SECTOR COUPLING SYSTEM DESIGN TOWARDS CARBON NEUTRALITY AND MARKET CHALLENGES – A GERMAN PERSPECTIVE

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Dr. Ralph Pfeiffer
System Development
National and European Grid Planning Processes
AMPRION GMBH

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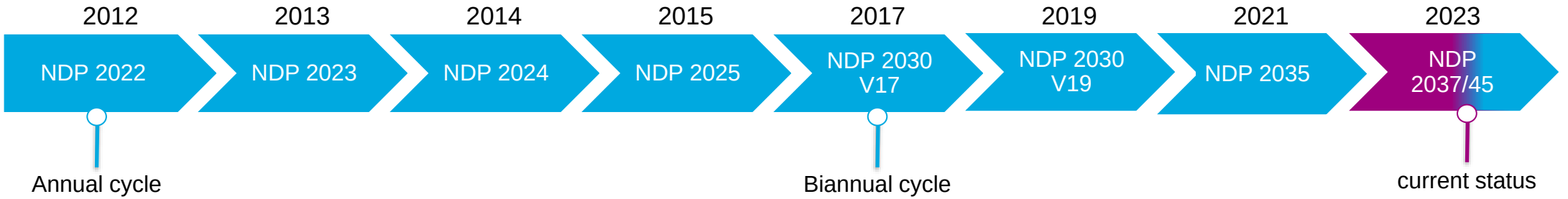
NATIONAL NETWORK DEVELOPMENT PLAN (NDP)
LEGISLATIVE FRAMEWORK

NATIONAL NETWORK DEVELOPMENT PLAN
LEGALLY MANDATED PROCESS SINCE 2012

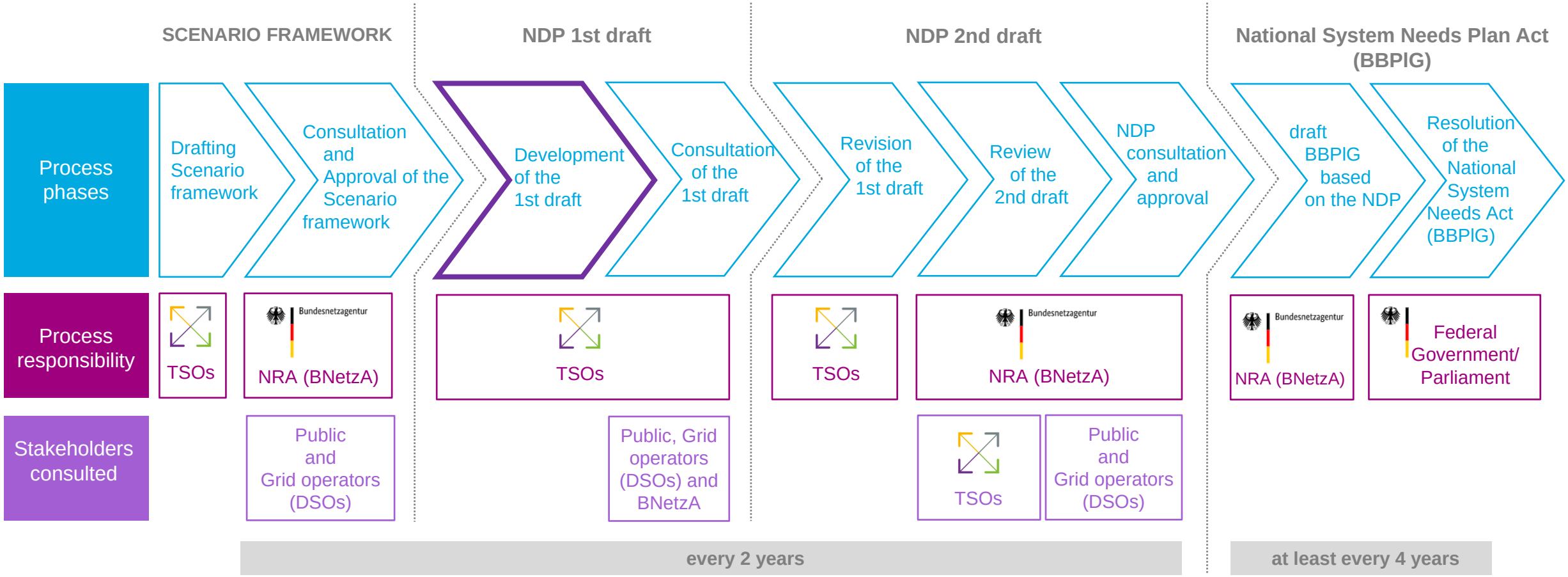
The Energy Industry Act (§12b l 2 EnWG) requires German Transmission System Operators (TSOs)* to deliver a joint network development plan (NDP) bi-annually.

The aim is to identify the need for network expansion and to infer reinforcement and expansion measures, which are then reviewed and approved by the National Regulatory Agency (NRA): Bundesnetzagentur (BNetzA).



* 50Hertz Transmission GmbH
Amprion GmbH
TenneT TSO GmbH
TransnetBW GmbH

NATIONAL NETWORK DEVELOPMENT PLAN (NDP)
NUMEROUS CONSULTATIONS



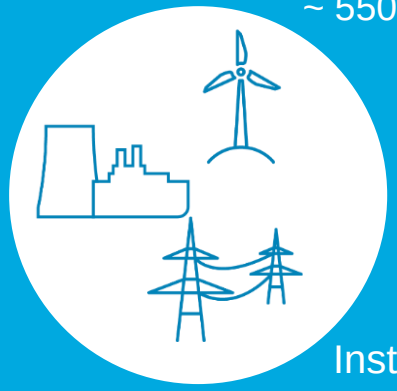
THE KEY DRIVERS FOR CARBON-NEUTRALITY IN 2045

