Efficient Transition Towards Renewable Energy

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DG Energy
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Criteria for Sustainable Electricity Supply:

1. **Affordability**
   - Low cost
   - Low subsidies
   - Low structural effort

2. **Security**
   - Diversification of supply
   - Power on demand and redundancy
   - Sustainable energy resources
   - Available technology

3. **Environmental compatibility**
   - Low pollution, climate protection
   - Low risks for health and nature
   - Low land use and structural impacts

4. **Social compatibility**
   - Fair access to energy
   - Balance of dependencies and interdependencies
   - Flexibility during transition

Portfolio of Energy Sources for Electricity:

- ✓ Coal, Lignite
- ✓ Oil, Gas
- ✓ Nuclear Fission, Fusion
- ✓ Concentrating Solar Power (CSP)
- ✓ Geothermal Power (Hot Dry Rock)
- ✓ Biomass
- ✓ Hydropower
- ✓ Wind Power
- ✓ Photovoltaic
- ✓ Wave / Tidal

ideally stored primary energy

storable primary energy

fluctuating primary energy

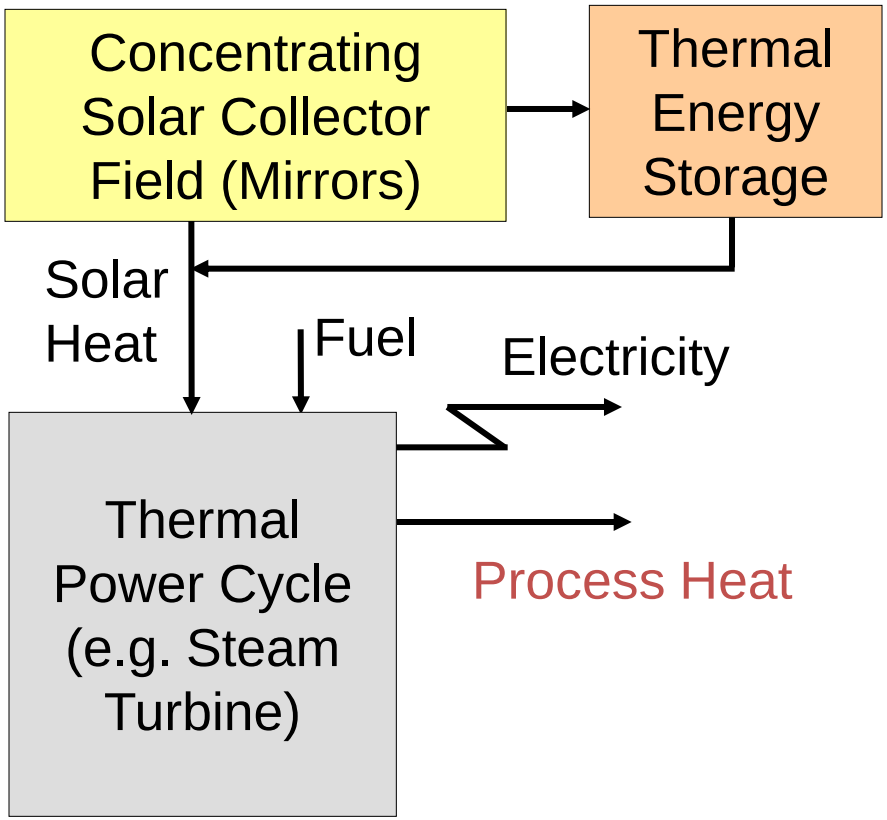
Important Frame Condition:

The available firm capacity must be larger than peak load

$$\sum P_{installed} \cdot CC \geq S \cdot P_{load,\,max}$$

$P_{installed}$	installed capacity
CC	capacity credit of each technology
$P_{load,\,max}$	peak load
S	security margin (e.g. 1.25 for 25% reserve capacity)

Principle of a Concentrating Solar Thermal Power Plant



- concentrated, easily storable solar thermal energy as fuel saver
- spinning reserve
- firm capacity, power on demand
- combined generation of process heat for cooling, industry, desalination, etc.

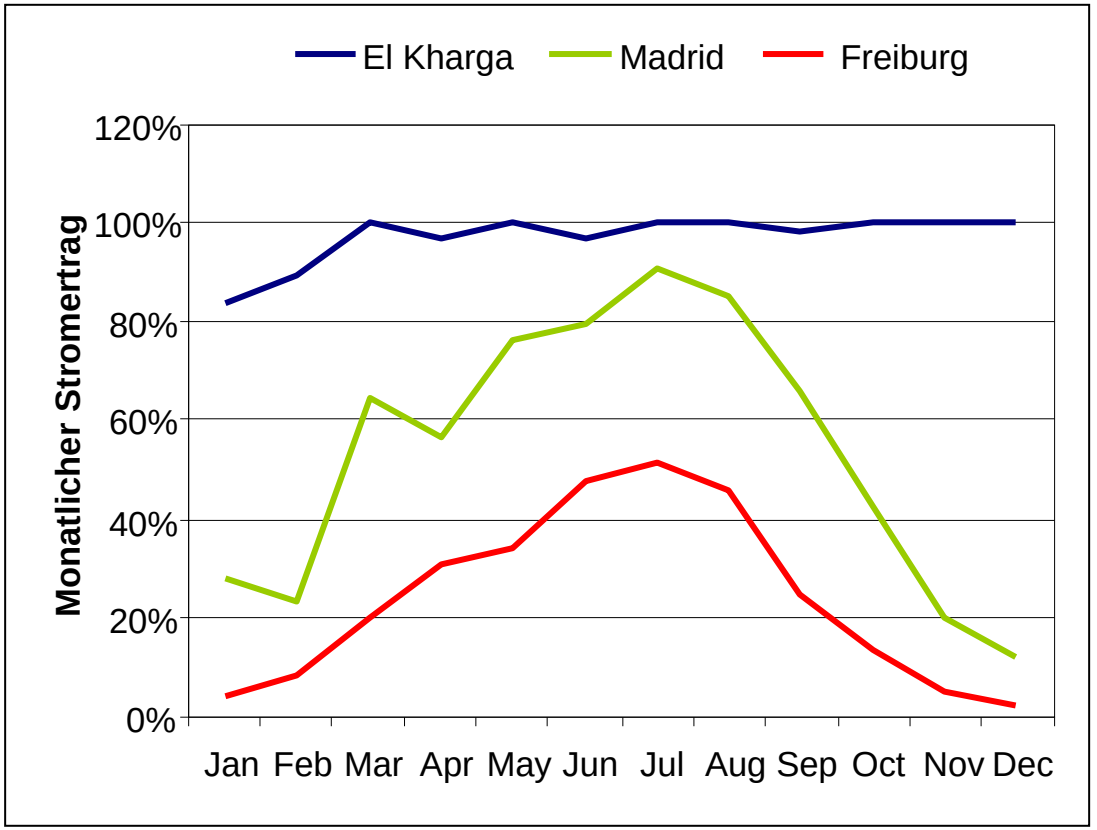
Why CSP imports from North Africa?

Higher availability than in EU → flexible renewable power

CSP with large solar field and storage (SM4) at three sites:

NA advantages:

- more sunny days
- lower latitude
- ➔ lower seasonal variation of electricity yield



The Conventional Alternating Current (AC) Electricity Grid

1. **AC grid** capacity (NTC) in NA between 0.5 to 1.0 GW (Germany 8.5 GW)
2. If the AC grid grows proportional to power demand, it will achieve German standards by 2050 only in Egypt (8 GW NTC), but not in the rest of NA
3. Long-distance losses in AC grid are high (10-15%/1000 km)
4. No traceability of electricity sources in the AC grid

➔ Balancing of power supply and demand between neighbors to increase redundancy and plant utilization: **yes**

➔ Long-distance transport of flexible solar power on demand: **no**

➔ **AC grid is not suitable for long-distance exports from NA to EU, but for balancing among direct NA-EU neighbors**

Point-to-Point HVDC Links

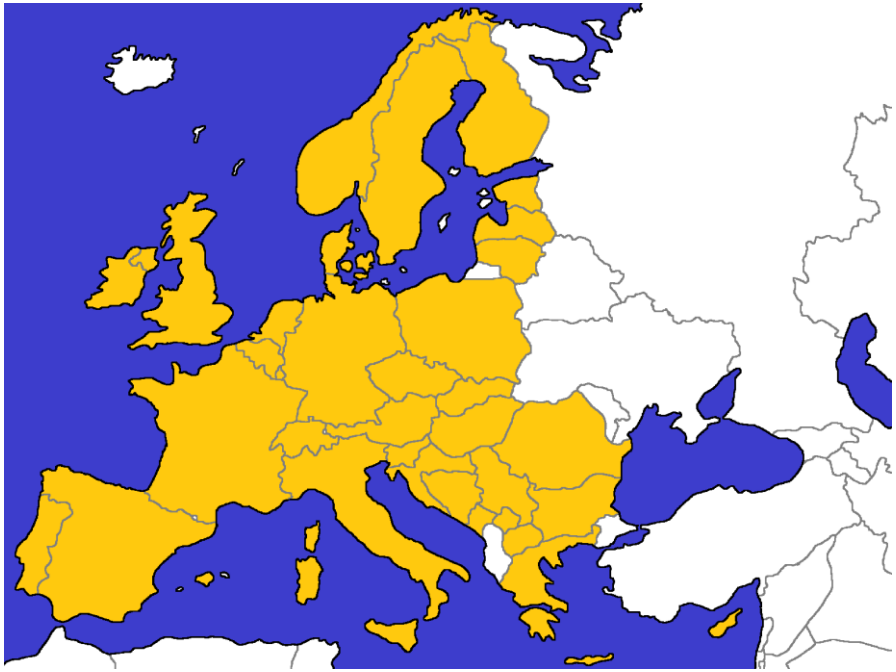
1. **HVDC links** (100 GW) used world-wide to bring flexible renewable power from A to B
2. A 15% contribution to EU demand in 2050 will require 100 GW NTC
3. Long-distance losses in HVDC links are low (3-5%/1000 km)
4. Full traceability of electricity sources in a HVDC link

➔ Balancing of power supply and demand between (oversea) neighbors to increase redundancy and plant utilization: **yes**

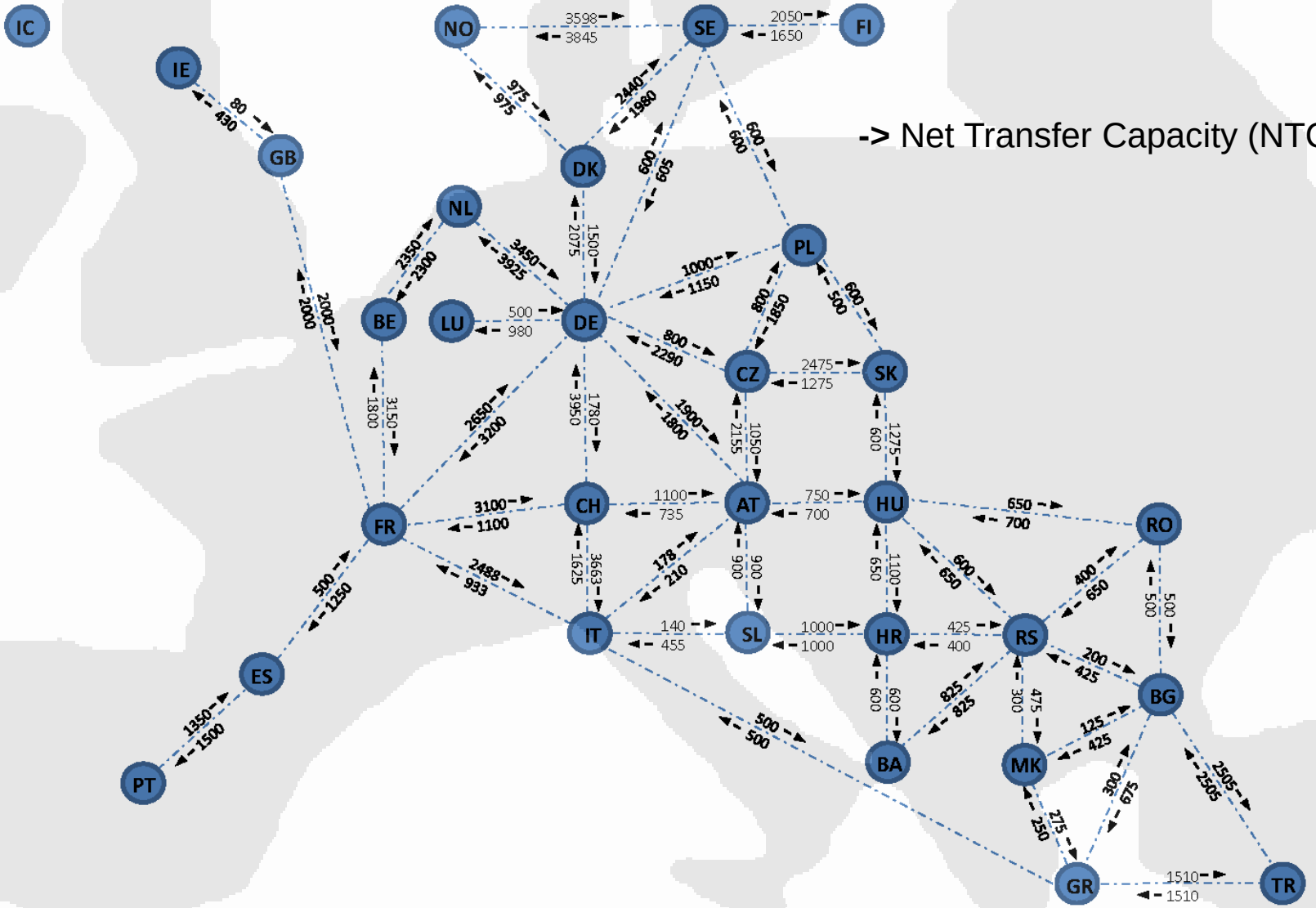
➔ Long-distance transport of flexible solar power on demand: **yes**

➔ **HVDC is suitable for long-distance exports from NA to EU, and can also be used for balancing among NA-EU neighbors over the Mediterranean**

Flexible Solar Power Imports from a European Point of View



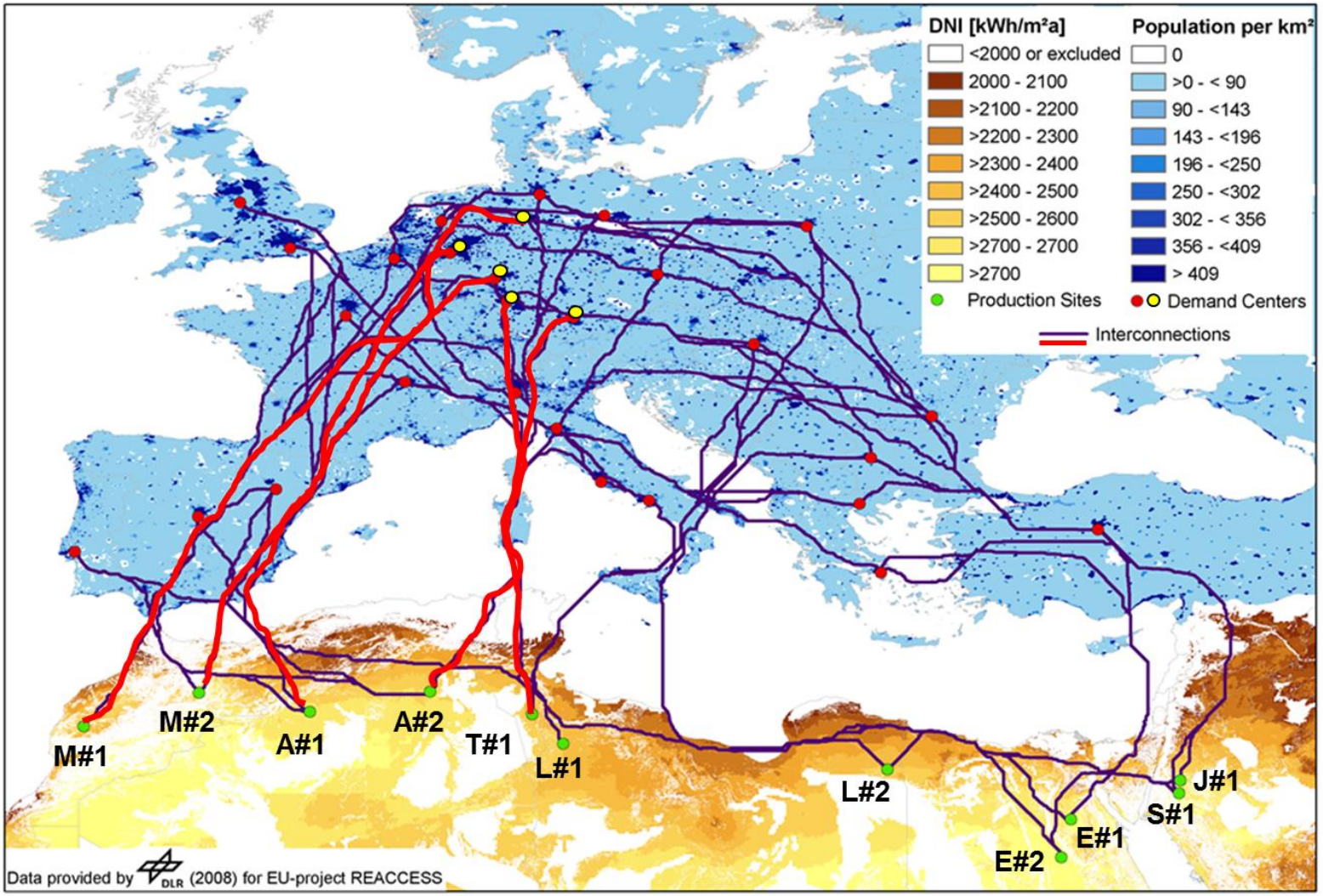
Model of the European Electricity Grid …



