Analysis and tools to support energy system transition

Knowledge-exchange between US and German power system operators

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Delegation Trip to Germany
Berlin, September 28, 2017

Agenda

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Agenda

I	What is Fraunhofer-Gesellschaft and Fraunhofer IWES?
II	Developing Long-Term Scenarios with High Levels of Decarbonisation
III	Current Challenges of the Integration of Large Amounts of Wind and Solar Power
IV	Technical Challenges and Prospects in Power Systems with High Penetration of Renewable Energies
V	Training and Knowledge Transfer at Fraunhofer IWES

Fraunhofer-Gesellschaft conducts applied research and comprises 66 institutes across Germany

Fraunhofer-Gesellschaft

- Europe's **largest applied research organisation**
- Undertakes research for **direct use by private** and **public enterprises**, providing a wide range of benefits to society
- **80 research units**, including **66 Fraunhofer Institutes**
- **Staff** of around **24,500**
- **Annual research budget** of around **2.1 bnEUR**

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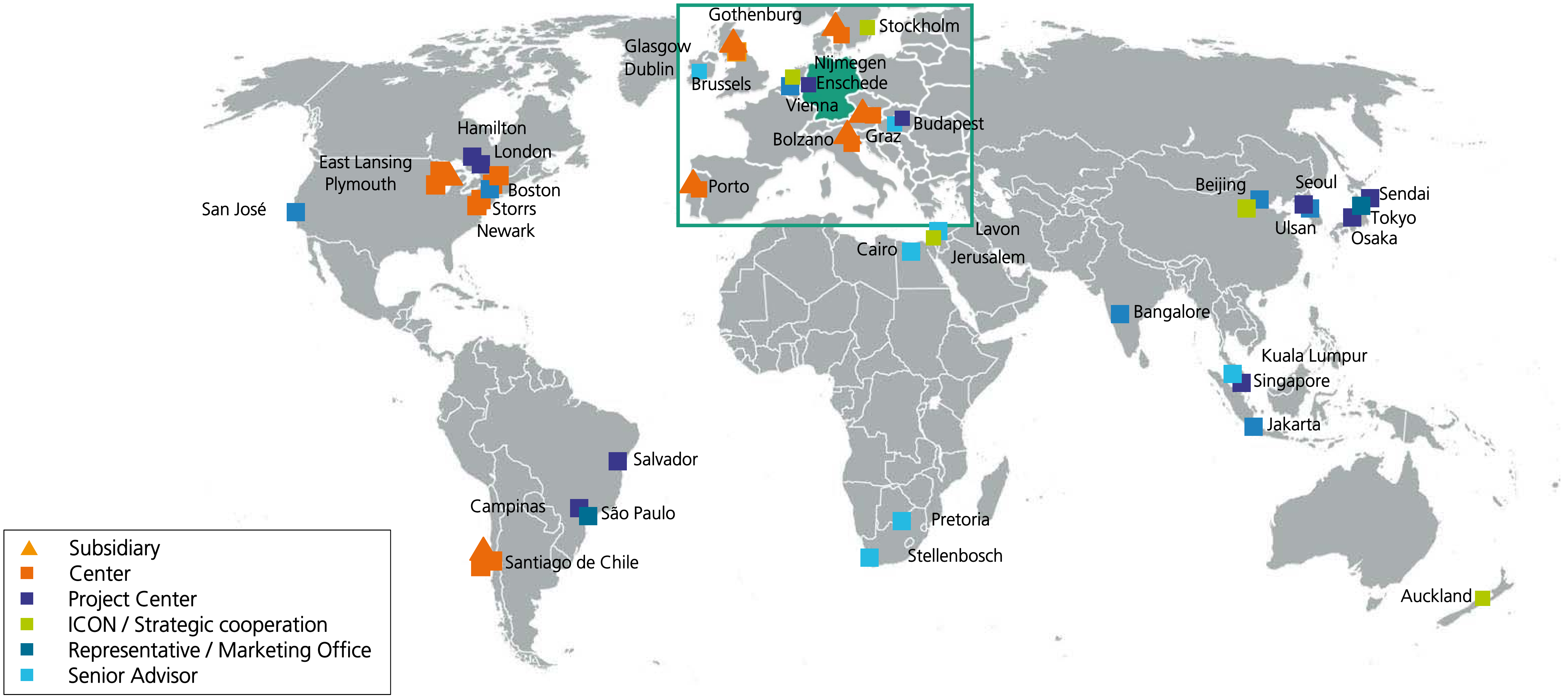
Fraunhofer has several locations and contact possibilities worldwide



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The Energy System Technology branch of Fraunhofer IWES is located in Kassel

Our service portfolio deals with **current and future challenges** faced by the **energy industry** and **energy system technology** issues.

We explore and develop **solutions for** sustainably **transforming renewable based energy systems**.