- **Sector Coupling**
- **Flexibilities**

THE POWER SUPPLY SYSTEM UNDER TRANSFORMATION

Power Supply System 2022

Net Electricity Demand 2021:
~ 550 TWh



Installed RES Capacity:
140 GW

Installed Conventional Capacity:
78 GW

North-to-South Transport:
25 GW

Maintaining Security of Supply

Reinforcing and Extending Grid Infrastructure

Developing the Regulatory Framework further

Financing Investments

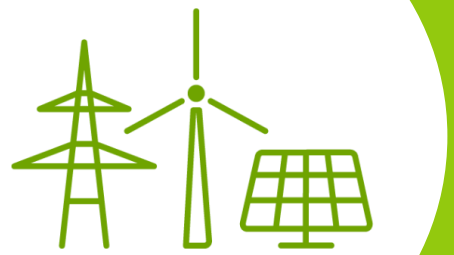
Carbon-neutral Power Supply System 2045

Net Electricity Demand: ~1,100 TWh

Installed RES Capacity:
> 680 GW

Electrolyser Capacity:
55-80 GW

Small-Scale Battery Storage Capacity:
~ 100 GW



North-to-South Transport:
> 80 GW

Utility-Scale Battery Storage Capacity:
43-55 GW

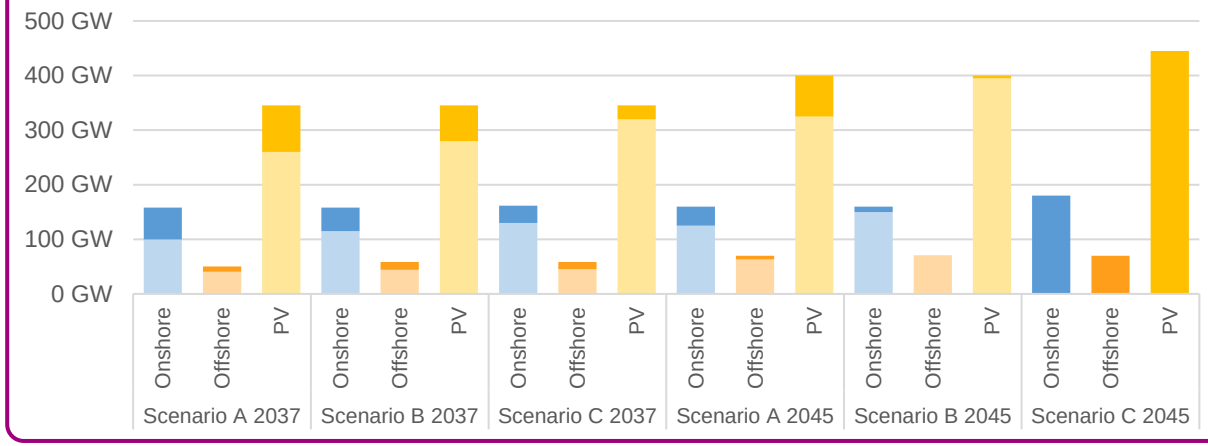
SCENARIO FRAMEWORK SETS OUT THREE DEVELOPMENT PATHS TO ACHIEVE CARBON NEUTRALITY IN 2045

Development paths for 2037 and 2045

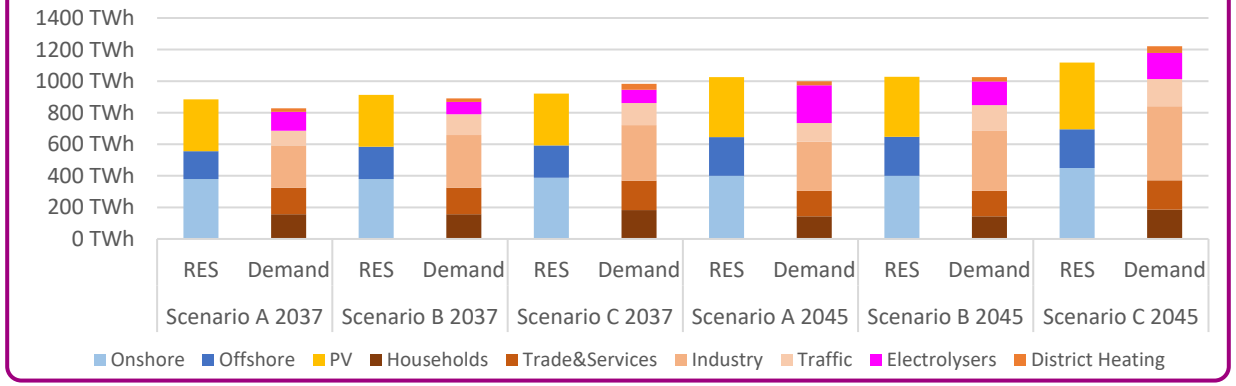
- H_2 Scenario A – Hydrogen Scenario
- Scenario B – „All Electric“ – high efficiency
- Scenario C – „All Electric“ – low efficiency

- Assumption of a high degree of energy self-sufficiency
  - Import ratio for hydrogen only 50%
  - Increase in net consumption up to 1200 TWh
- National targets for renewable energy sources (RES) are taken into account
  - RES share of net electricity demand at about 100%
  - Full RES market integration
- Market-oriented operation of new technologies (heat pumps, electric mobility, battery storage, ...) with flexibility of up to 100%.
- Scenario assumptions for other European countries are consistent with ENTSO-E planning products (considered 1.5 ° C target)

Installed RES capacities (draft + approval)