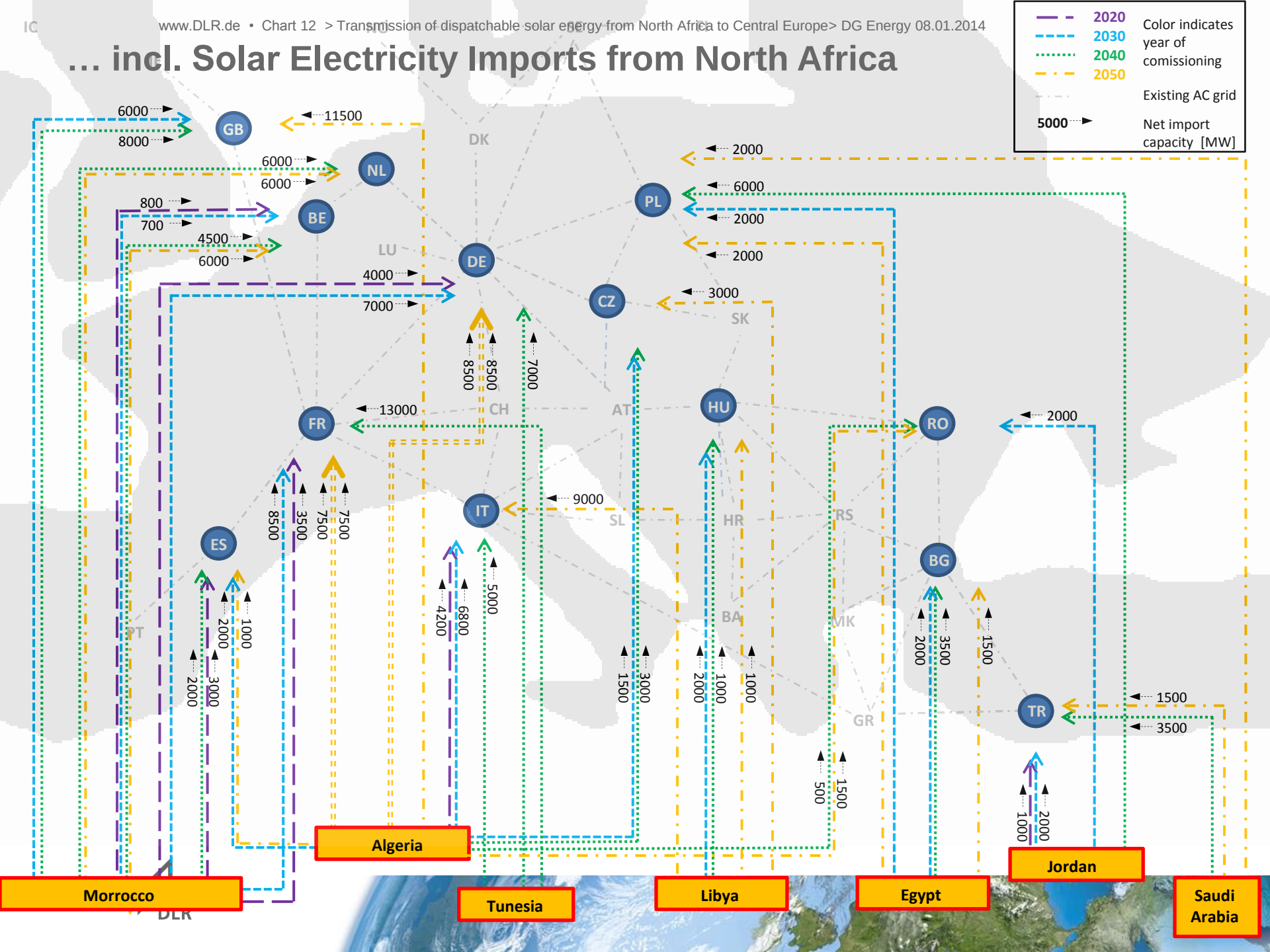
-> Net Transfer Capacity (NTC) in MW

DLR und Univ. Stuttgart, Dissertation Daniel Stetter (2012)

Identification of 33 corridors – REACCESS (2008)



… incl. Solar Electricity Imports from North Africa

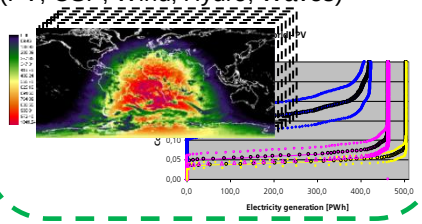


Energy Data Analysis Tool *EnDAT*

Hourly profiles of RE generation, electricity and heat demand

RE potentials

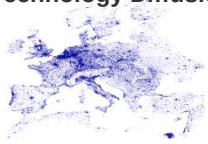
Installable capacities, power plant model, hourly power output, cost and full load hour potentials
(PV, CSP, Wind, Hydro, Waves)



Electricity demand

Heat demand

Technology Diffusion



Hourly RE generation profile

Hourly load profile

Hourly load profile

Hourly load profile

Energy System Optimization Model *OptiMo*

Temporally and spatially resolved cost-minimized energy supply

RE-Generation
PV, CSP, Wind, Geothermal, Waves, Hydro, Biomass

Conventional Generation
Nuclear, Lignite CCGT, Gas

Flexible CHP
Heat storage
Peak boiler
Electric boiler
Solar share

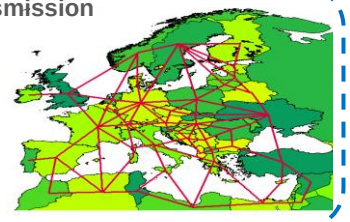
Heat Generation
CHP
Heat Pumps
Gas & Biomass
Solar

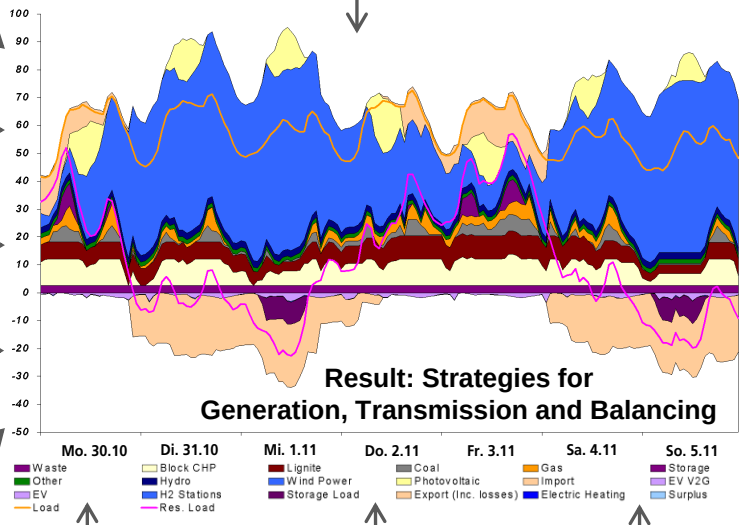
Transmission

AC-Grid Transmission
Current transfer capacities

DC-Grid-Transmission
HVDC inter-country level

DC-CSP-Transmission
HVDC CSP plants in Africa





Result: Strategies for Generation, Transmission and Balancing

Demand Response
Industry & private sector

E-Mobility
BEV/EREV: charge strategies, V2G. Battery capacity hourly resolved
***FCEV*:** flexible on-site H_2-generation

Storage
Pumped hydro
Compressed air
Hydrogen

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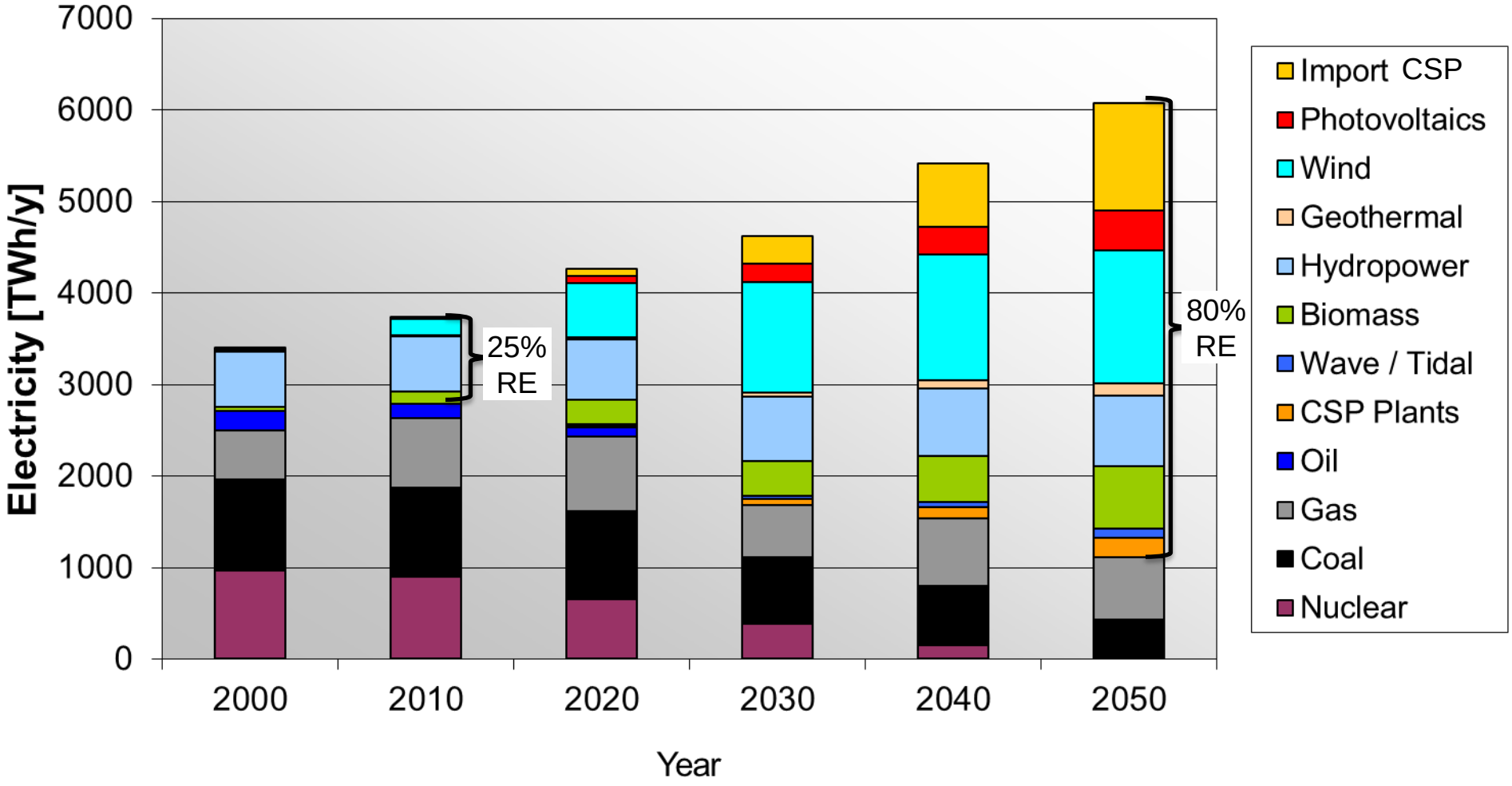
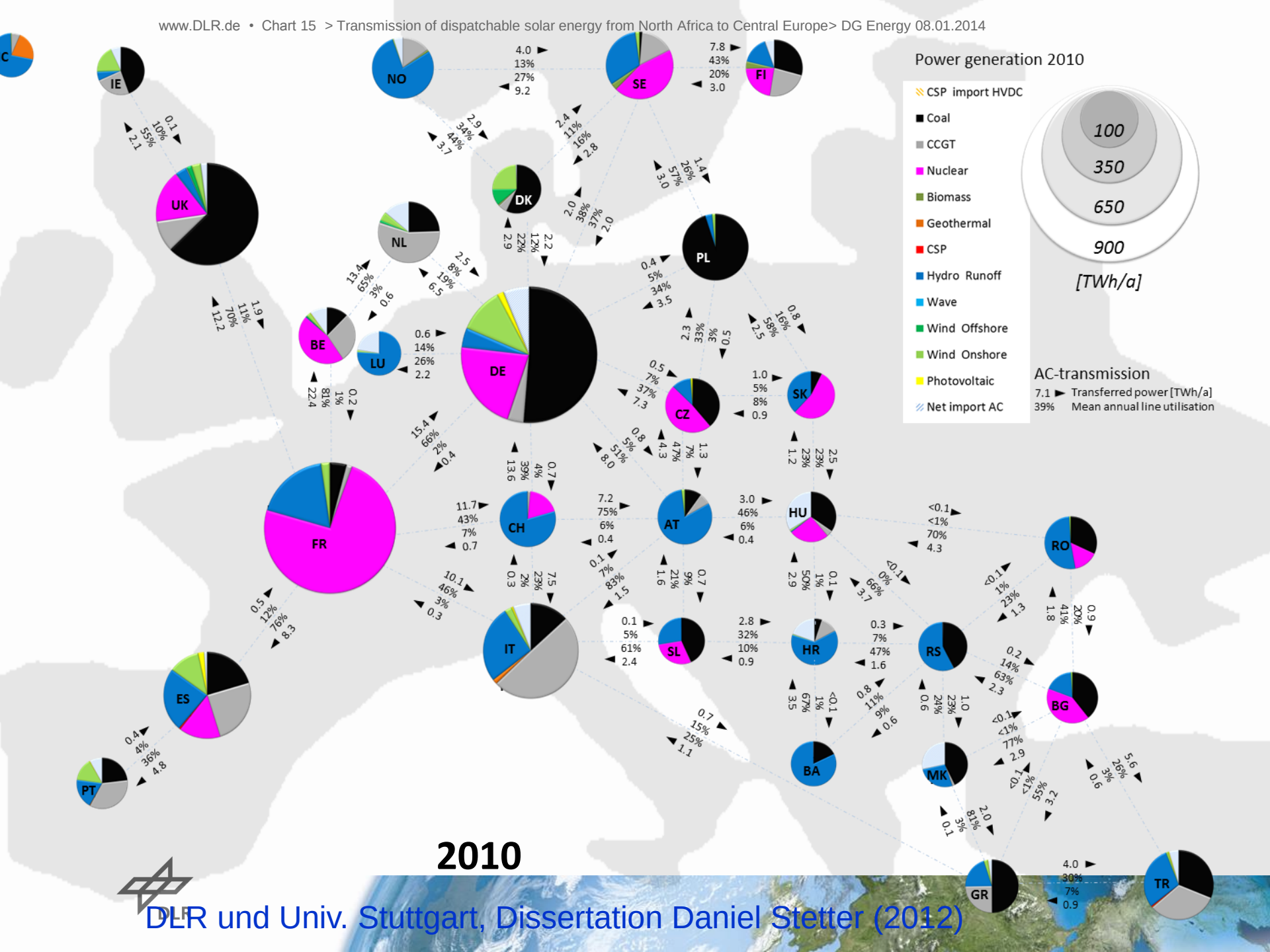
Electricity Demand Europe (ENERGEO 2012)