- Personal: approx. 310
- Annual budget: approx. 22 Mio EUR
- Director: Prof. Dr. Clemens Hoffmann

www.energiesystemtechnik.iwes.fraunhofer.de

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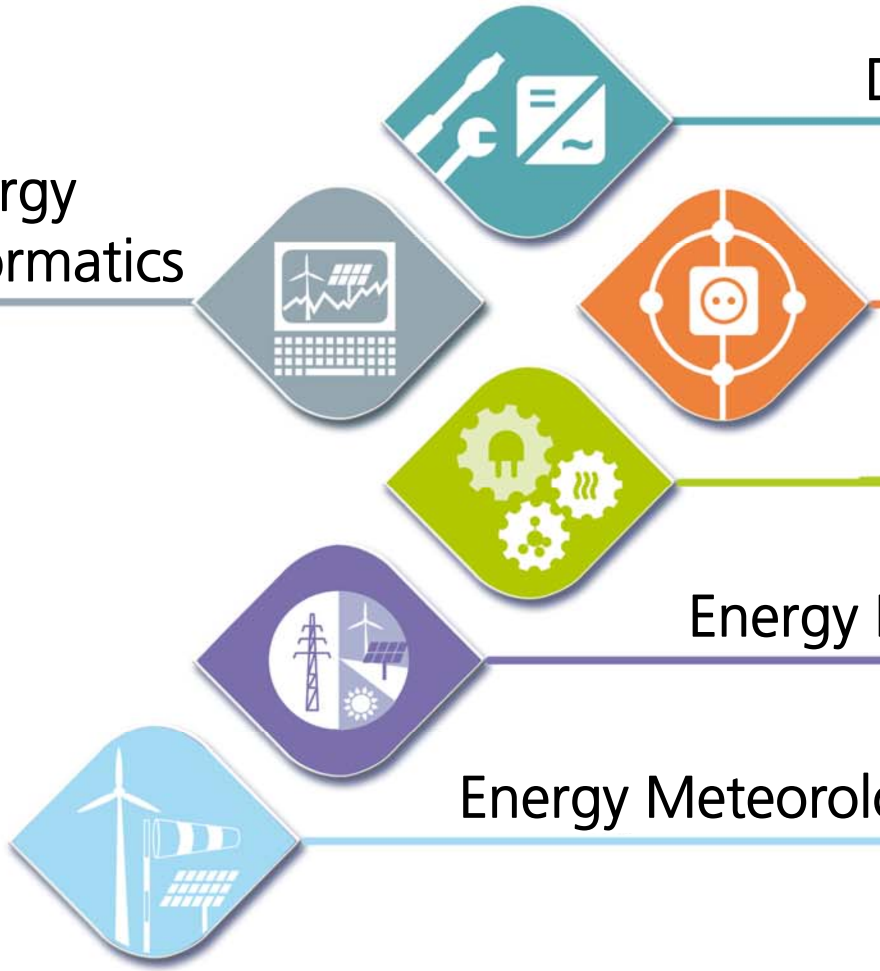
We research and develop solutions in different fields of expertise



Energy Informatics

Device and System Technology

Electrical Grids

Energy Process Engineering

Energy Economics and System Design

Energy Meteorology and Renewable Resources

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Energy Economics and Energy System Technology are our two business areas

Energy Economics

- Energy meteorological information systems
- Consulting and analyses in energy economics
- Virtual power plants
- LiDAR Wind measurements
- Training and knowledge transfer

Energy System Technology

- Power electronics and devices
- Grid planning and operation
- Measurement and test services
- Decentralised energy management
- Hardware-in-the-loop systems
- Systems engineering

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Energy Economy and System Analysis Group at Fraunhofer IWES mainly answers its research questions with the SCOPE model family

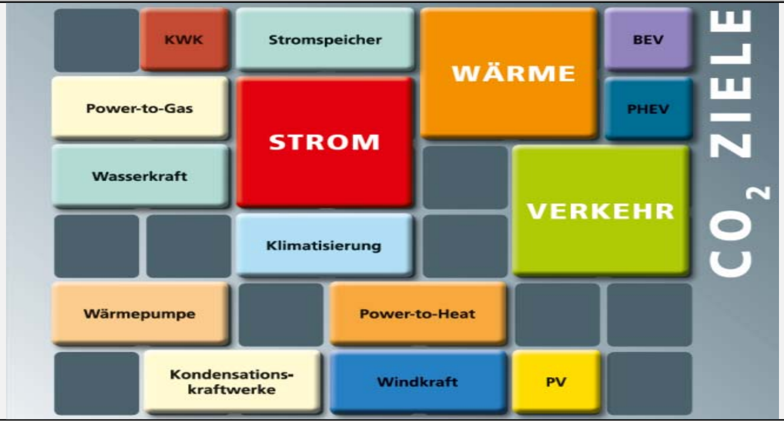
Research focus

- **Dynamic simulation of power markets** in Germany and Europe
- **Scenario development for energy system transformation** towards decarbonisation
- **Technology evaluations in future energy markets** (particularly. at **sector coupling interfaces** power – heat und power - mobility)
- **Grid and storage expansion** analyses

Current projects

- **North Seas Offshore Network (NSON-DE),** BMWi, 2014 – 2017
- **Treibhausgasneutrales Deutschland,** UBA, 2016 – 2018
- **Klimawirksamkeit Elektromobilität,** BMUB, 2016 – 2018
  http://publica.fraunhofer.de/documents/N-439079.html
- **Wärmewende 2030,** AGORA, 2016
  http://bit.ly/2kDMHst
- **Interaktion EE-Strom-Wärme-Verkehr,** BMWi, 2012-2015
  http://publica.fraunhofer.de/documents/N-356297.html

SCOPE model family



- **Sector-wide dispatch and expansion planning model** for analyses of future energy supply systems
- **Modular** and **customisable techno-economic fundamental market model** with **various configurations**
  e.g. block-specific unit commitment (day-ahead, balancing reserve), Expansion planning of grids and units (TEP/ GEP)
- **Implemented in MATLAB**, solved by **IBM ILOG CPLEX** on IWES-owned **High-Performance Computing Cluster**