RES generation and net electricity demand

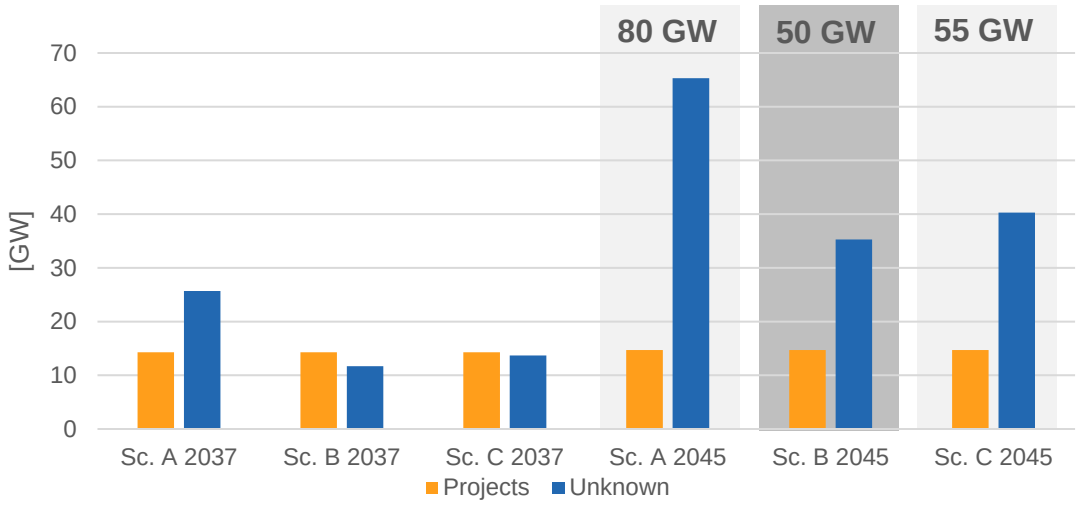


UP TO 80(!) GW ELECTROLYSERS IN NDP 2037/45

15 GW PROJECTS – 65 GW MAX. LEFT TO ALLOCATE

- Production of emission-free hydrogen is one pillar to reach carbon-neutral energy system in 2045
- Projects for up to 15 GW installed capacity already known from industrial partners
- Remaining “gap” to reach scenario target capacity is allocated in a grid-supportive manner
- Power-to-gas production is modelled fully market-oriented

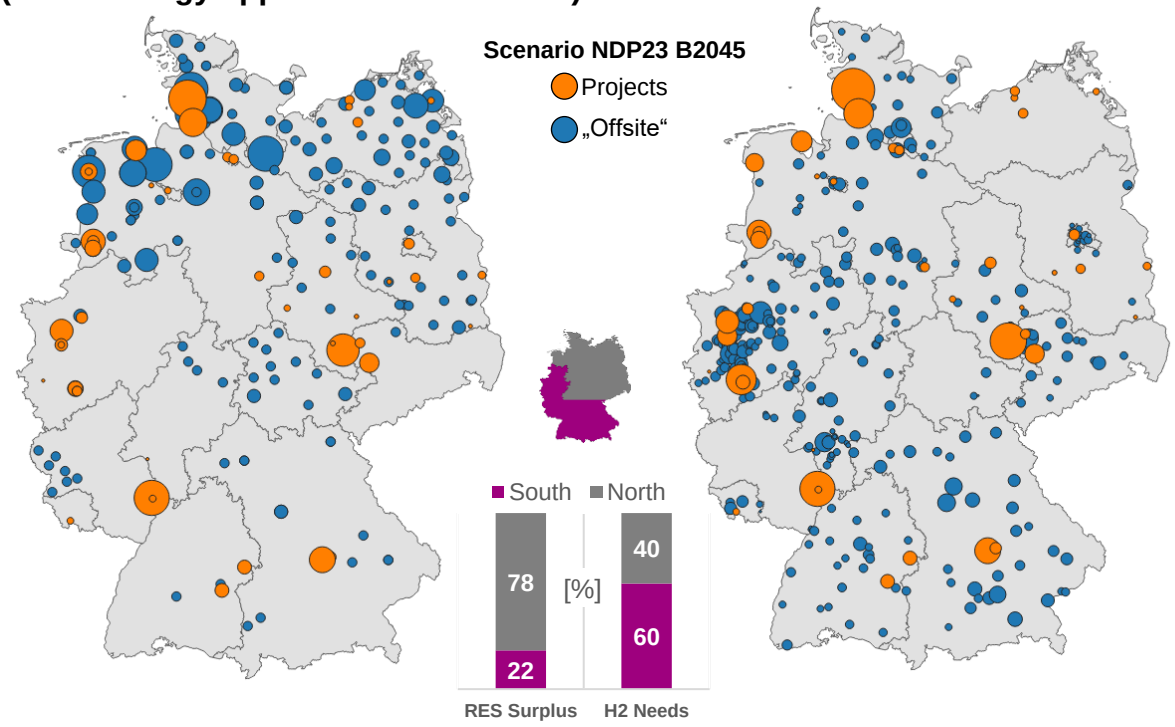
Installed Electrolyser Capacity in NDP 2037/45



Allocation Methodologies for Electrolysers

Based on residual RES surplus (methodology applied in NDP 2037/45)

Based on H2-Needs

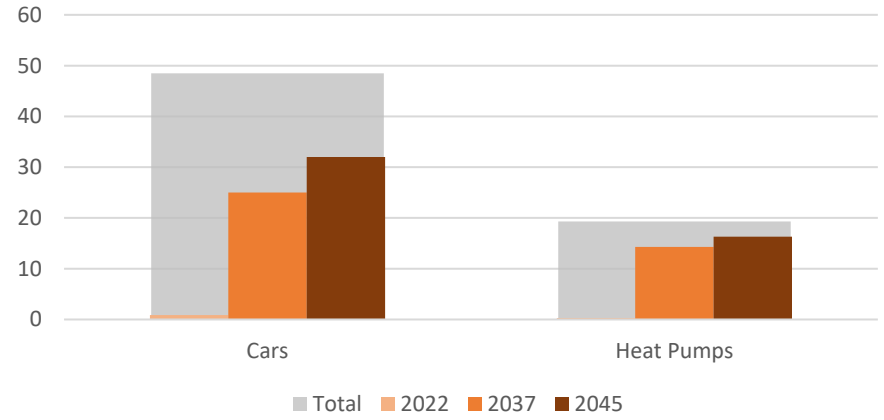


➔ Both allocations methodologies are extreme in regards to the respective characteristics, the actual allocation will most likely lie in between