Power generation 2010
CSP import HVDC
Coal
CCGT
Nuclear
Biomass
Geothermal
CSP
Hydro Runoff
Wave
Wind Offshore
Wind Onshore
Photovoltaic
Net import AC
100
350
650
900
[TWh/a]
AC-transmission
7.1 ► Transferred power [TWh/a]
39% Mean annual line utilisation
IE
NO
SE
FI
UK
DK
NL
PL
BE
LU
DE
CZ
SK
FR
CH
AT
HU
RO
IT
SL
HR
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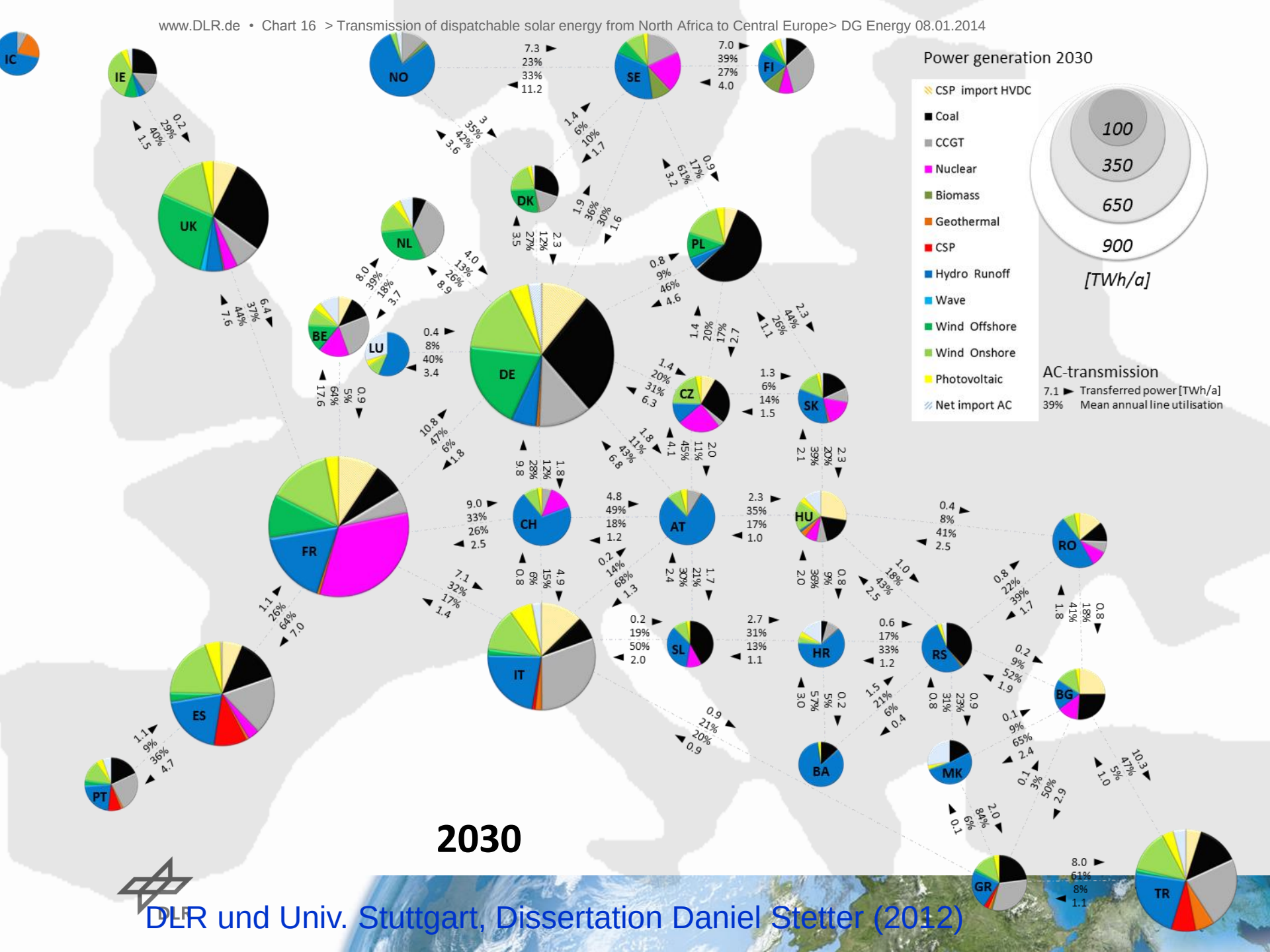
TR
2010


Power generation 2030
CSP import HVDC
Coal
CCGT
Nuclear
Biomass
Geothermal
CSP
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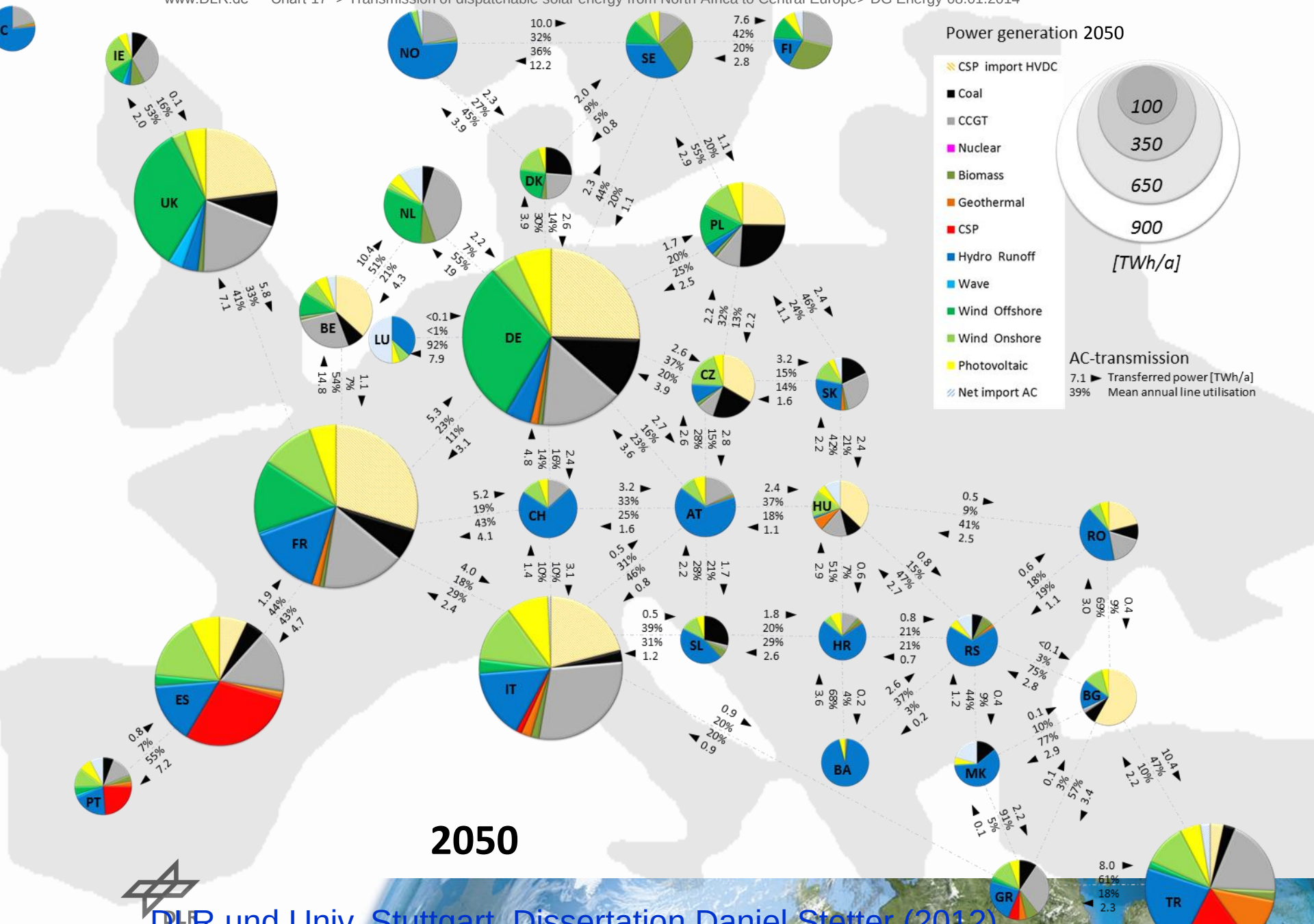
2030


Power generation 2050
CSP import HVDC
Coal
CCGT
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Biomass
Geothermal
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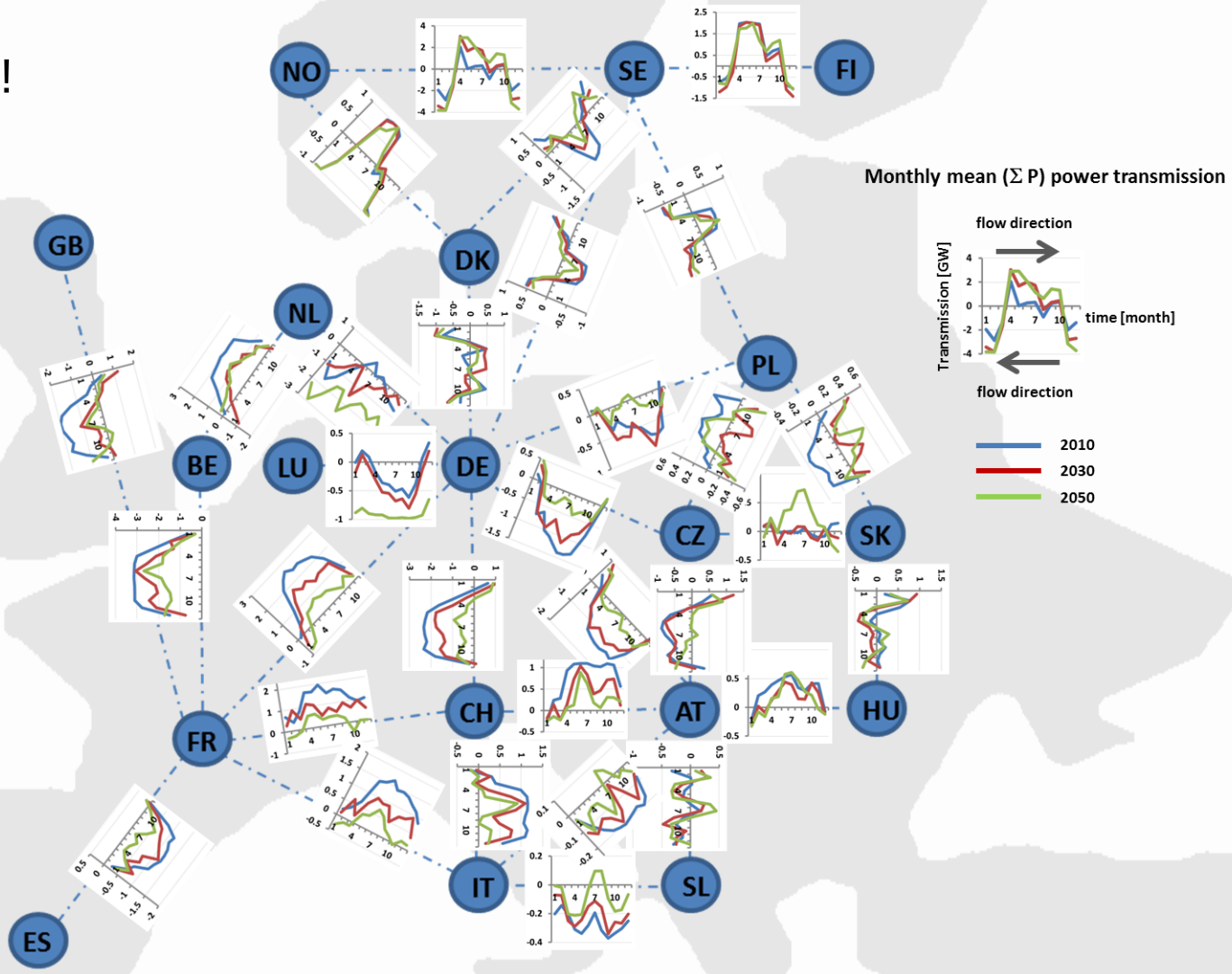
TR
2050

Effect on the EU Electricity Grid

Grid load is reduced!

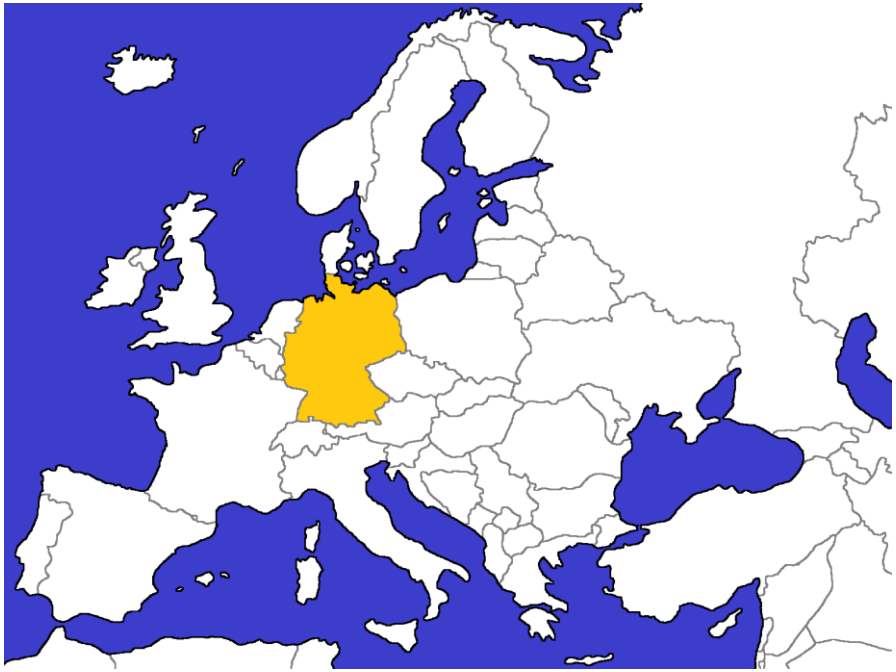
No additional storage needed!

Consistent and compatible country scenarios!

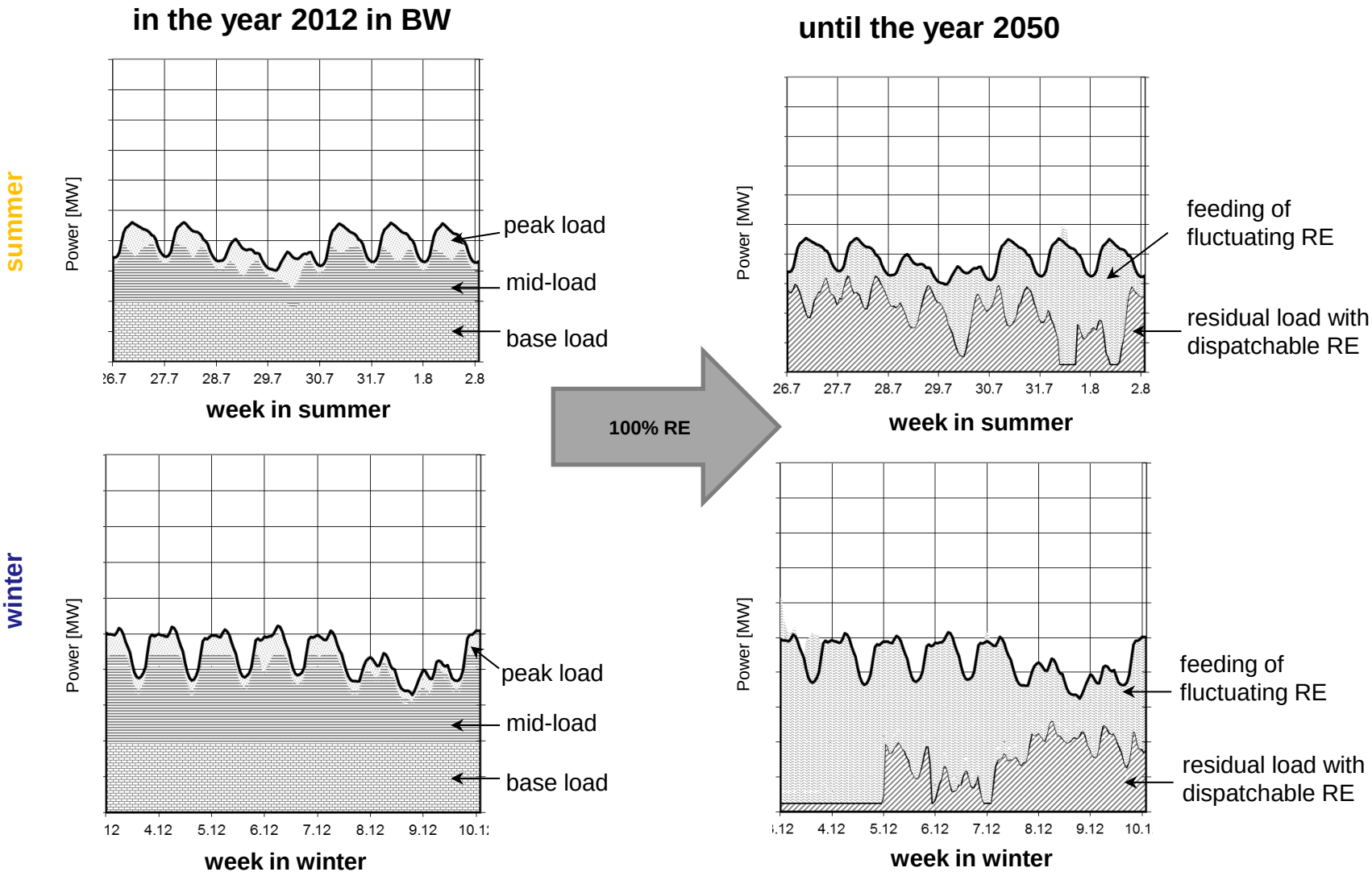


DLR und Univ. Stuttgart, Dissertation Daniel Stetter (2012)