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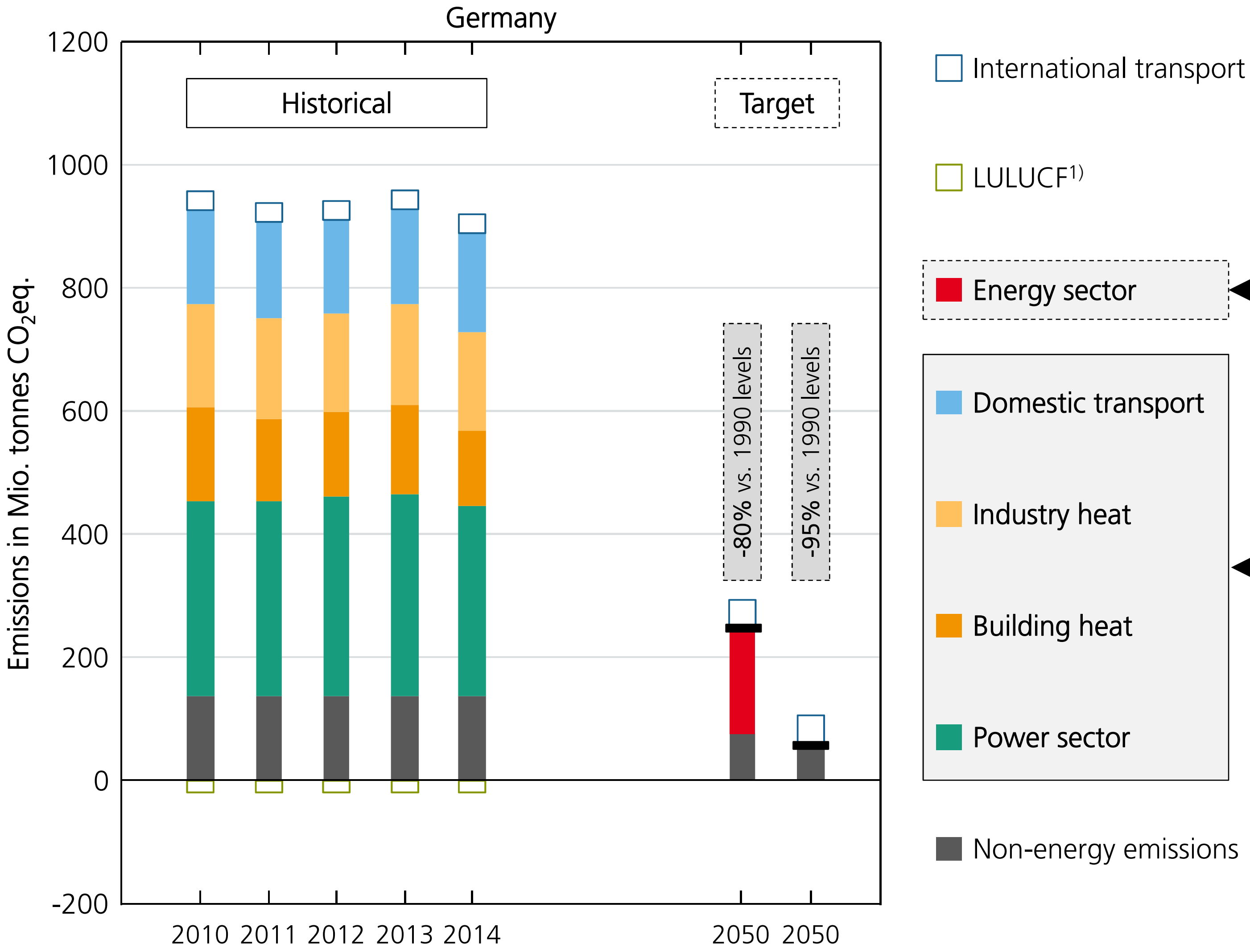
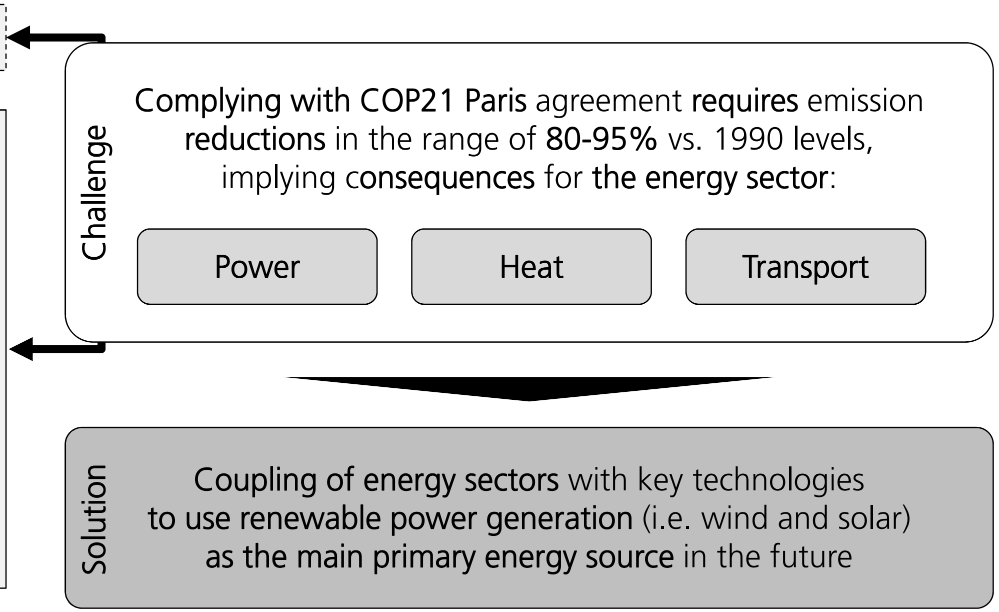
Long-term climate targets are very ambitious and decarbonisation challenges the energy sectors – promising solution via sector coupling technologies based on wind and solar power