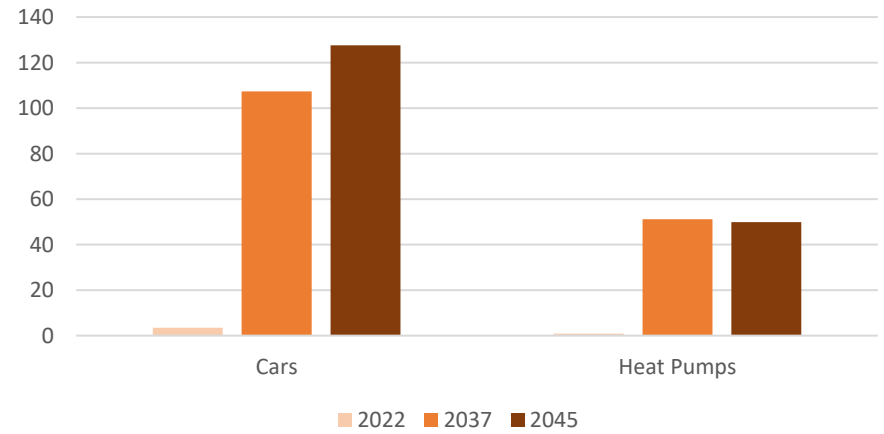
DECENTRALIZED FLEXIBILITY THOROUGH ELECTRIC VEHICLES AND HEAT-PUMPS

- Efforts to decarbonize households mainly focused on electrification
  - Share of electric cars increases up to 67% in 2045 (2% today)
  - Share of residential houses with Heat Pumps increases up to 85% in 2045 (1% today)
- These new electric loads provide a significant potential of flexibility
  - Loading of electric cars can be optimized, based on assumed mobility-patterns
  - Heating can be shifted within a two-hour range to react on electricity prices
  - Up to 100% of these units can are considered as market-oriented

Scenarios B/C: Deployed Units [in Million]



Scenarios B/C: Potential of Flexibility [GW]



NDP 2037/45 – A SELECTION OF RESULTS

METAHEURISTIC OPTIMISATION OF EXPANSION OPTIONS BASED ON GENETIC ALGORITHM

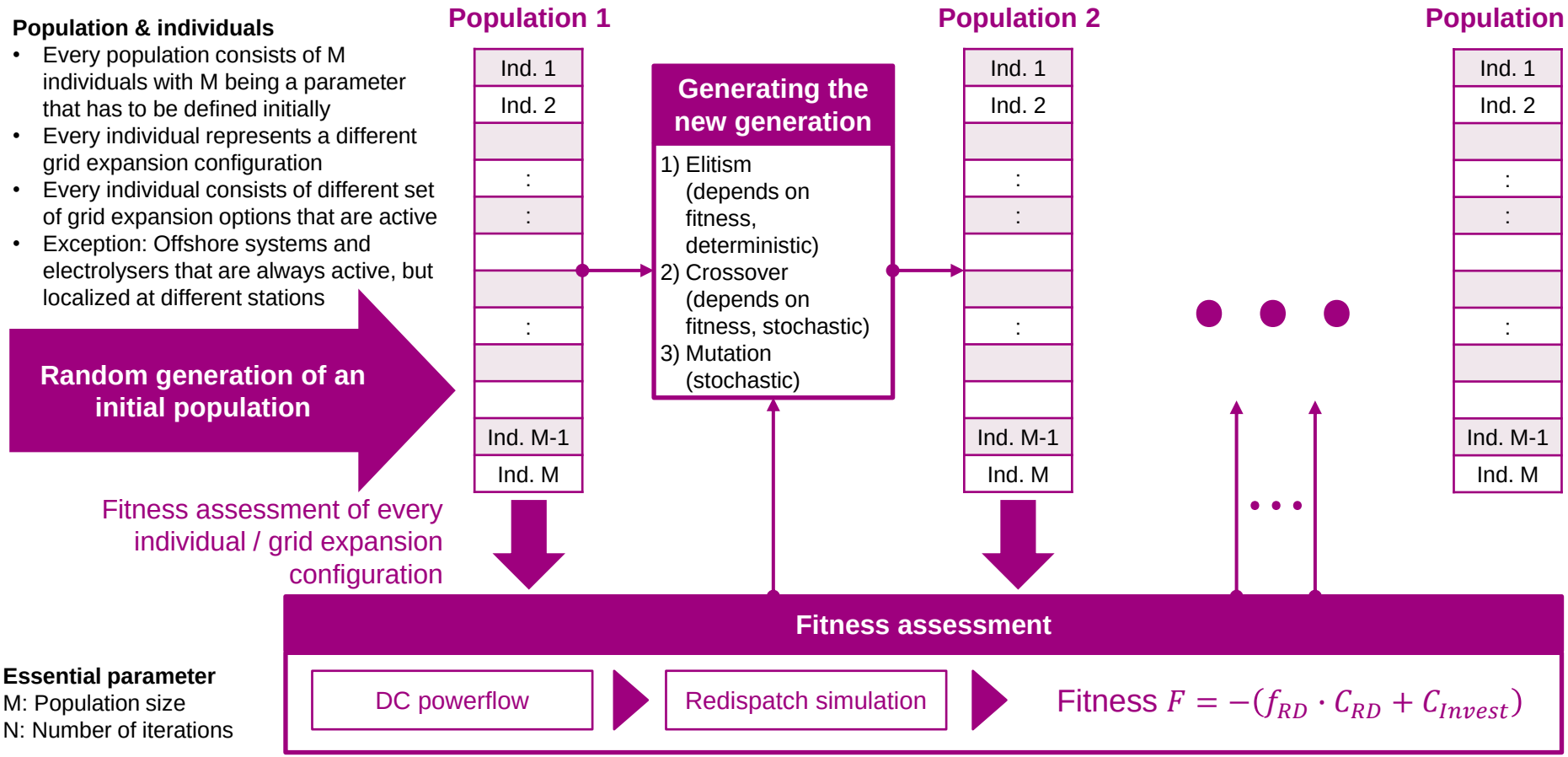
Input & Parameterization

- **Offshore systems for grid connection and electrolyzers with unknown location**
- **Grid expansion options**
  - Potential AC expansion (HTLS, new lines)
  - Potential locations for phase shifting transformers
  - Potential onshore and offshore DC systems for interconnection
  - Onshore connection points for offshore generation
  - Potential locations of electrolysers