Flexible Solar Power Imports from a German Point of View



Paradigm change in the load profile

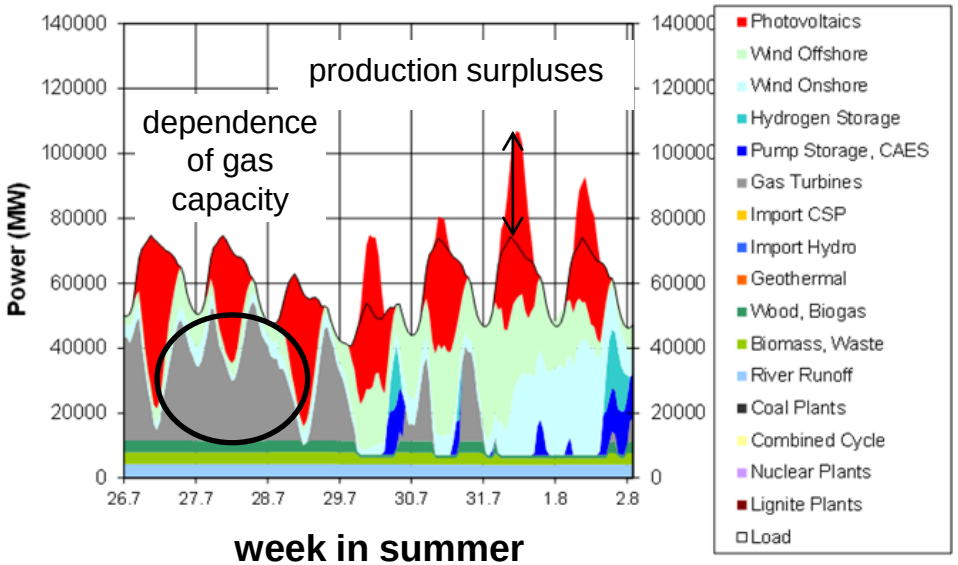


Quelle: Hess, D., 2013, Fernübertragung regelbarer Solarenergie

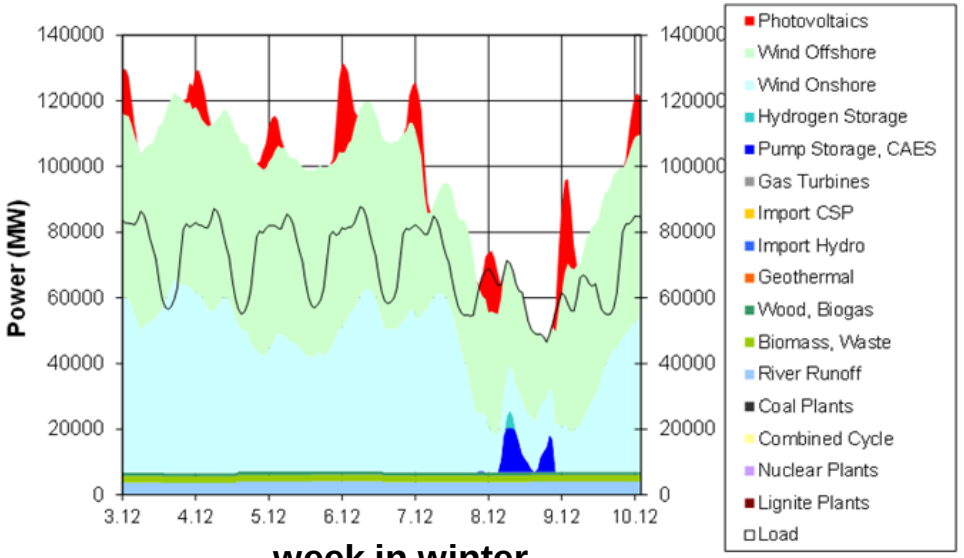
A 90% RES-E scenario for Germany without CSP imports:

375 GW + 40 GW NTC + 40 GW Storage

Energy source	Installed Capacity	Annual electricity yield	average utilization
	MW	TWh/a	h/a
Variable / renewable	235500	551.3	
Photovoltaics	100000	98.9	989
Wind Onshore	70000	156.4	2235
Wind Offshore	60000	257.7	4295
River Runoff	5500	38.2	6951
Flexible / renewable	8000	37.9	
Biomass, Waste	4000	22.1	5515
Wood, Biogas	4000	15.9	3964
Geothermal		0.0	0
Import Hydro		0.0	0
Import CSP		0.0	0
Fossile / Nuclear	90000	56.4	
Gas Turbines	90000	56.4	627
Coal Plants	0	0.0	0
Combined Cycle	0	0.0	0
Nuclear Plants	0	0.0	0
Lignite Plants	0	0.0	0
Storage and net transfer	80000	48.7	
Pump Storage, CAES	20000	15.7	785
Hydrogen Storage	20000	13.8	688
H2-Storage Capacity (days)	1		
Net Transfer Capacity (NTC)	40000	19.3	482
Total power park	**373500**	**579**	**1551**



week in summer



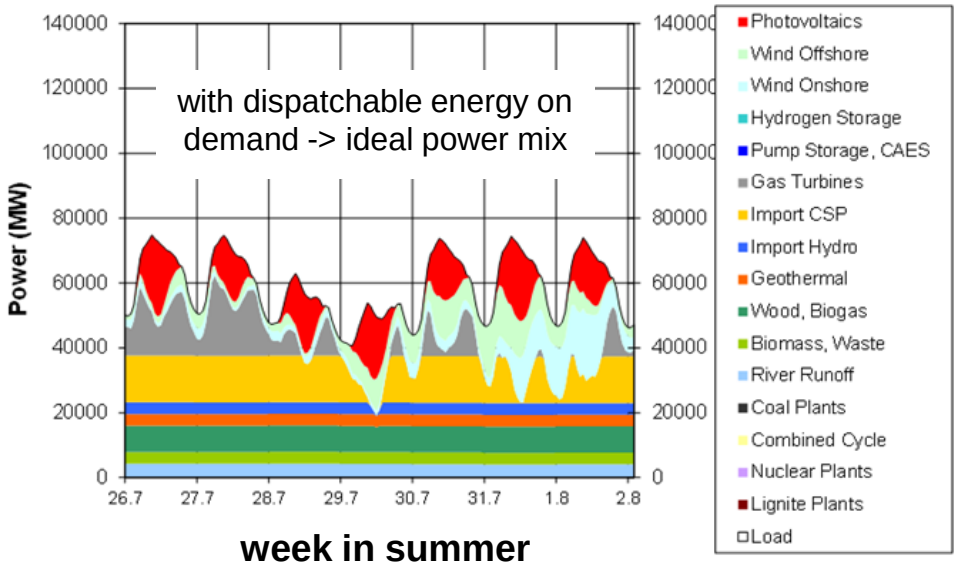
week in winter

low average utilization

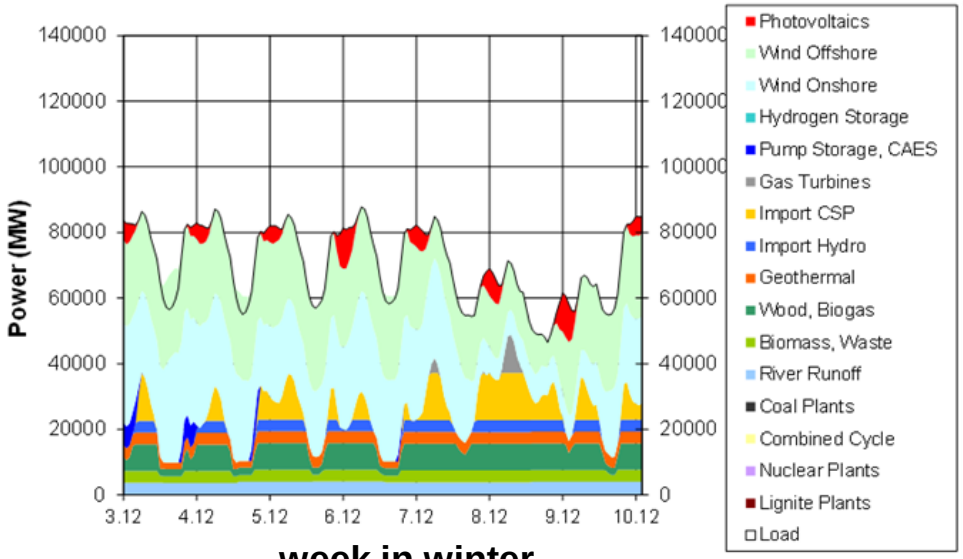
A 90% RES-E scenario for Germany with CSP imports:

225 GW + 8 GW NTC + 20 GW HVDC + 8 GW Storage

Energy source	Installed Capacity	Annual electricity yield	average utilization
	MW	TWh/a	h/a
Variable / renewable	117500	288.1	
Photovoltaics	45000	44.5	989
Wind Onshore	40000	89.4	2235
Wind Offshore	27000	116.0	4295
River Runoff	5500	38.2	6951
Flexible / renewable	35000	220.2	
Biomass, Waste	4000	30.0	7502
Wood, Biogas	7000	49.8	7112
Geothermal	4000	30.2	7547
Import Hydro	4000	25.8	6462
Import CSP	16000	84.3	5271
Fossile / Nuclear	65000	54.4	
Gas Turbines	65000	54.4	837
Coal Plants	0	0.0	0
Combined Cycle	0	0.0	0
Nuclear Plants	0	0.0	0
Lignite Plants	0	0.0	0
Storage and net transfer	16000	3.1	
Pump Storage, CAES	7500	1.9	255
Hydrogen Storage	0	0.0	0
H2-Storage Capacity (days)	0		
Net Transfer Capacity (NTC)	8500	1.1	135
Total power park	**225000**	**561**	**2494**



week in summer



week in winter

higher average utilization

CSP imports from NA to Germany via HVDC links will lead to:

1. 150 GW less power plants for the German “Energiewende”
2. 5 times less grid capacity (no significant expansion)
3. 5 times less power storage (no significant expansion)
4. 90% RES-E can be achieved much faster and with much less effort
5. Allows every European country to follow a similar strategy without creating external costs by RES-E surplus and gaps to be balanced by neighbors

Alternative:

Surplus (??) from Moroccan wind power and PV (??) exported to Europe through a “Supergrid” in Andalucia (??)

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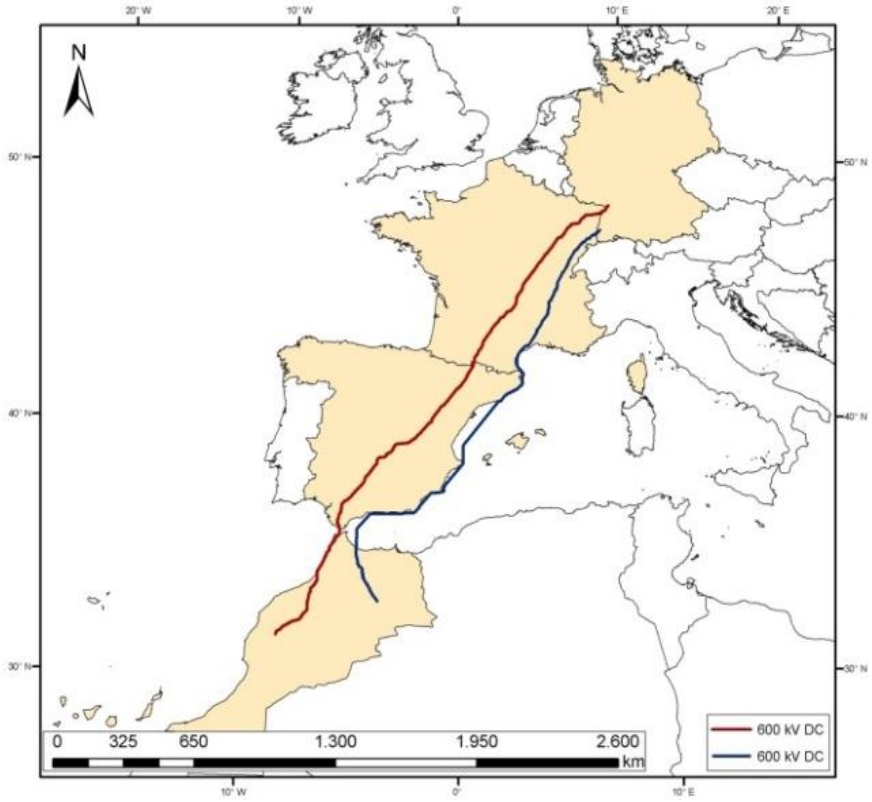
Model of a first CSP-HVDC link between Morocco and Germany



Discussion partners of the study – Transmission of dispatchable solar energy from North Africa to Central Europe

industry

ABB

a.hak ELECTRON

TRANSNET BW

amprion

Rte Réseau de transport d'électricité

RED ELÉCTRICA DE ESPAÑA

المكتب الوطني للكهرباء Office National de l'Electricité

masen Moroccan Agency for Solar Energy

A+S CONSULT

DREES & SOMMER

enolcon

ACWA POWER

DLR

research

DLR Deutsches Zentrum für Luft- und Raumfahrt

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HIGHWAY 2050

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cooperative society

Raiffeisenbank Pfaffenhausen eG

Cooperatives Europe

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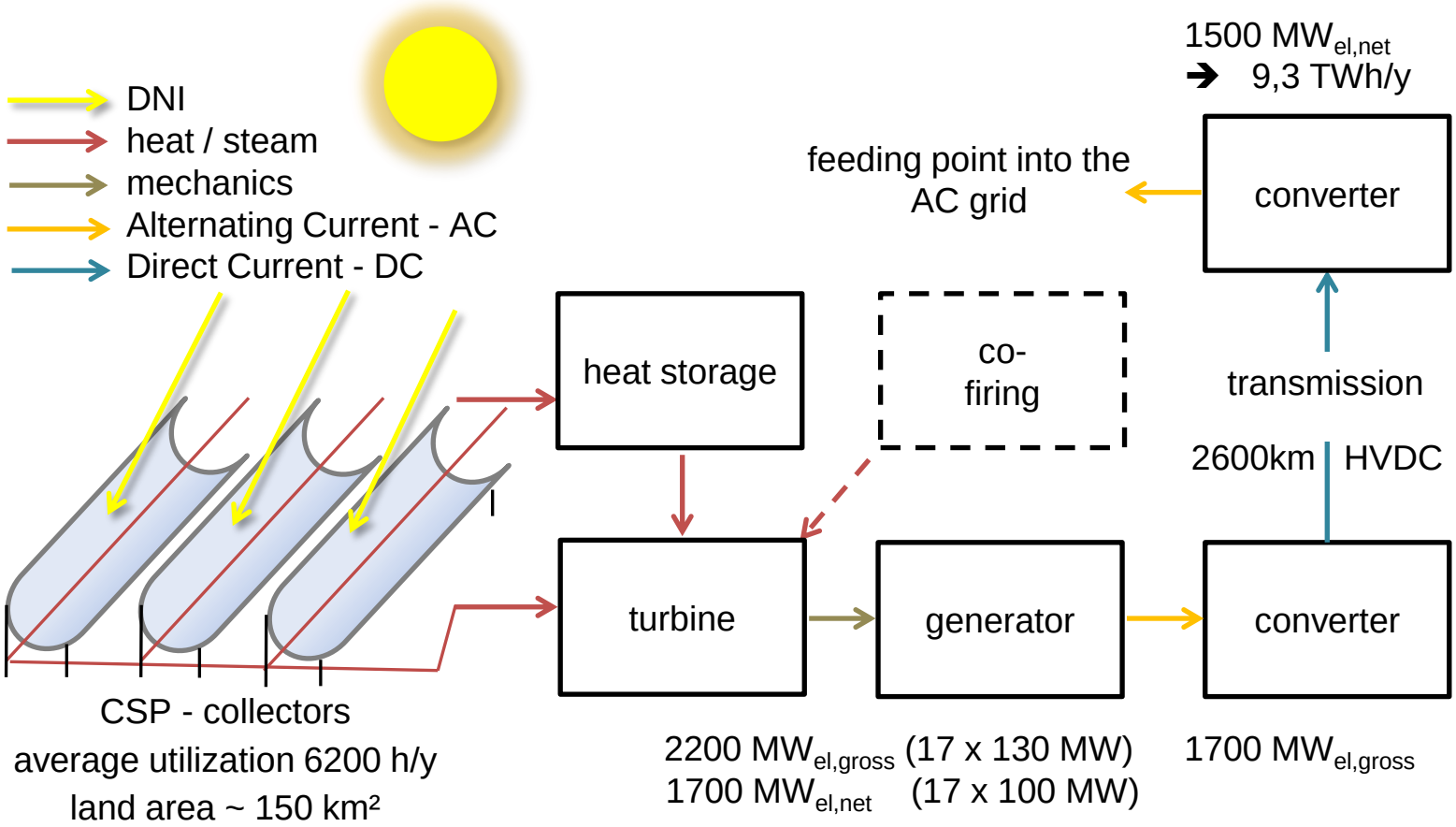
Transmission of dispatchable solar energy: CSP-HVDC link