[1)] Land use, land-use change and forestry (LULUCF)

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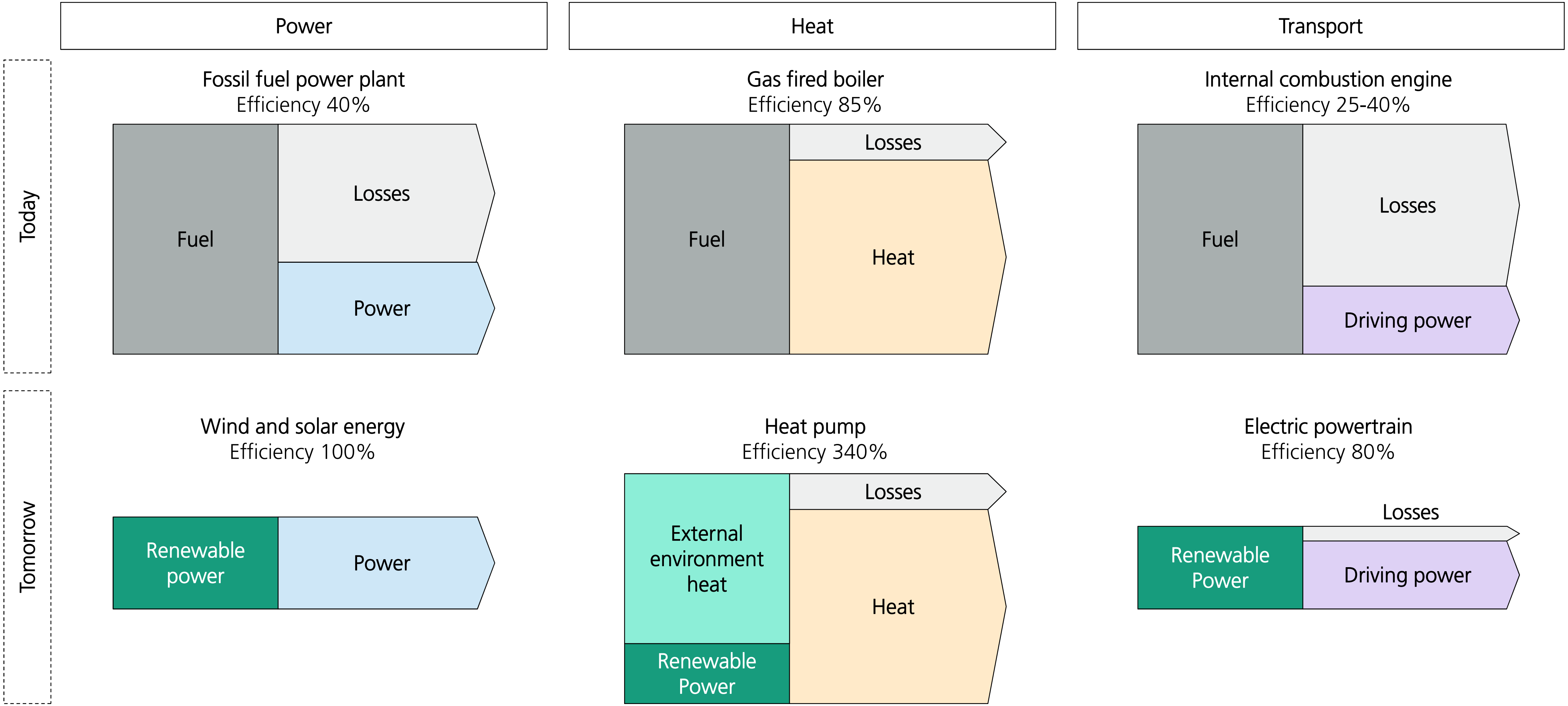
Heat pumps and electric vehicles are key technologies for coupling of energy sectors – they increase the energy efficiency and substitute fossil fuels



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One SCOPE configuration serves the development of cost-optimised target scenarios of future energy systems with energy and emission targets

Input data

- Fuel cost
- Technology cost
- Potentials and restrictions
- Energy demand time series (power, heat, industry, transport)
- Technology-specific time series (wind, solar, natural inflow, COP, solar thermal, …)

Linear Optimization Model (LP)[1)]

Europe and/ or Germany

Objective is to minimise investment and system operation cost

subject to compliance with climate protection targets

full consecutive year,
hourly resolution (8760h)
historical climate reference years

Output data

- Optimised power generation mix
- Optimised heat generation mix
- Optimised transport mix
- Energy framework and installed capacities
- CO_2 emission price(s)
- …