Population & individuals

- Every population consists of M individuals with M being a parameter that has to be defined initially
- Every individual represents a different grid expansion configuration
- Every individual consists of different set of grid expansion options that are active
- Exception: Offshore systems and electrolysers that are always active, but localized at different stations

Random generation of an initial population

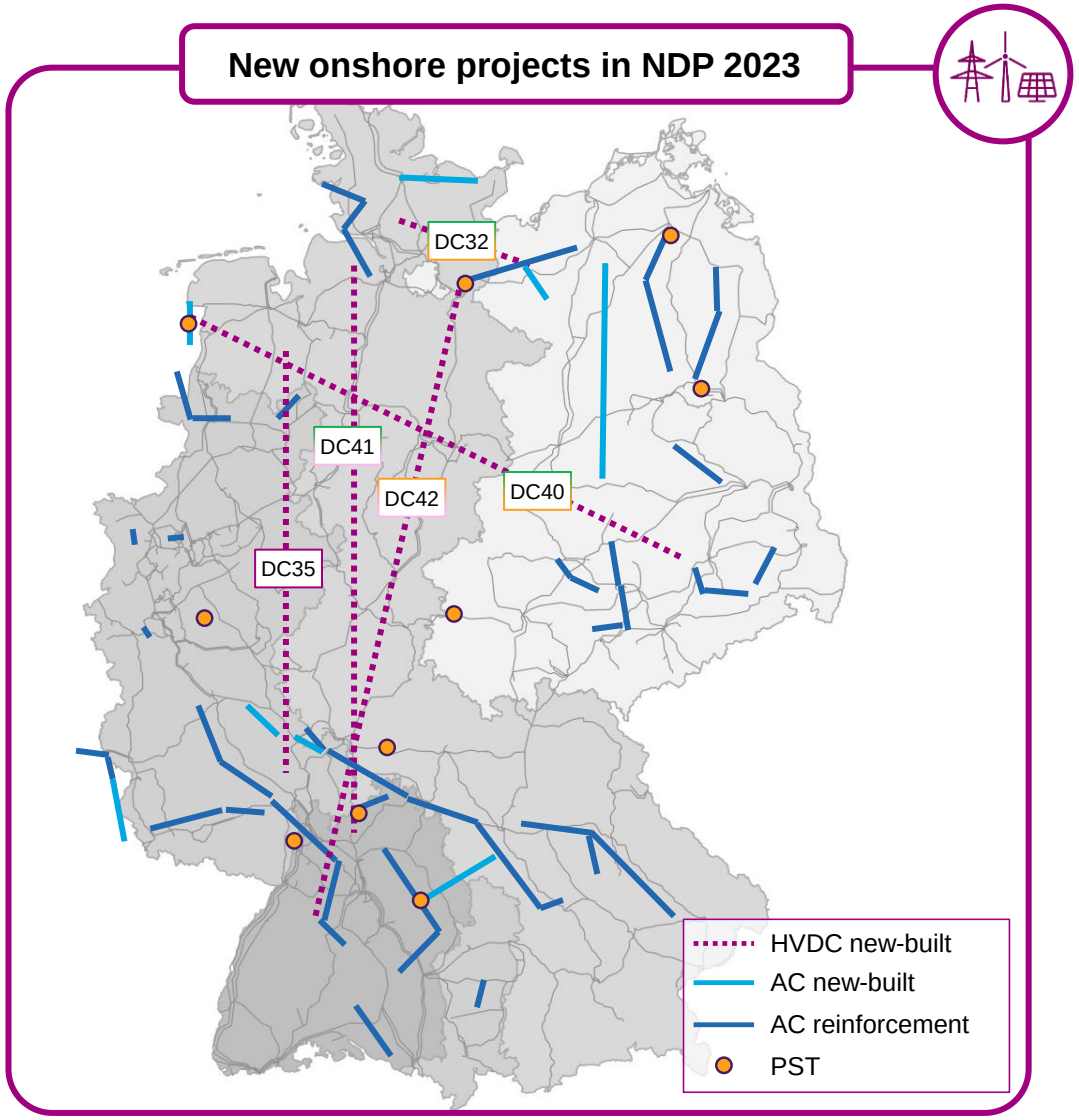


Essential parameter
M: Population size
N: Number of iterations

C_{RD}: Redispatch cost; C_{Invest}: Investment cost

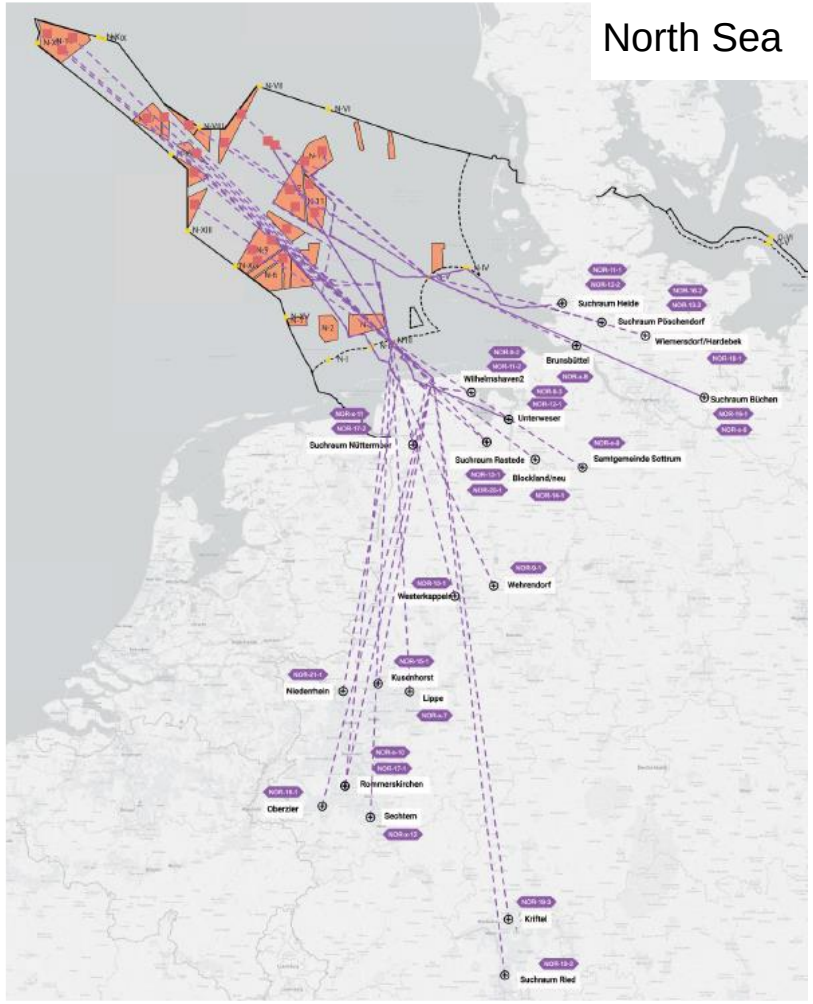
ONSHORE GRID FOR CARBON-NEUTRALITY

TRANSMISSION SYSTEM GROWS BY MORE THAN 40%



- The German TSOs have developed a carbon-neutral energy system in Germany for the first time
- The **target onshore transmission grid** is needed **by 2037** already
- After 2037 additional RES generation is integrated predominantly by
  - power-to-hydrogen sector coupling
  - exploitation of demand-side flexibilities
- Newly identified HVDC-expansion:
  - five new-built HVDC transmission projects (approx. **2,600 km**)
- Newly identified AC-expansion:
  - approx. **1,300 km** new-built AC transmission line projects
  - approx. **3,200 km** AC transmission line reinforcement projects
- Together with projects identified in previous NDPs the **total onshore transmission system expansion** amounts to **> 15,000 km** (35,000 km → > 50,000 km)

EFFICIENT OFFSHORE-WIND INTEGRATION IS CRUCIAL



Offshore-wind in 2045

70 GW

installed capacity in Germany

13,300 km

New offshore connection HVDC-lines needed

Connections close to demand centres

reaches from the Rhine-Ruhr region (Düsseldorf, Dortmund, Cologne) to the Rhine-Main region (Frankfurt)

Advantages:

- integration in existing AC-infrastructure
- reduction of generation redispatch
- reduction of AC-power flows and reactive power demand

Interconnection of offshore connections

sea-side DC interconnections

Advantages:

- redundancy of connections and increased flexibilities
- reduction of onshore grid expansion
- enhanced European market integration

INTERCONNECTION IS A JOINT EUROPEAN INITIATIVE

NATIONAL OFFSHORE INTERCONNECTION PROJECTS

NDP 2037/45 IDENTIFIES TWO PROJECTS

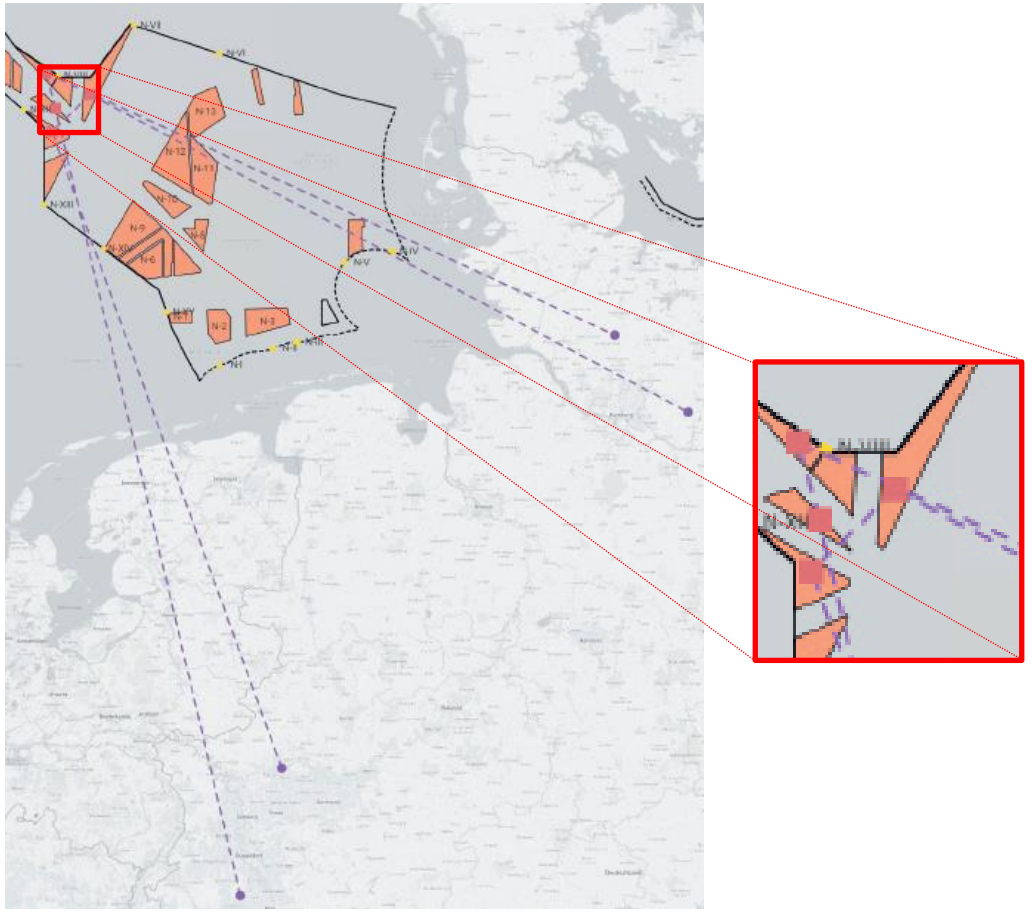
Benefits of national offshore interconnection