DNI: Direct Normal Irradiance
CSP: Concentrating Solar Power
HVDC: High Voltage Direct Current

Source: Hess, D., 2013, Fernübertragung regelbarer Solarenergie

First model of a CSP-HVDC link, cost and land requirements

MOR-E-F-D

HVDC 2600 km
1.7 GW / 1.5 GW_{net}
1,9 – 5,1 billion €
150 km²

CSP 2.2 GW
CSP 12 -18 billion €
150 km²

MOR-E-F-D

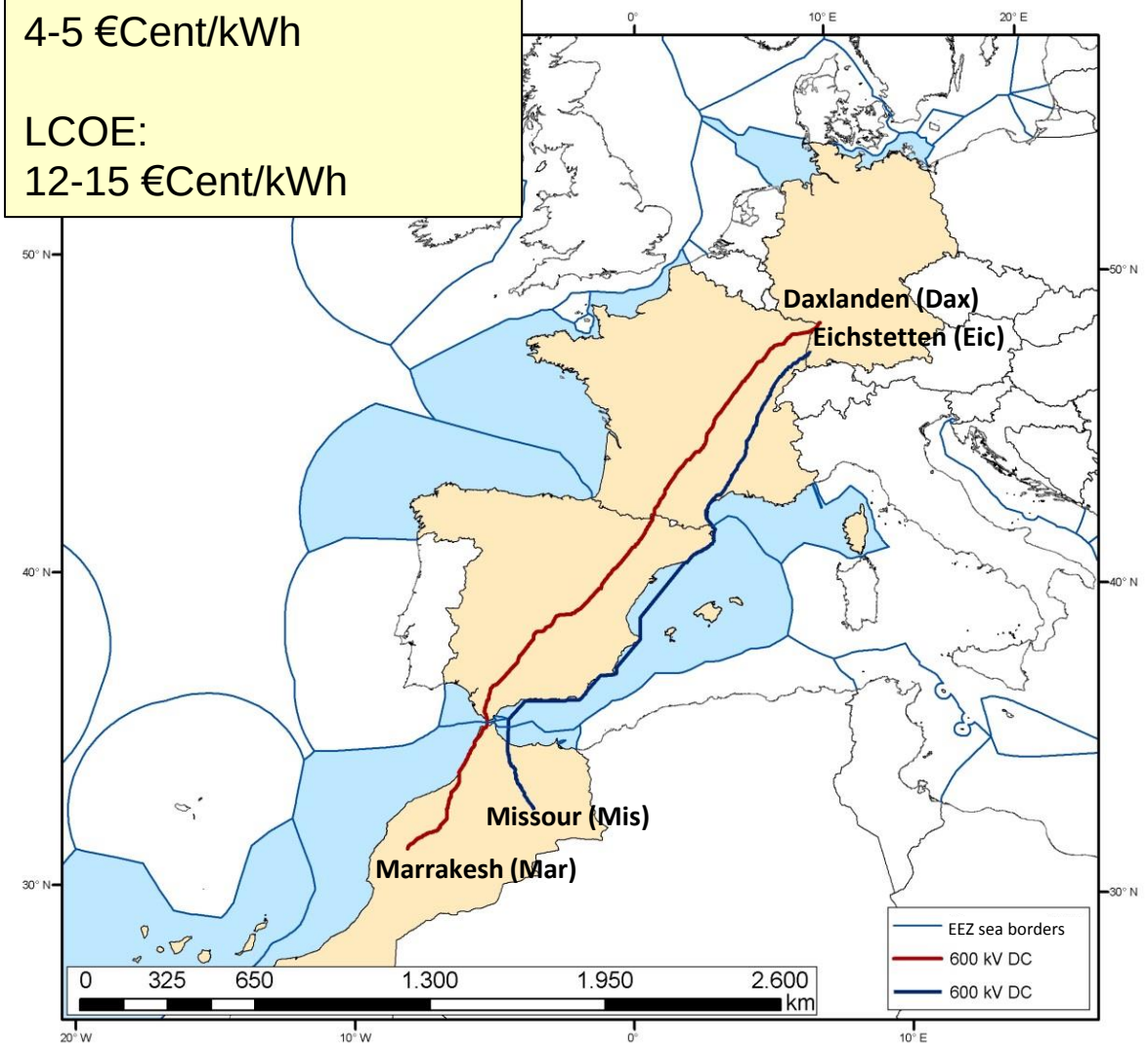
HVDC 2300 km
1.7 GW / 1.5 GW_{net}
3,7 – 4,9 billion €
75km²

CSP 2.2 GW
CSP 12 -18 billion €
150 km²

-> 9.32 TWh/a
16-23 billion € (real 2010)
feasible until 2024

O&M:
4-5 €Cent/kWh

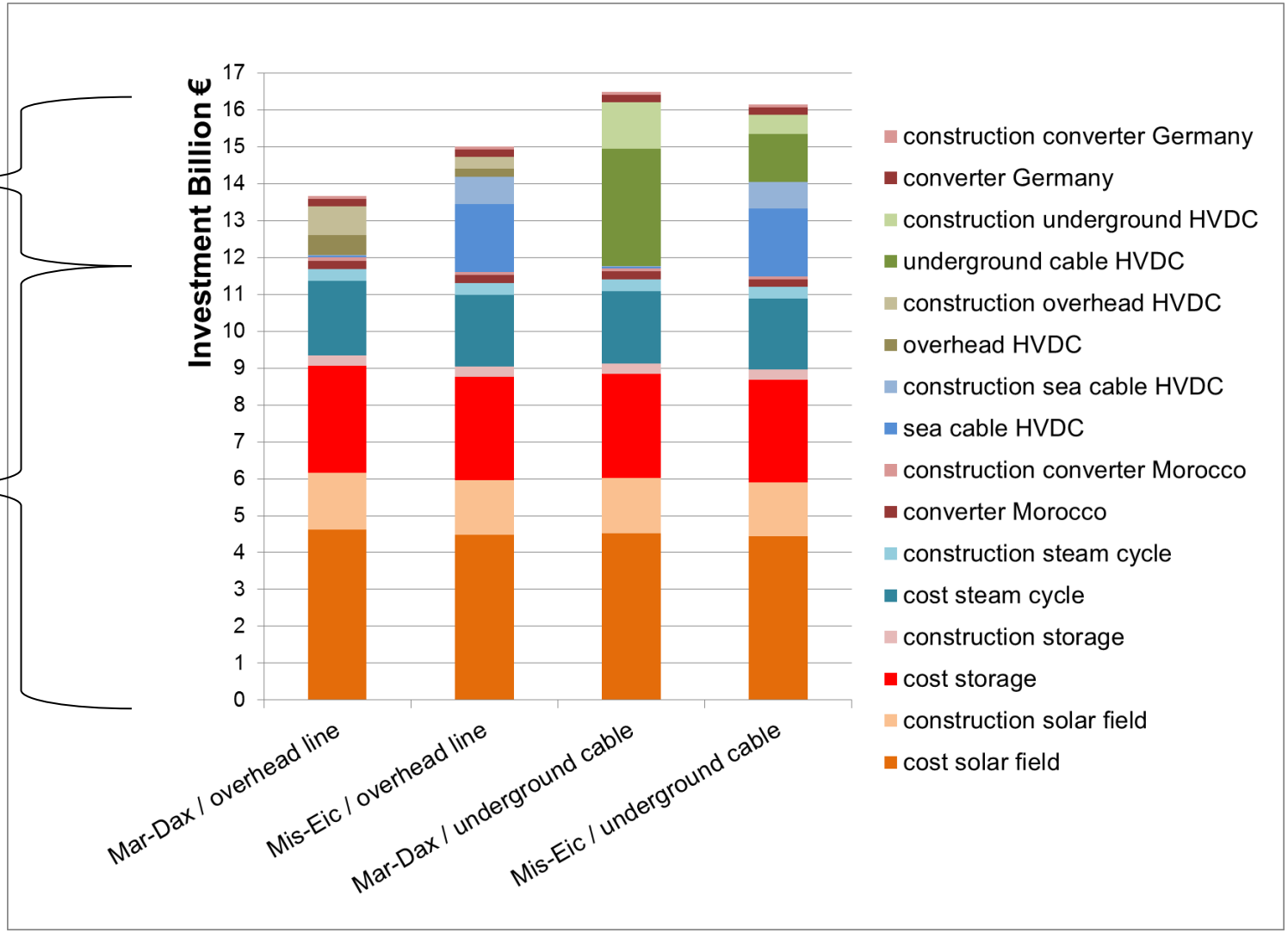
LCOE:
12-15 €Cent/kWh



Total investment cost of the four CSP-HVDC alternatives

HVDC

CSP

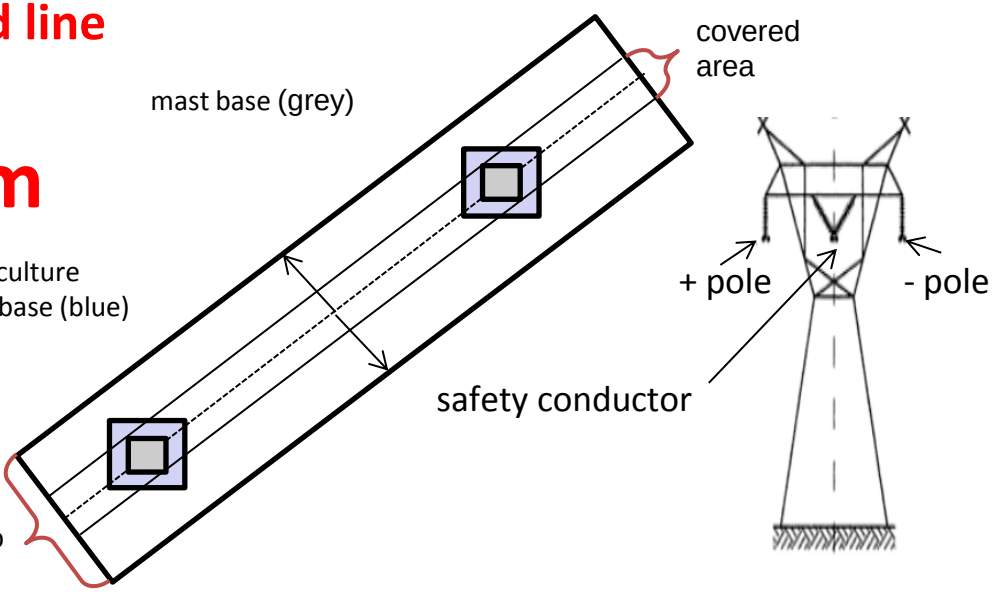


Adequate permanent payment for the required land

Overhead line

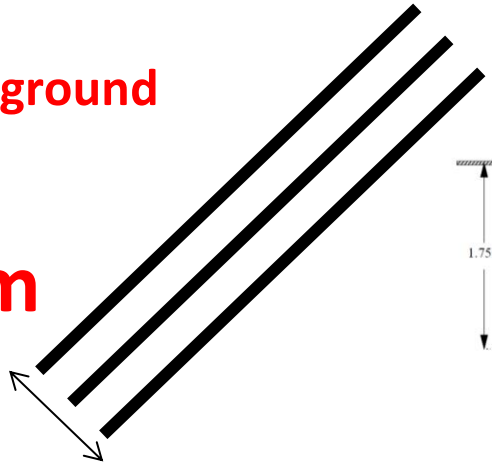
70 m

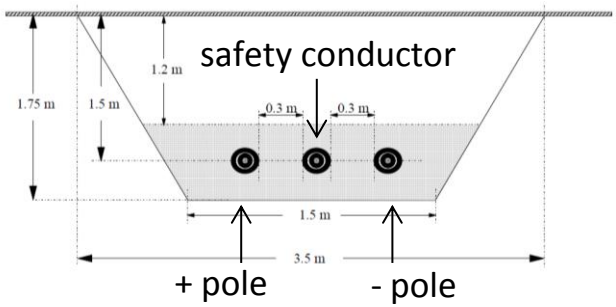
Restriction of agriculture through the mast base (blue)



Underground cable

4 m





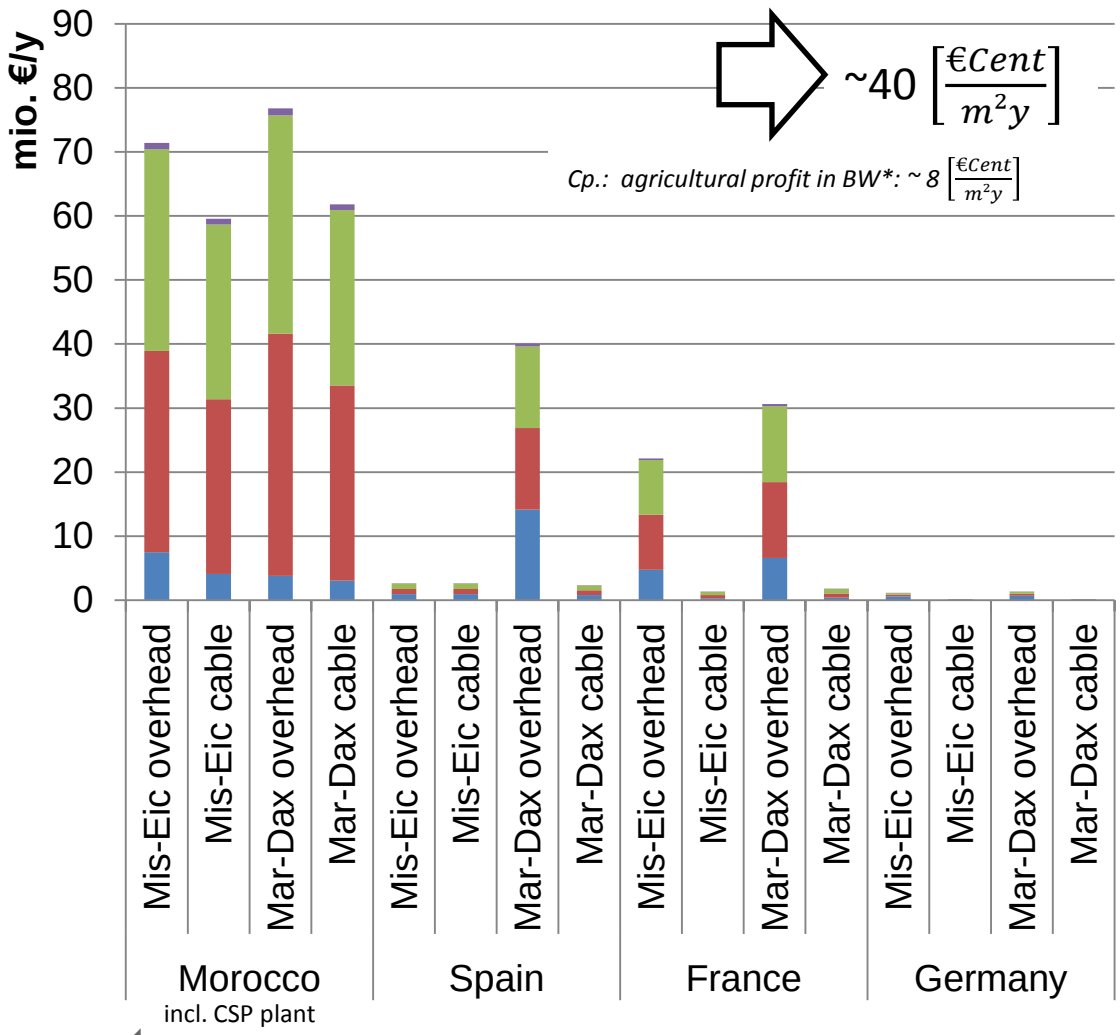
unit

$$\left[\frac{€Cent}{TWh \cdot m^2 \cdot y}\right]$$

cheaper overhead line and more expensive underground cable can reach through this compensation payment **cost neutrality** within their lifetime!