Markets

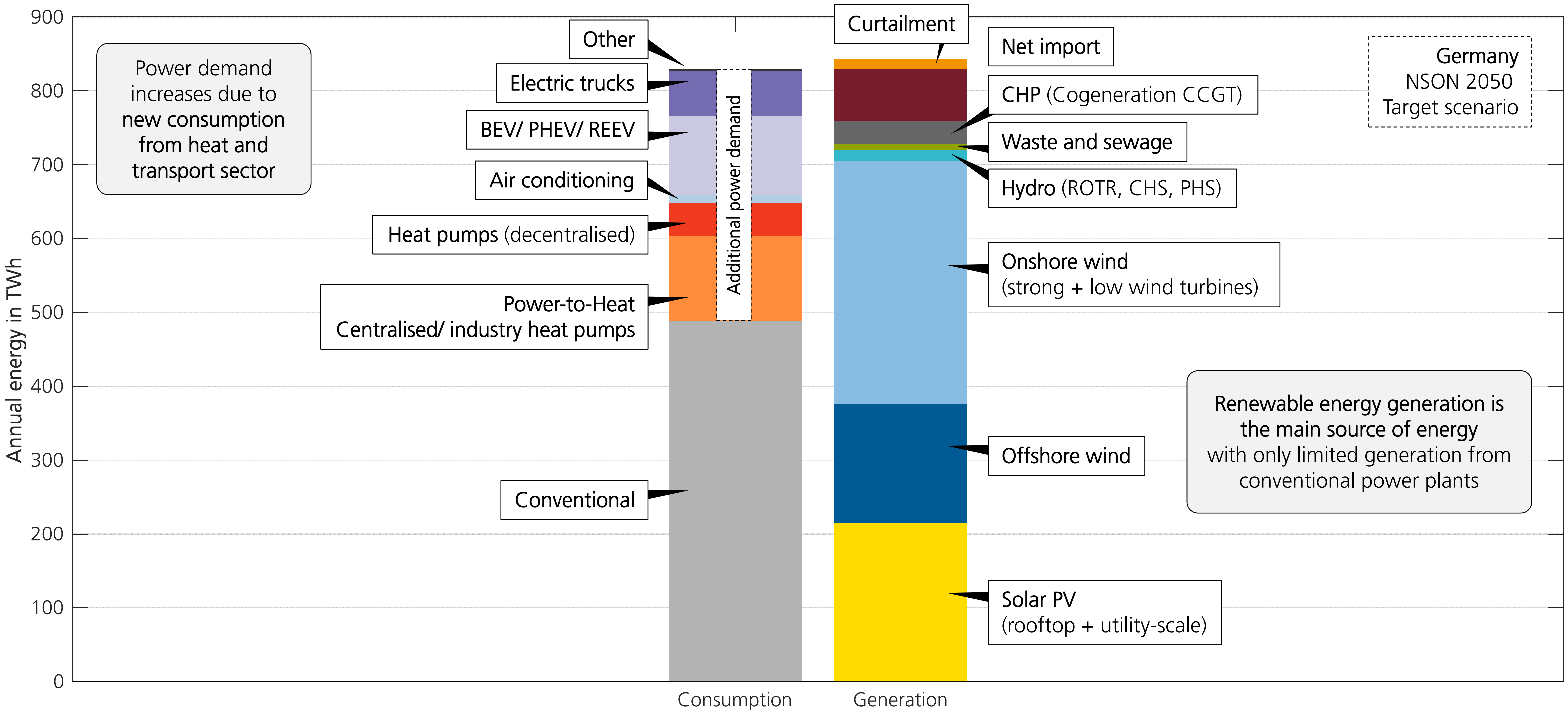
- Power market
- Heat markets (various building types and temperatures)
- Gas markets (national/ international)
- Mobility demand
- CO_2 markets (national/ international, sector-specific)

Technology options

Wind, Solar	Energy storage	Power-to-Gas	BEV	PHEV/ REEV
Hydro power	Cogeneration	Cooling process	Boiler	Electric truck (OHL)
Condensing Plant	Power-to-Heat	Heat pump	Solar thermal	Geothermal

[1)] Static and deterministic Generation Expansion Planning (GEP) model.

Power sector sees higher volumes as it is expected to supply the heat and transport sector in order to fulfil climate targets in the overall energy sector (-87.5% carbon emissions vs. 1990 level)



