a 100% renewables scenario is possible without construction of new pump hydro storage facilities or hydrogen

-Scandinavian hydro power is very valuable as dispatchable power

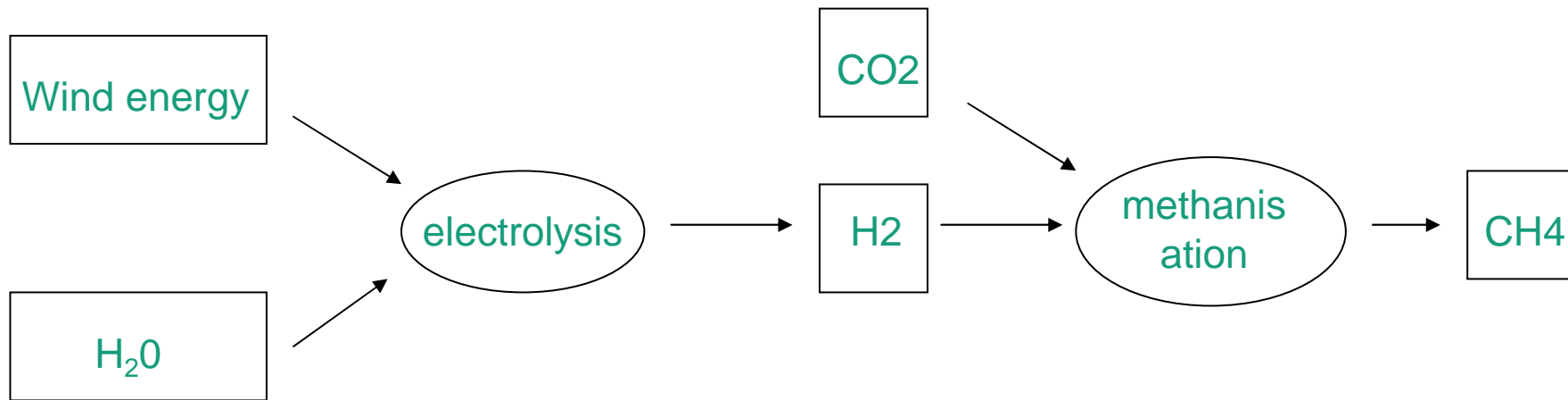
- if there is a cap on transport, hydrogen storage is needed in many regions and supply by renewables becomes considerably more expensive for many regions

Source: Czisch 2005

The Combined Power Plant



Alternatives to pump hydro storage ? Renewable power methane



Thank you for your attention!