- In-depth analysis of national offshore interconnection projects in German NDP 2037/2045
- Results shows positive cost-benefit ratio

Offshore Interconnection Projects	
Length	73 km
CAPEX	1,200 Mio. € (cable: 400 / platform: 800 Mio. €)
Redispatch reduction	98 Mio. € / years → ~ 1,500 Mio. € for 25 years

- ➢ Assessment of national offshore interconnection by national regulator until end of 2023
- ➢ In case of positive decision: inclusion in national legislation

National Offshore Interconnection Projects



MARKET CHALLENGES FOR A CARBON-NEUTRAL POWER SUPPLY SYSTEM

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CHALLENGES OF TRANSFORMATION

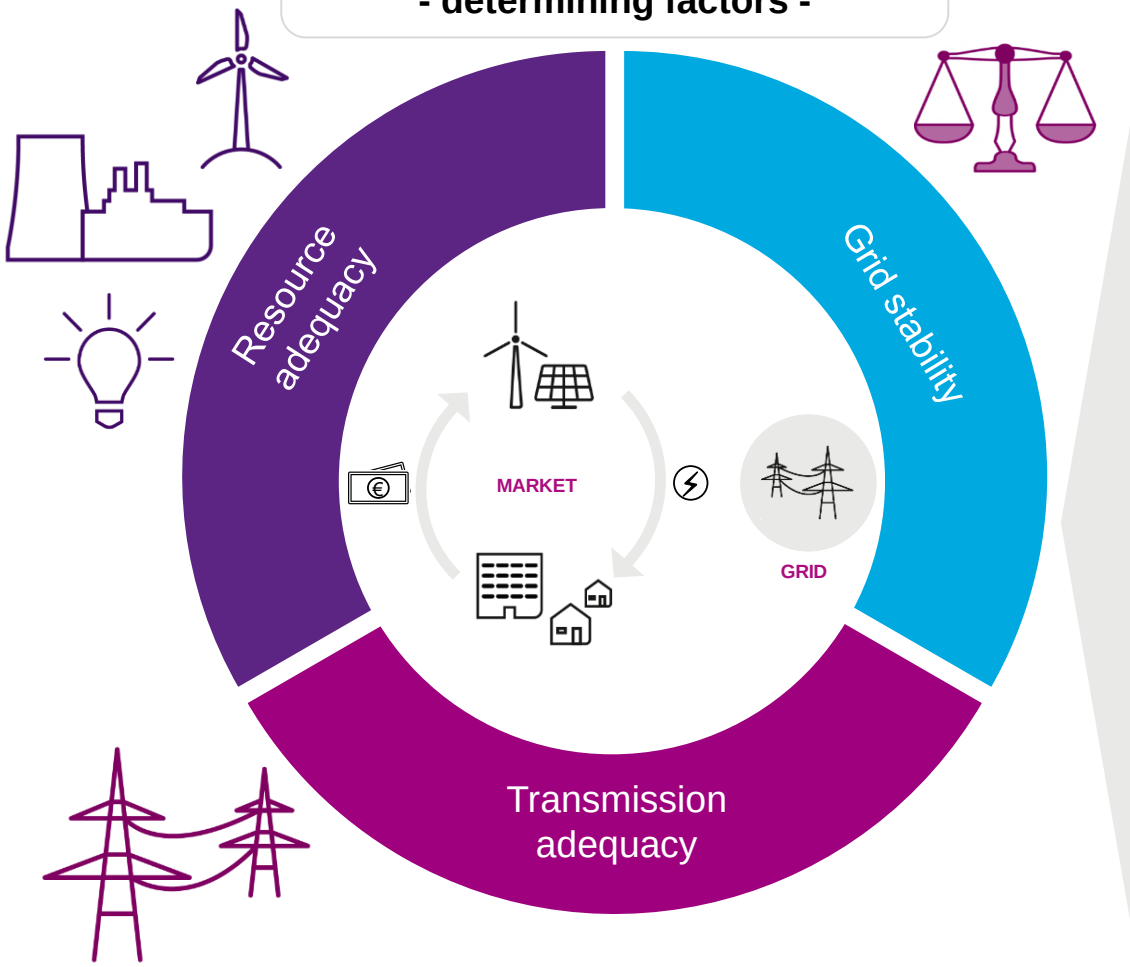
System Security

- challenges -

- Substitution of firm generation capacity by resource-dependent RES generation
- Displacement of synchronous generators by IBRs
- Integration of new equipment
- Increasing power exchanges and higher cross-border capacities
- Higher utilisation of the transmission system
- More volatile and rapidly-changing power flows

Security of Supply

- determining factors -



TSO responsibility

- physical reality -

- Transmission of active power
- Securing steady-state voltage stability (reactive power)
- Balancing
- Securing the provision of grid inertia
- Dynamic reactive power control
- Securing the provision of short-circuit current
- Securing island operation capability
- Securing black-start capability

POTENTIAL SOLUTION

A SYSTEM ENGINEERING VIEW ON THE ENERGY SYSTEM

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SYSTE(M)ARKET

SYSTEM planning + **electricity MARKET**

Security | **Innovation**

The SYSTE(M)ARKET is designed to ensure resource adequacy and robust system operation in the long term by providing incentives for

a) an adequate amount of capacity & necessary ancillary services in the system → **AMOUNT**