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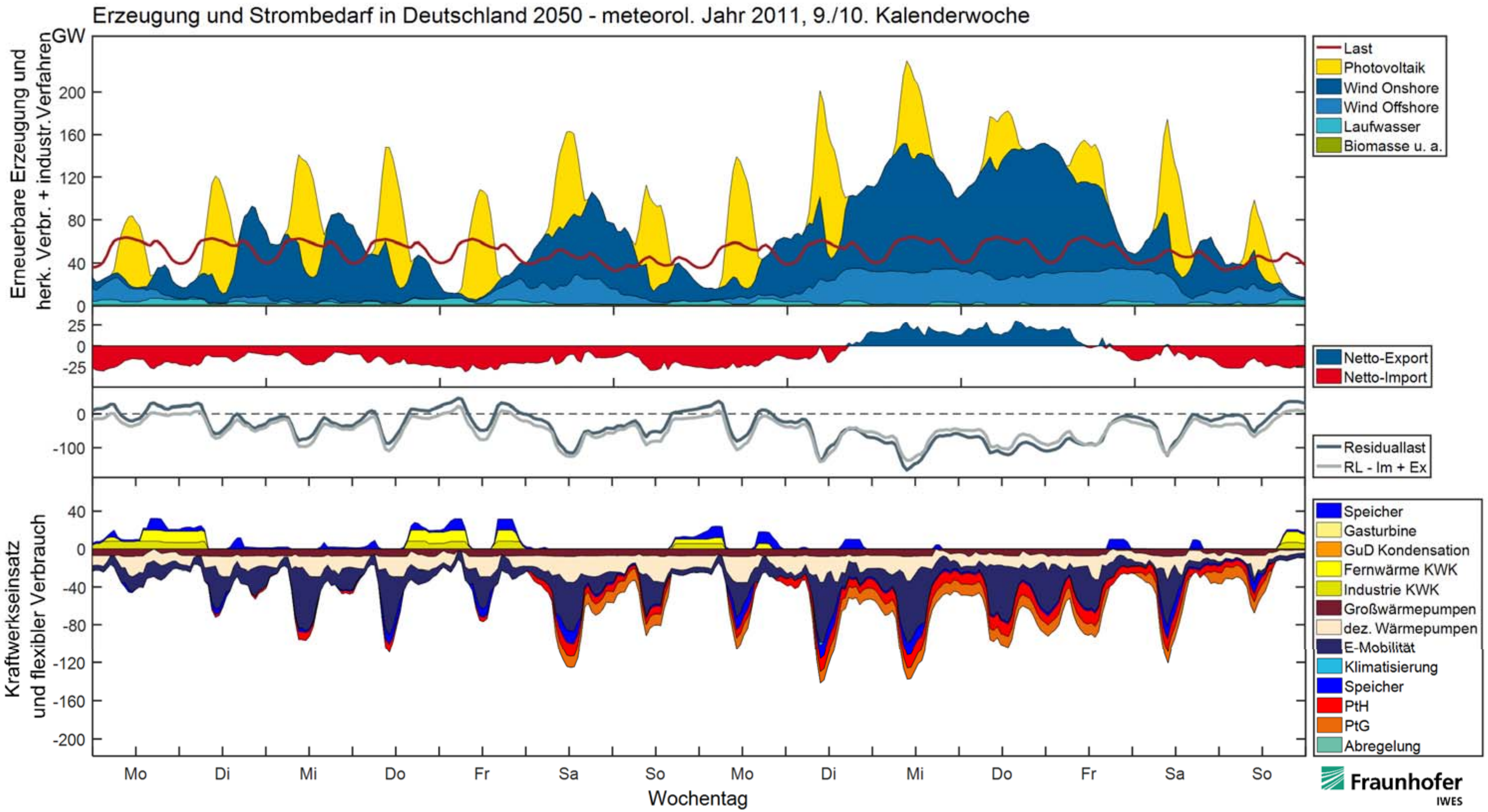
Exemplary week shows integration of renewable energy production through sector coupling – heat and transport sector introduce flexibility and directly use electricity



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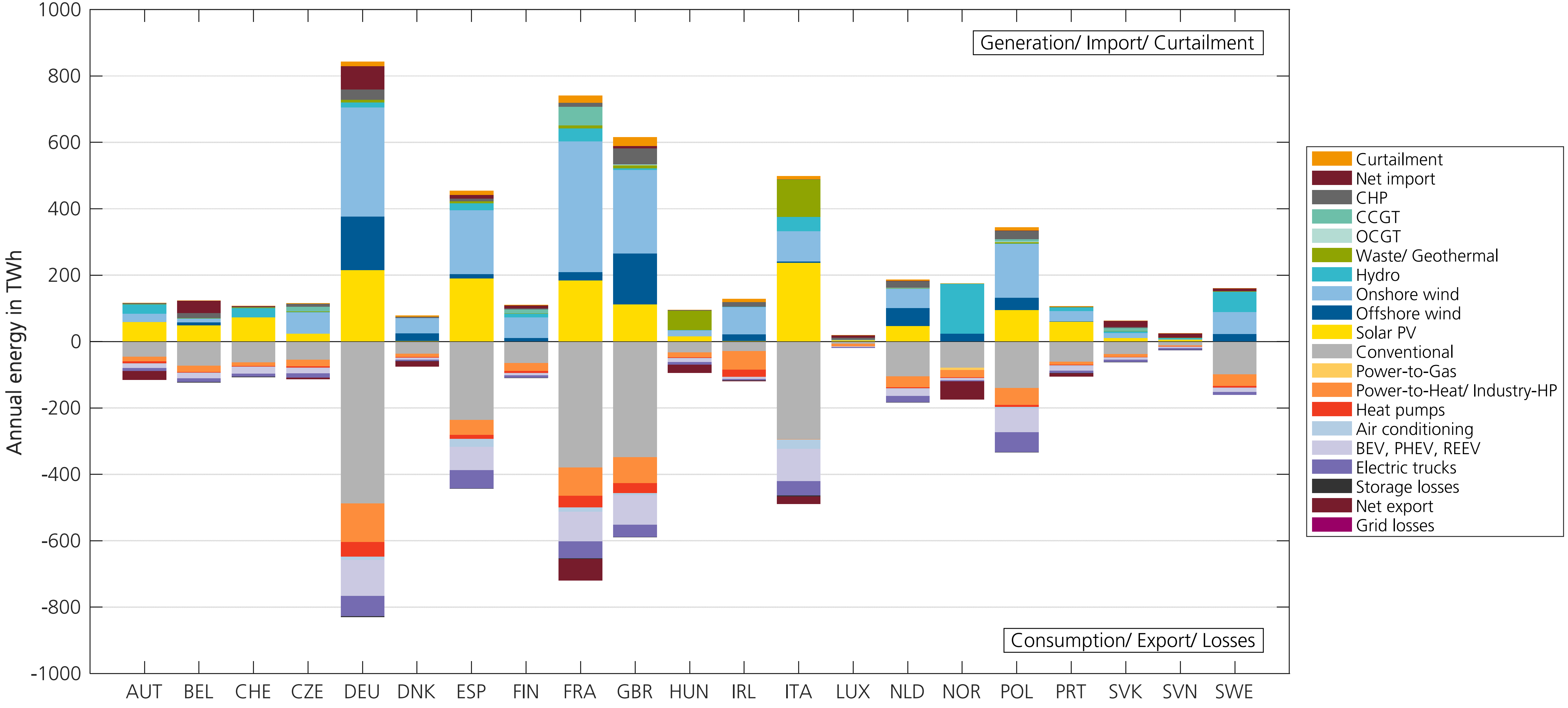
A similar pattern becomes visible for the other market areas in Europe – conventional generation is reduced to natural gas (mainly CHP) and existing nuclear plants by 2050