free choice of technology is made possible -> increased acceptance

Annual income for the concerned nations, their municipalities and landowners (riparians) – each time with 4 routes



~40 $\left[\frac{€Cent}{m^2y}\right]$

Cp.: agricultural profit in BW: ~ 8* $\left[\frac{€Cent}{m^2y}\right]$

0.67 – 1.56 $\left[\frac{€Cent}{kWh}\right]$ costs for the consumers

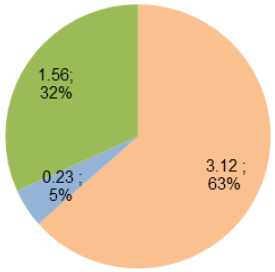
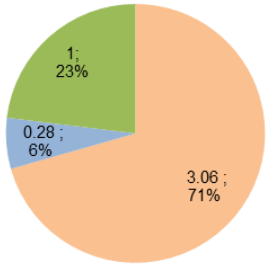
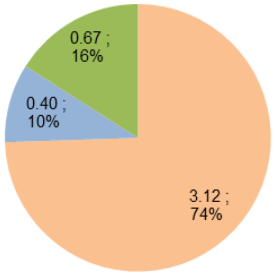
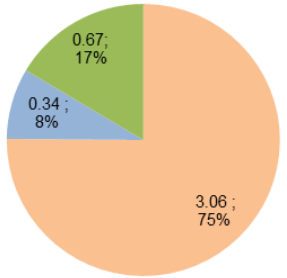
- annual income for the nations and their municipalites from the concession fee
- annual income for the nations and their municipalites from tax of the motivation payment
- annual income for the landowners from the motivation payment
- annual income for the landowners from the decreasing value

Today only the blue value is paid for the construction of transmission lines in Germany **ONCE**!

DLR

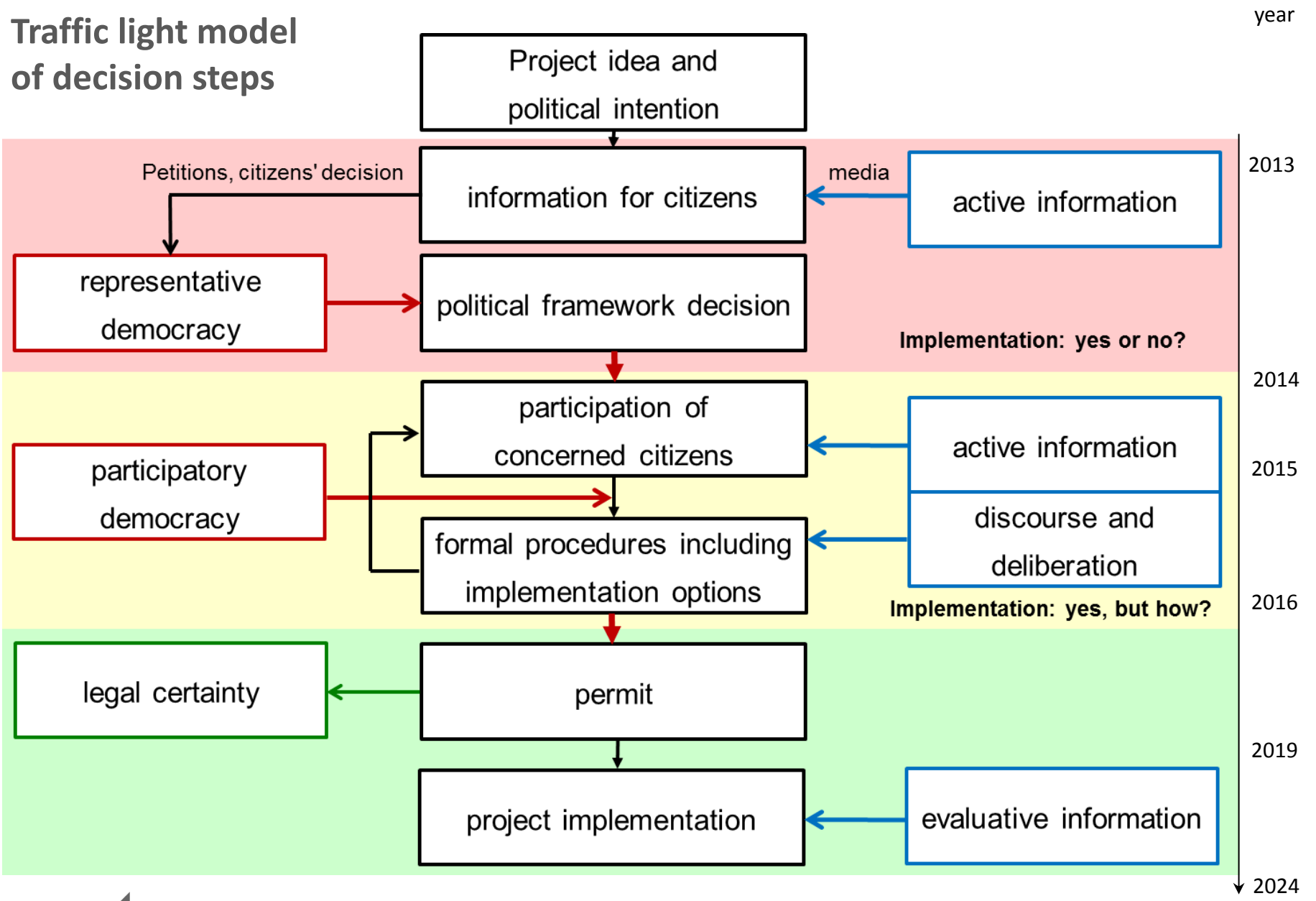
Source:*Landwirtschaftliche Betriebsverhältnisse und Buchführungsergebnisse 2012

Annual operation cost of the four CSP-HVDC alternatives

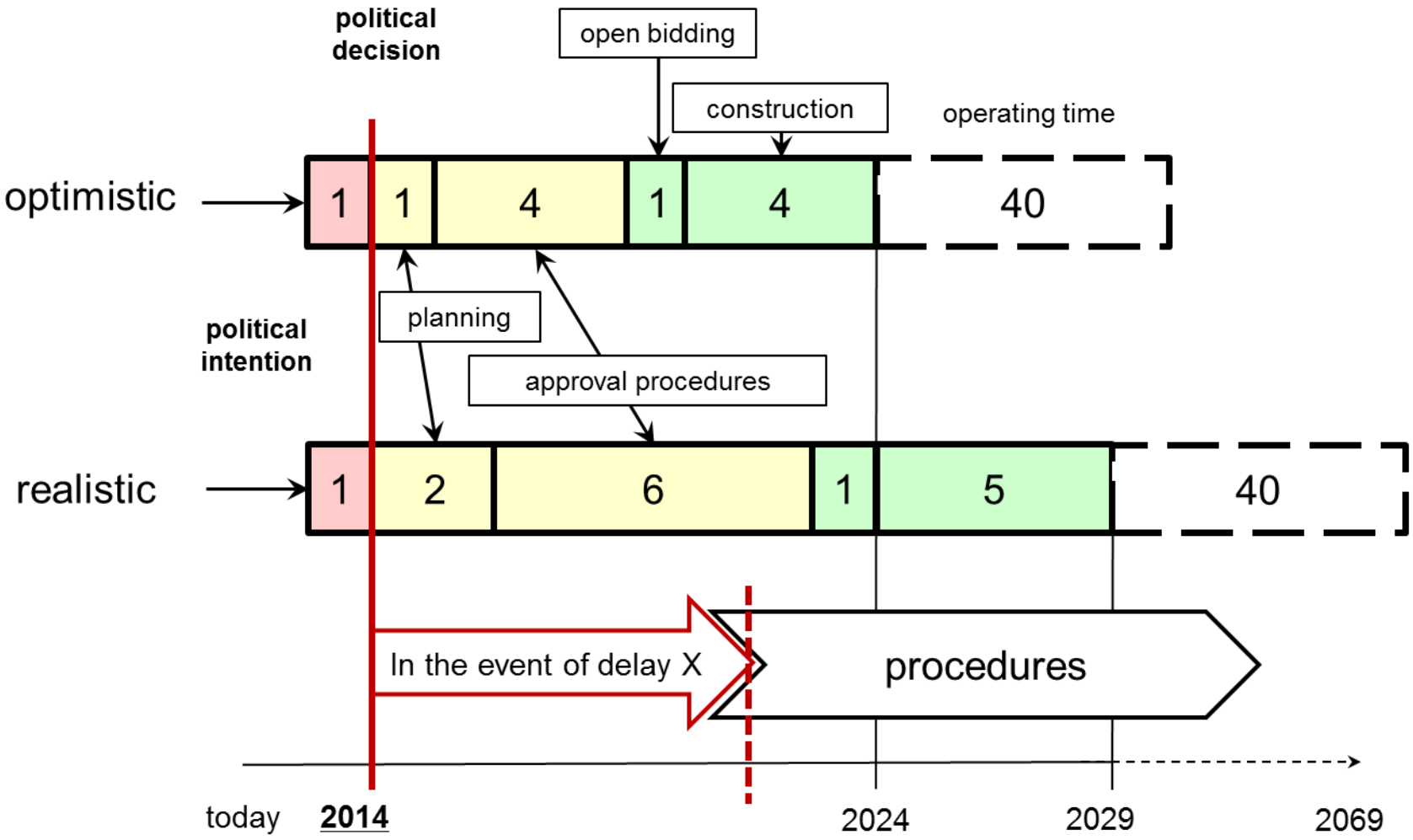
Alternative	Marrakesch-Daxlanden	Missour-Eichstetten
Overhead HVDC	 ∑4,91 €Cent/kWh	 ∑4,34 €Cent/kWh
Underground HVDC	 ∑4,19 €Cent/kWh	 ∑4,07 €Cent/kWh

O&M CSP O&M HVDC compensation costs

Traffic light model of decision steps



Time limit for a decision



How can the investment be paid that low interests incur and thus the capital costs remain low?

High investment:
16-23 billion €

→ High capital cost

↓

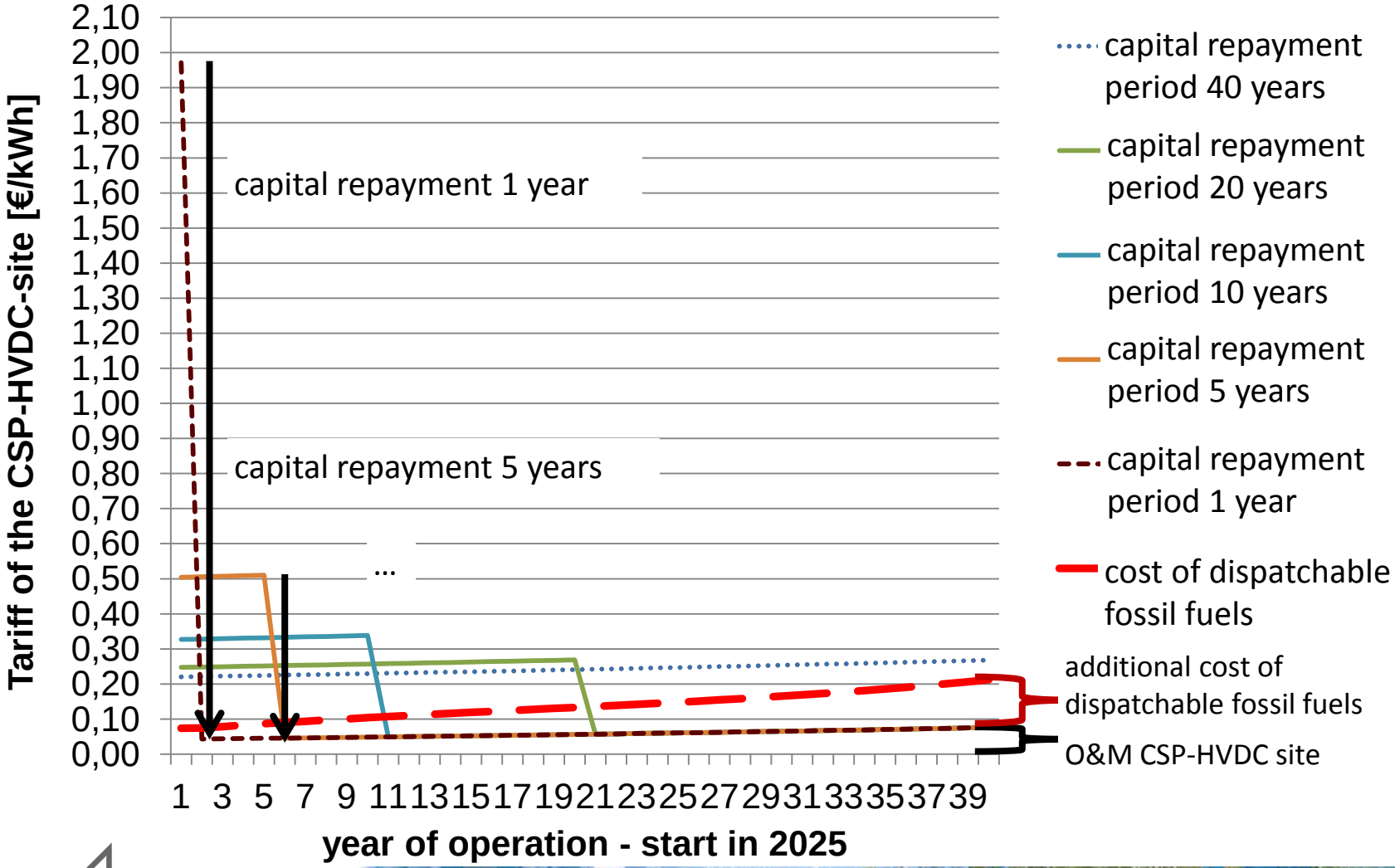
Short capital repayment period + Garanteed AAA Power Purchase Agreement (PPA)

↓

The tariff will be high but only for a short time

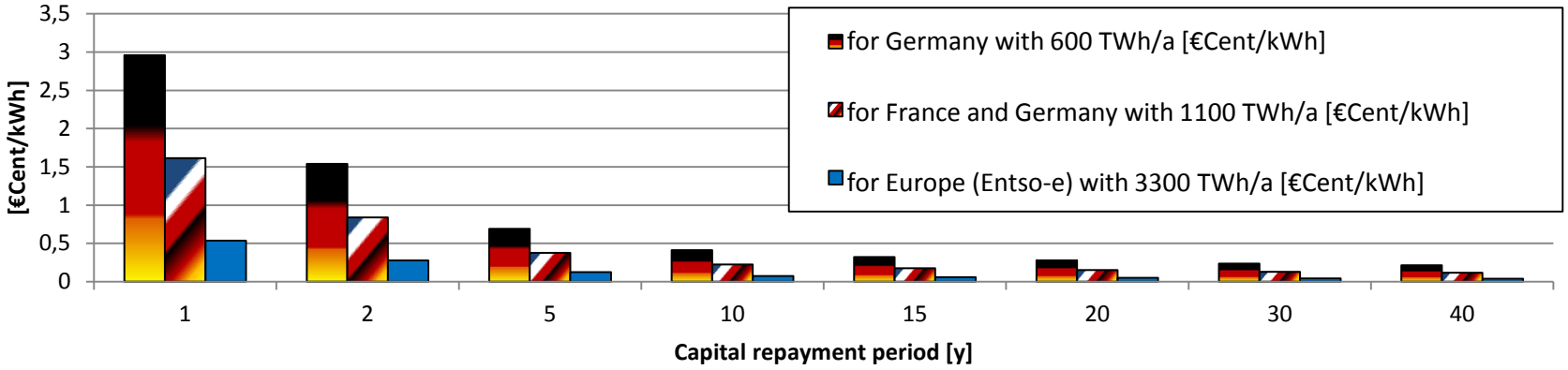
← Apportionment on a high number of consumers

Tariff of the CSP-HVDC site Mis-Eic with underground cable - How can 16 billion € be paid that low interests incur and thus the capital costs remain low?