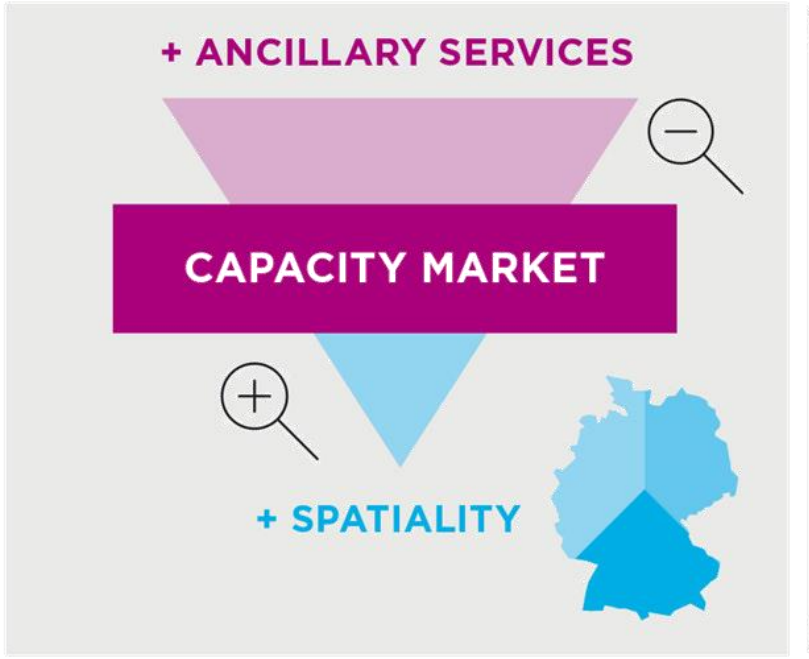
b) the system-serving placement of these capacities & services at the right location in the grid → **LOCATION**

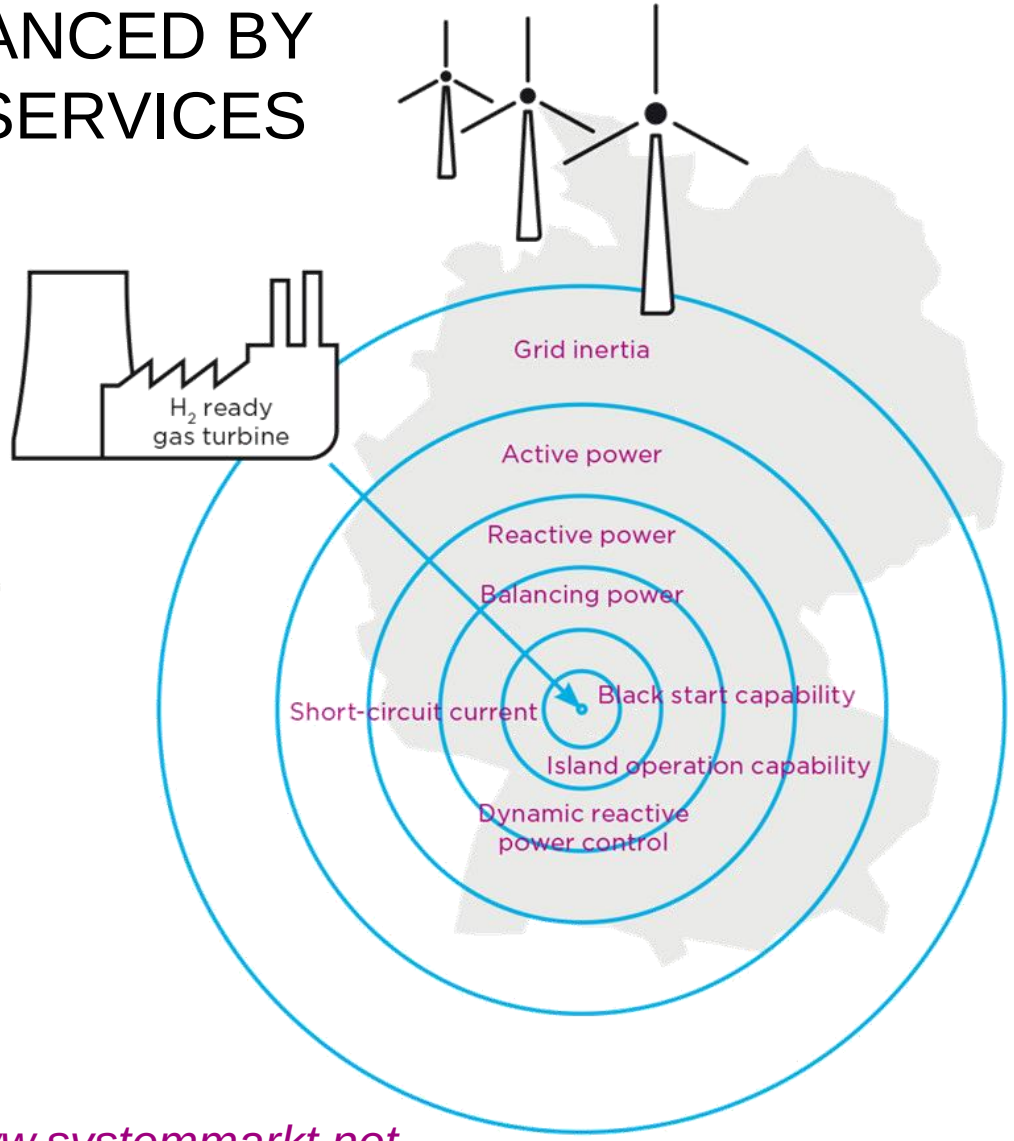
c) a system-serving design to serve also other system needs if possible & economically feasible → **SYNERGY**

This is achieved by the spatially and objectively differentiated long-term remuneration for the provision of the necessary potentials (capacities)

BASIC CONCEPT

A CAPACITY MARKET ENHANCED BY SPATIALITY & ANCILLARY SERVICES





Further information also available at: *www.systemmarkt.net*

THANK YOU FOR YOUR ATTENTION!

Any questions?