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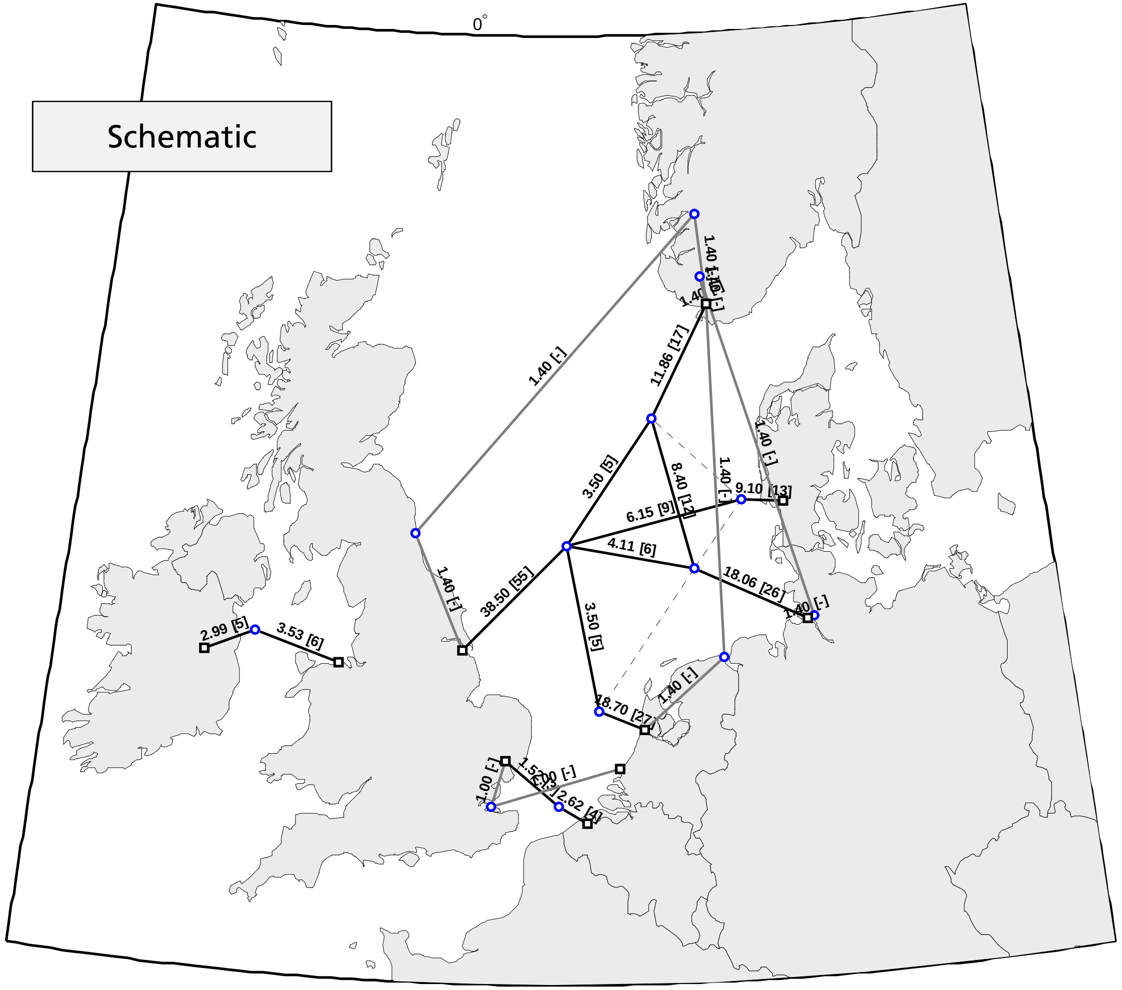
EXEMPLARY

Long-term scenarios with high levels of decarbonisation bring along challenges for planning tools which are designed to investigate more specific subjects



<u>Multi Market Area Dispatch and Offshore Grid Expansion Model</u>

Onshore market area

- Load coverage of residual load
- Technical restrictions of the hydro-thermal plants
- Technical restrictions of other flexibility options (e.g. as battery storage, flexible CHP, electric mobility)

Offshore grid region (area)

- Load coverage/ node balance of offshore hubs with wind generation/ curtailment/ storage
- Investment decision variables in offshore grid infrastructure

Power exchange between areas

- Im-/ export between onshore market areas
- Im-/ export between onshore market areas and offshore grid region