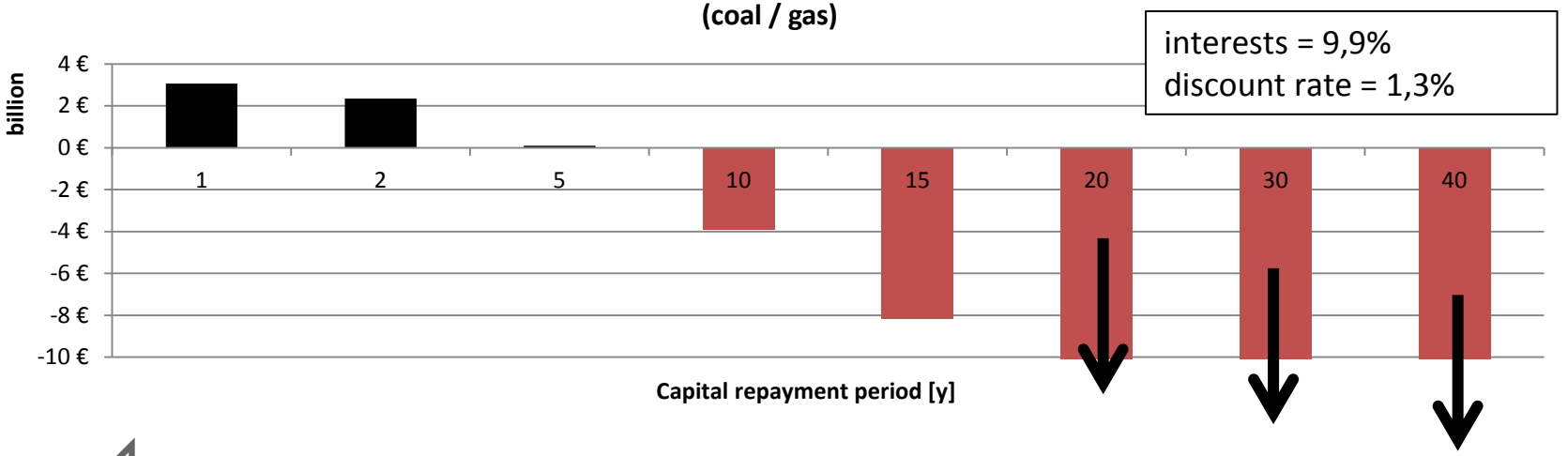


How can 16 billion € be paid that low interests incur and thus the capital costs remain low?

Apportionment of the costs on all electricity customers



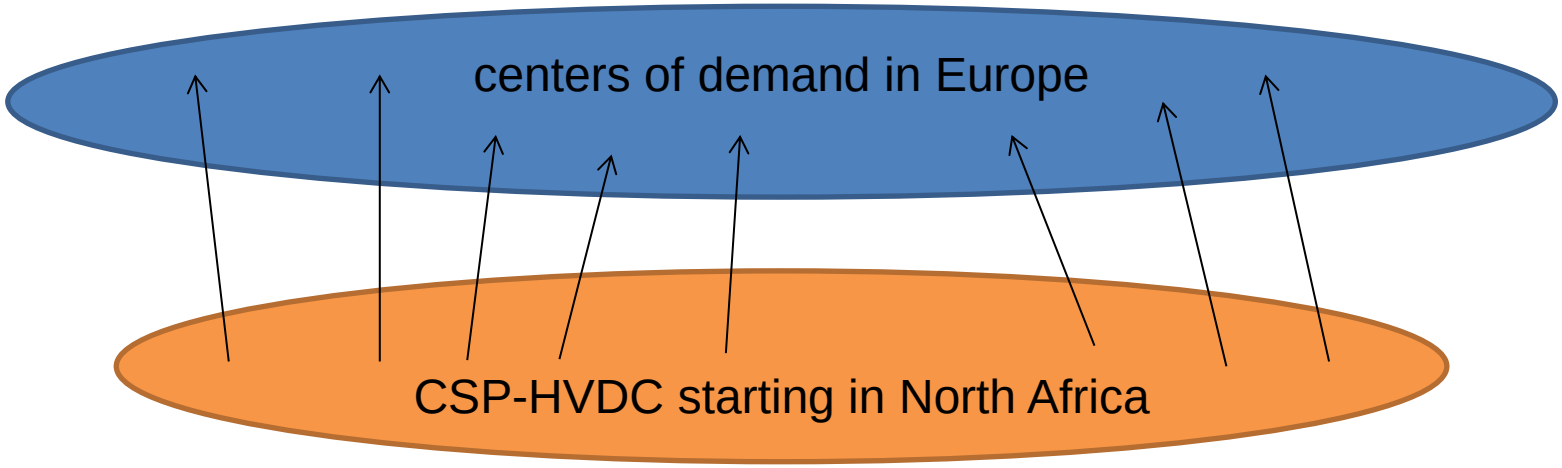
Savings (black) and additional costs (red) accumulated in 40 years versus dispatchable fossil fuels (coal / gas)



Investment plan based on a standardised and unified European apportionnement depending on consum of each country

- every member state will profit from learning curve
- every member state will get the capacity for that the state has paid
- stabalising the european electricity market with firm, constant cheap and renewable energy
- european apportionnement will not stress EU industry competition

-> with about 2 €Cent/kWh on a consumption of 3300 TWh/a all present european nuclear power plants (~125 GW) can be replaced by more flexible and renewable CSP-HVDC sites in the next 20 years



Conclusions

- For an electricity system with ~100% RE dispatchable renewable energy is necessary
- Only CSP with a new HVDC point-to-point infrastructure can enable an export of dispatchable renewable energy form North Africa to Europe
- The investment costs are at about 16-23 billion € for CSP and HVDC
- If we decide in 2013/2014 the project could be feasible until 2025
- Due to the compensation costs for the required land area, overhead transmission lines and underground cables can reach cost neutrality
- To avoid high capital costs garantees (AAA, PPA) and a short capital repayment period are needed

Current dialogs

- German-Moroccan Energy Partnership (Government Level, BMWi)

Bundesministerium für Wirtschaft und Technologie

Royaume du Maroc
Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement
Département de l'Environnement

- FP7 Project BETTER (4th cooperation mechanism)

INTELLIGENT ENERGY EUROPE
FOR A SUSTAINABLE FUTURE

BETTER

- Internal workshops with discussion partners

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Further steps

- preparation of a handbook for public participation
- publication of further scientific studies on the necessity of dispatchable solar electricity imports to Baden-Wuerttemberg on a multilingual website
- questioning of citizens in case studies in exemplary communities
- detailed cost-benefit analysis with risk assessment
- cooperation with ENTSO, TransnetBW, RTE, REE, ONEE in preparation for the inclusion in the "Union List" of a project with common interests (EU Regulation 347/2013)
- support of the necessary application documents and the required measures
- search for suitable project responsible

Potential information network for a multinational civil project

civils

participation in procedures

financial participation

information and agreement

information and agreement

framework

framework of cooperative societies

information and order

information and order

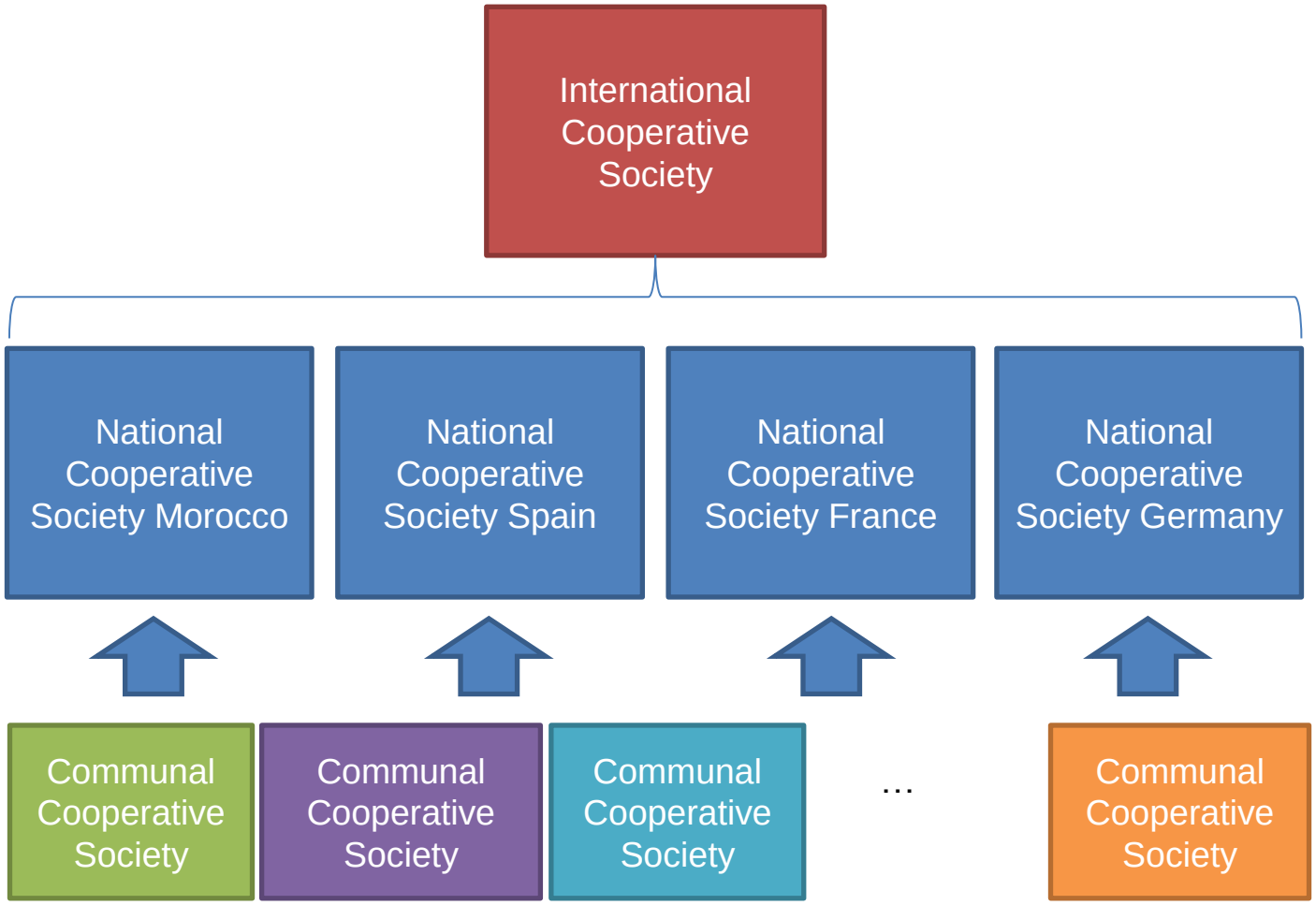
assistance

science

industry

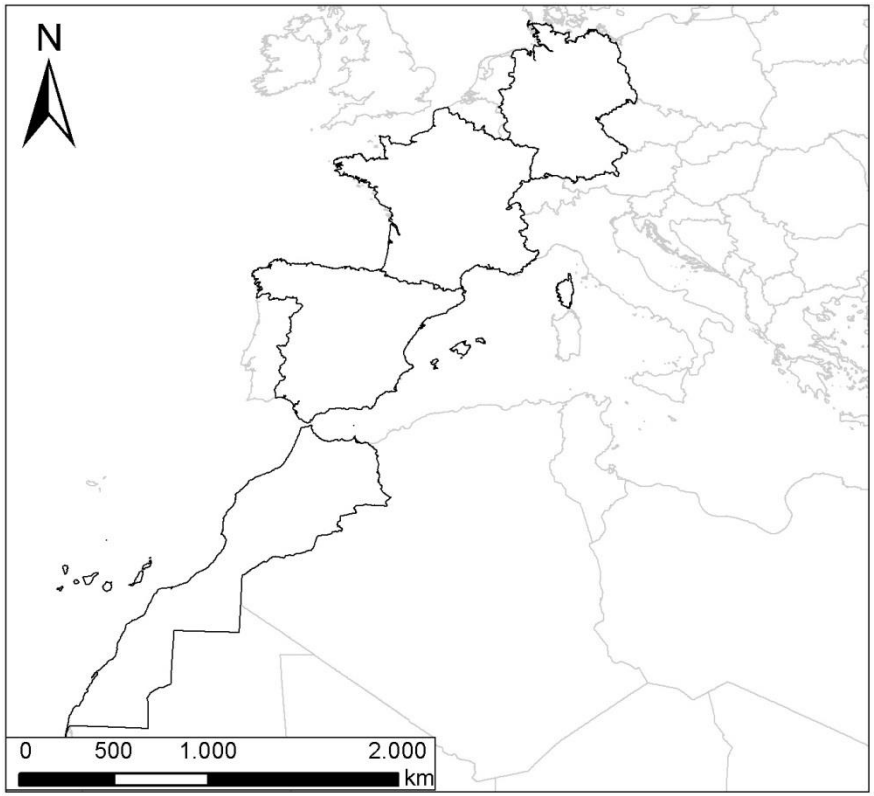
Politics, NGOs

International Cooperative Society for Citizen Participation

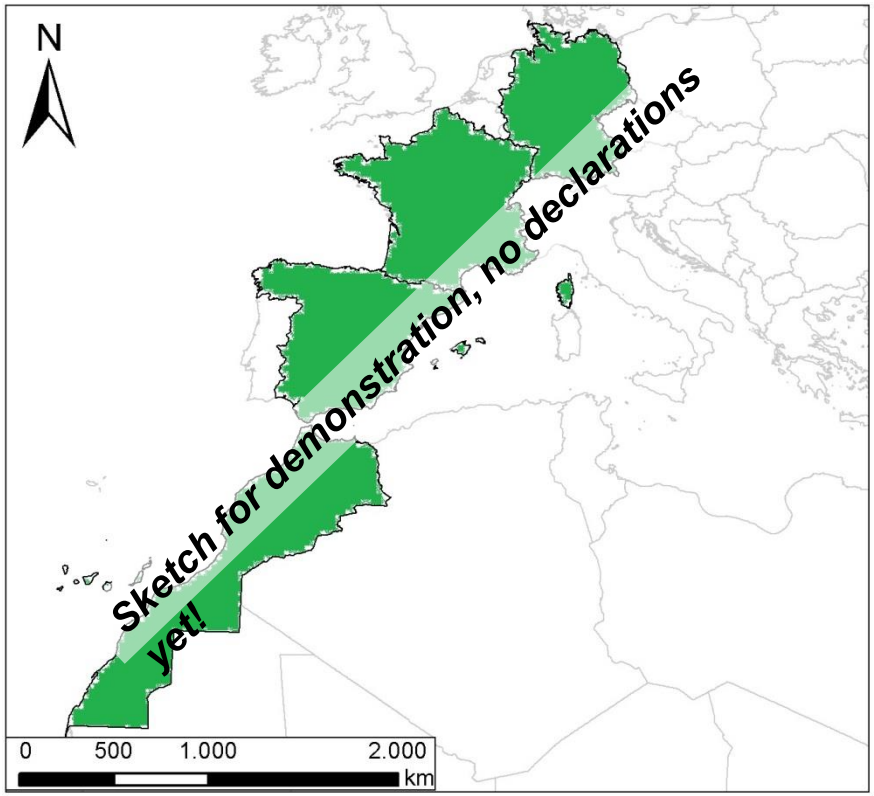


green: in favour
red: refusal
white: not yet decided

Declaration of intent on state level

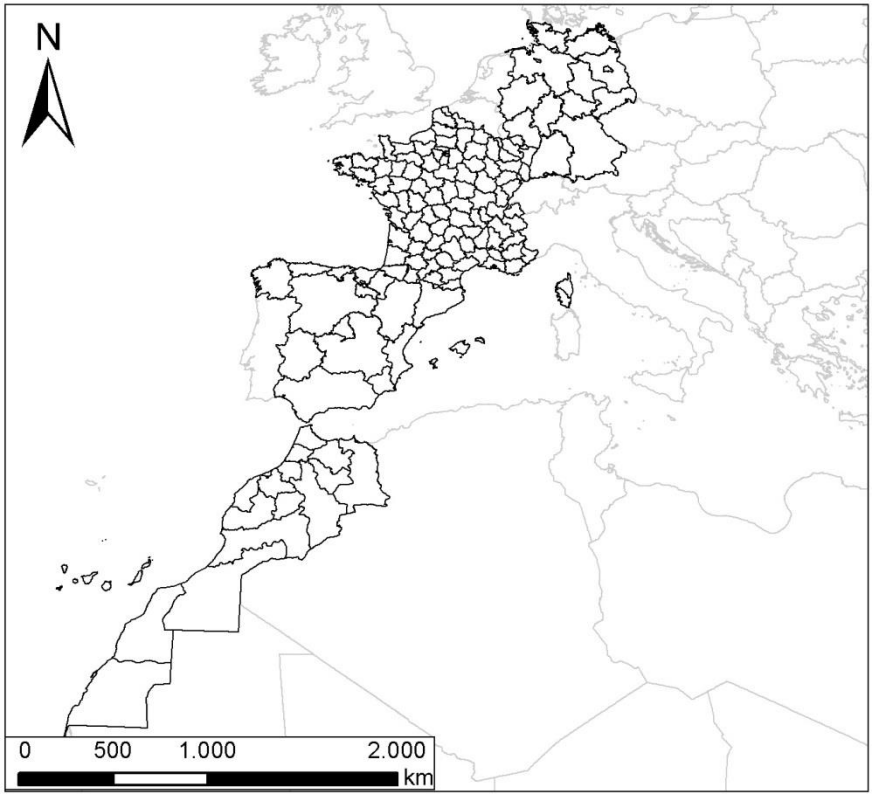


exemplary scientific model

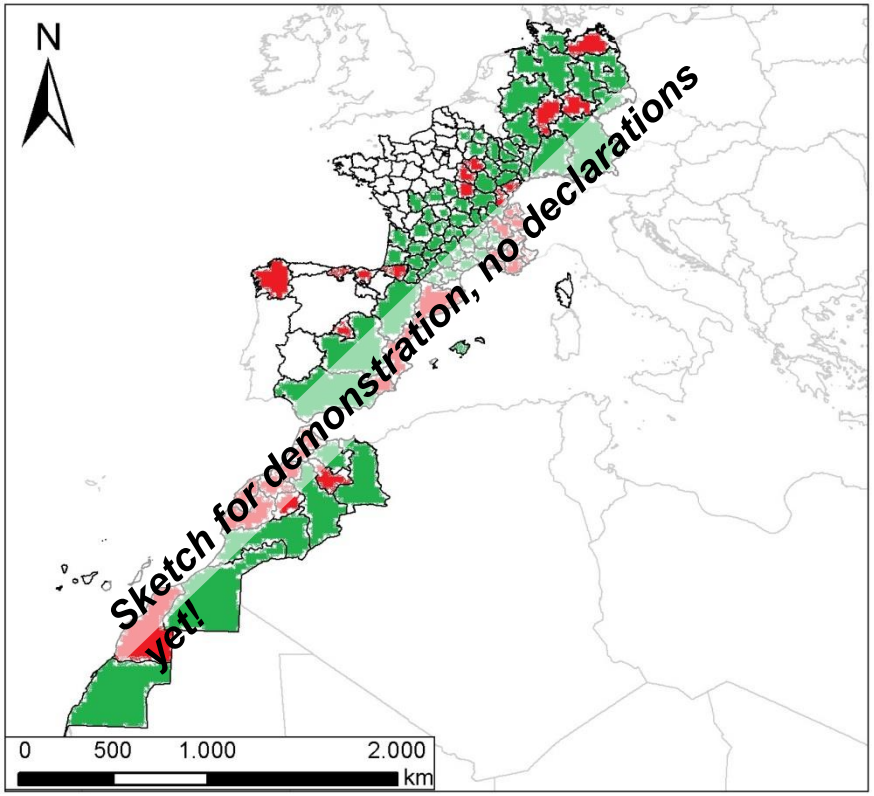


green: in favour
red: refusal
white: not yet decided

Declaration of intent on regional level

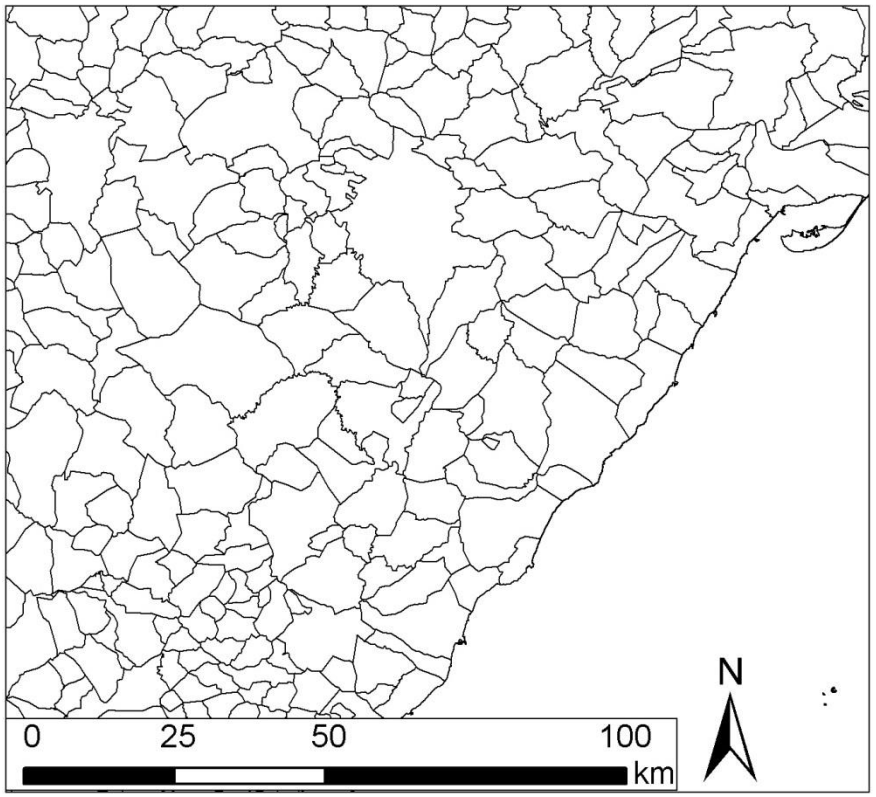


exemplary scientific model

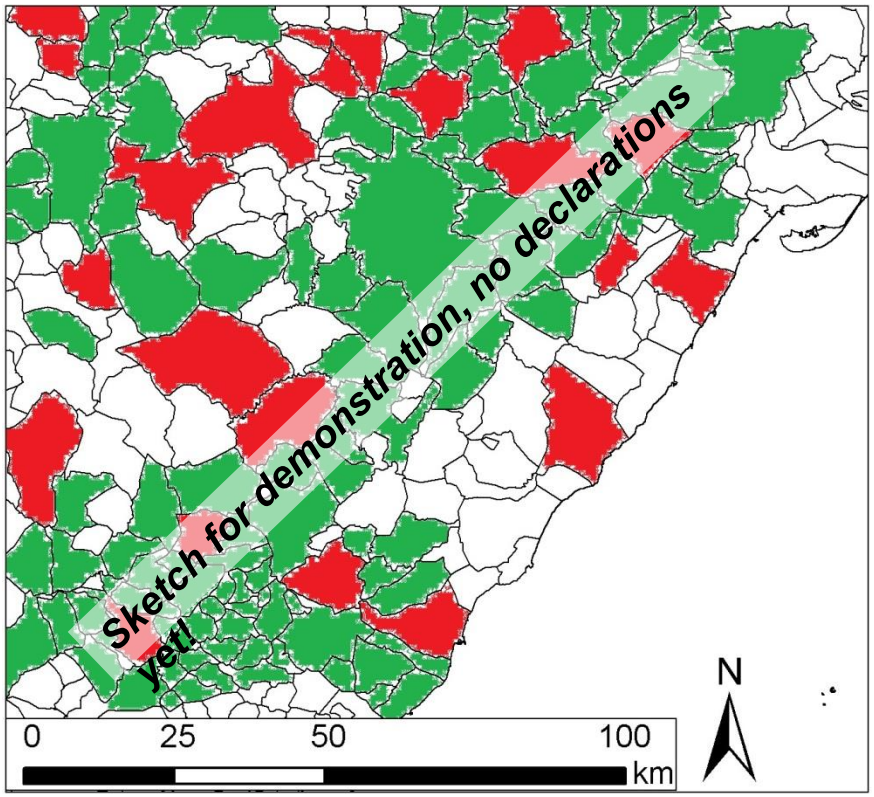


green: in favour
red: refusal
white: not yet decided

Declaration of intent on municipal level

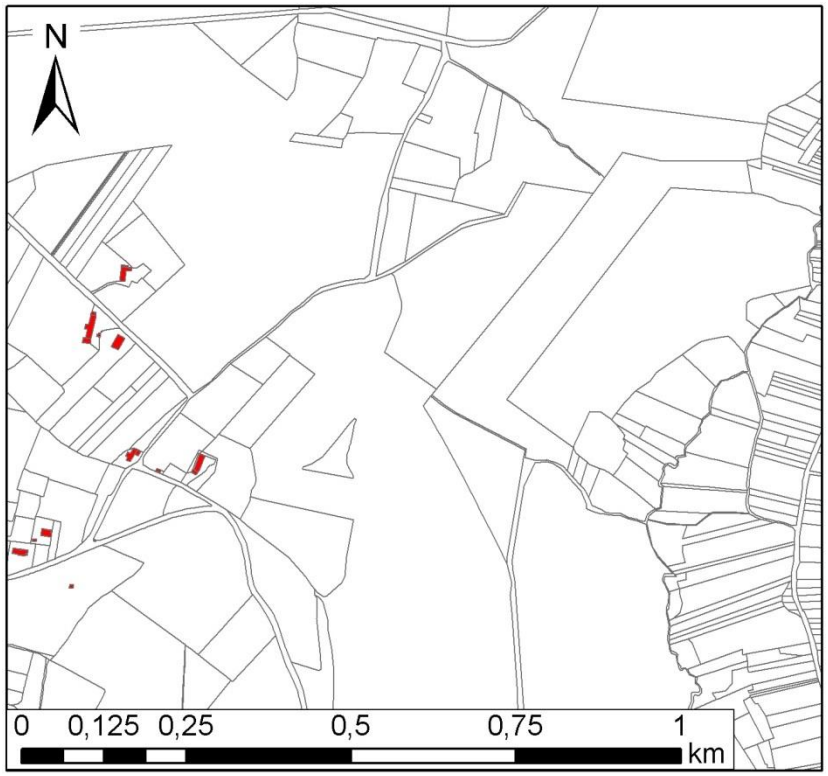


exemplary scientific model

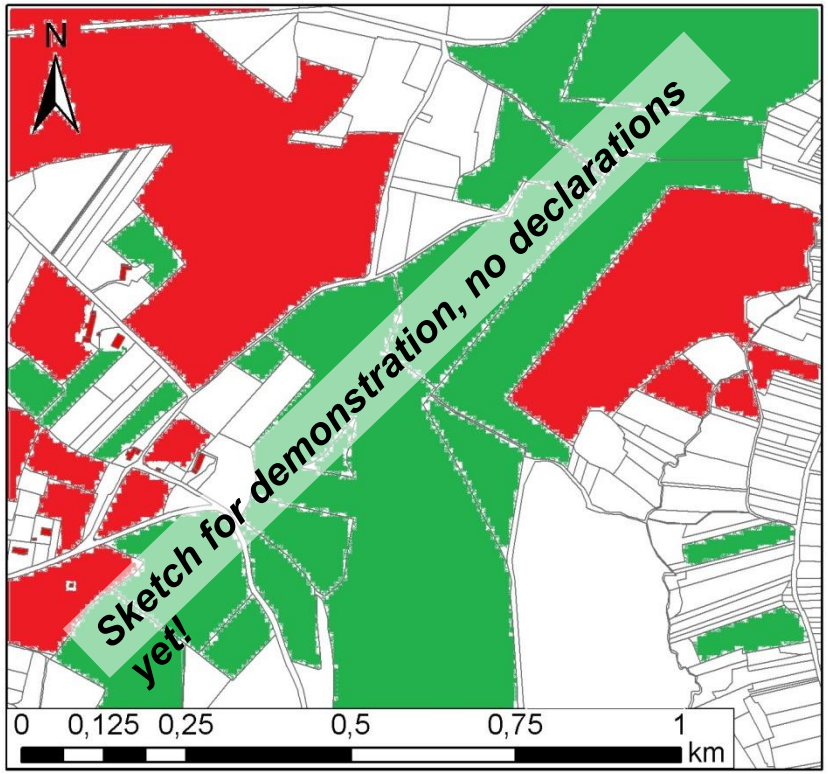


green: in favour
red: refusal
white: not yet decided

Declaration of intent on owner level



exemplary scientific model



On the interactive website can also appear:

- Image video about this potential project (animation of the power plant function, need in the energy system of a Central European control area, data and interviews with affected people of the power station, the transmission line and electricity customers)
- All current activities with citizens, in politics, science and economy
- Schedule of citizen participation and overall schedule
- All data in the field of economy, ecology, technology, social and institutional
- Already achieved progress and critique

Thank you for your attention!

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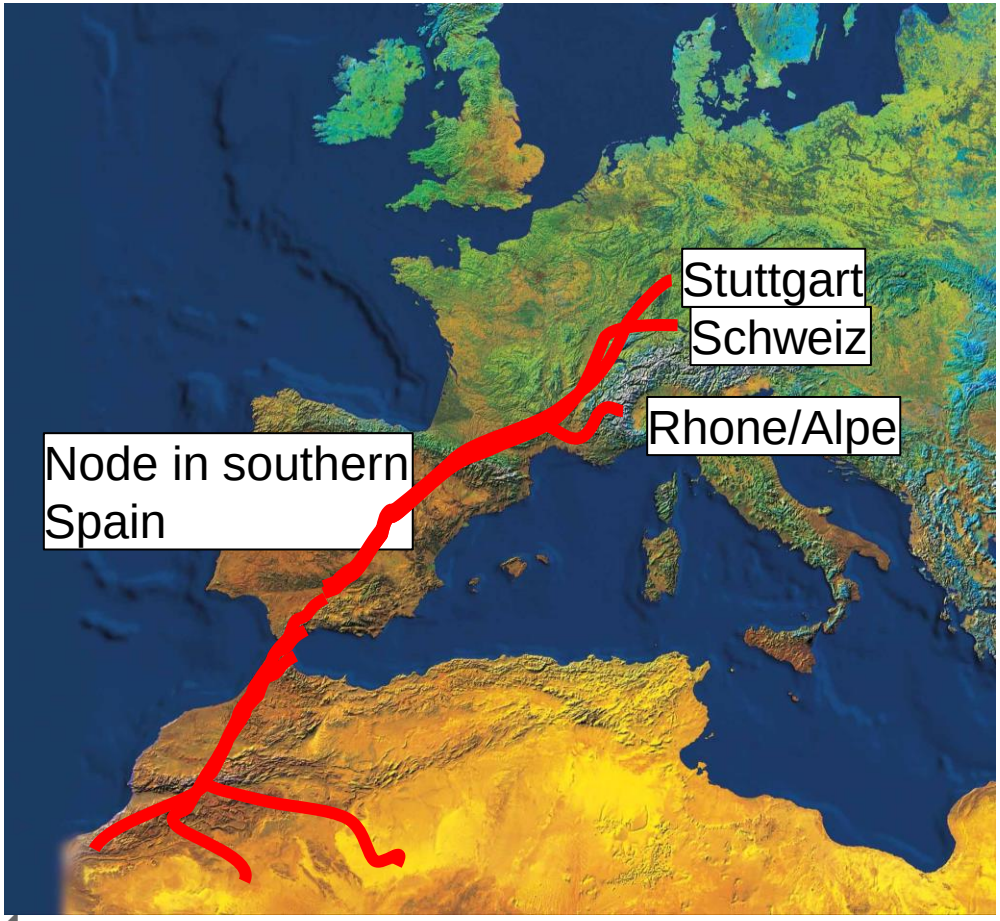
franz.trieb@dlr.de

Appendix

Construction in Phases



- Phase I
  Transport of solar power from southern Europe to the central European demand centres
- Bundle of cables which end in the participating countries
- Phase II
  Import of balancing power throughout the year from northern Africa