Omitting sector coupling and its interaction in planning tools focussing on e.g. offshore grid investments is not an option

Modelling (and solution) challenges are amplified even more

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Key messages regarding long-term energy scenario development in Germany and Europe

Focus used to be on reaching renewable shares in the traditional power sector
and making use of surplus energy

Coupling the traditional power sector with heat / industry / transport sectors
is crucial to decarbonise the energy supply system and
comply with climate targets

Generation from wind and solar will be the main source of energy
as simulations show its feasibility and LCOE are continuing to go down

Current alternatives expected to play a complementary role
Biomass, solar thermal, geothermal

Technology efficiency is still an important issue
although there are good wind and solar potentials across Europe,
but social acceptance imposes limits

High efficiency sector coupling technologies already relevant today
such as heat pumps & electric vehicles

Low efficiency sector coupling technologies become relevant in the long-term
such as Power-to-Heat & Power-to-Gas

Challenges for power system planning and operation models
to adequately address future system flexibility
from a methodological perspective

Limitations and assumptions:

Installed capacities are optimised to the absolute minimum
by the deterministic generation expansion planning model
(particularly conventional generation capacities)

Presented scenario is to be seen as a lower bound
since e.g. balancing reserve markets are not included

Flexibility of the new consumers is assumed as a given
implying that they see some kind of flexibility signal

European balancing via the electricity market is a vital assumption
as it facilitates significant balancing between regions

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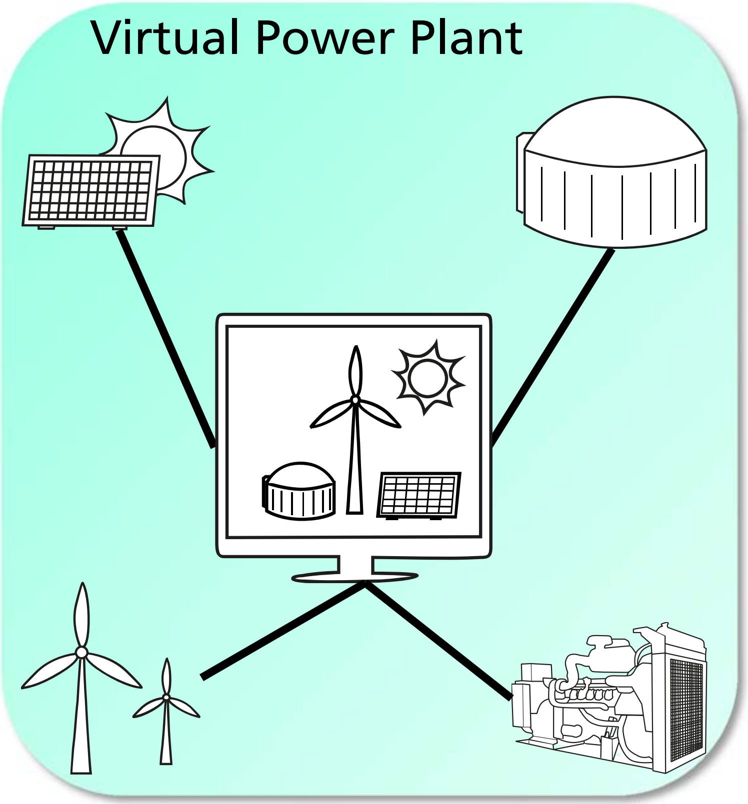
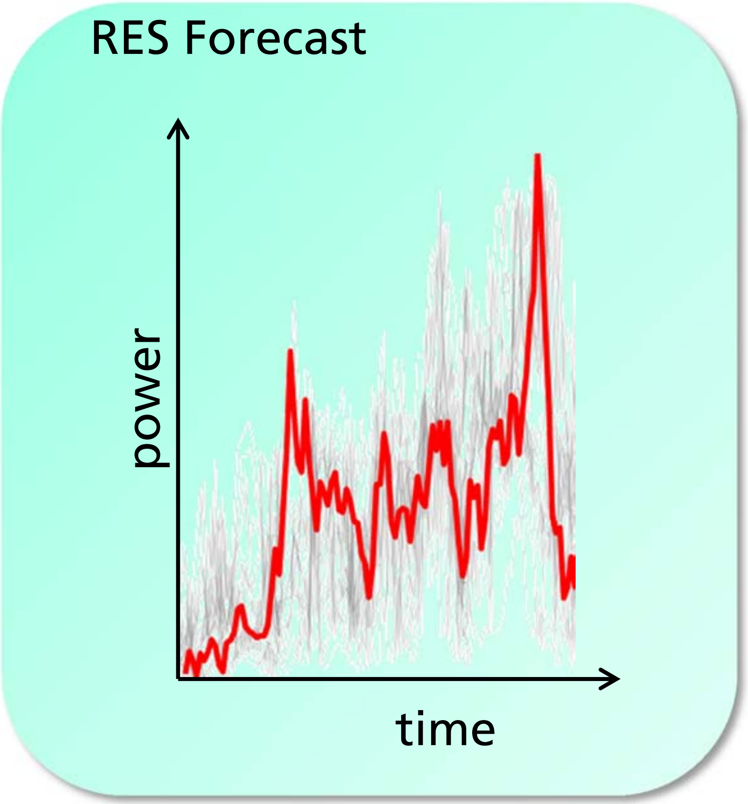
CURRENT CHALLENGES OF THE INTEGRATION OF LARGE AMOUNTS OF WIND AND SOLAR POWER





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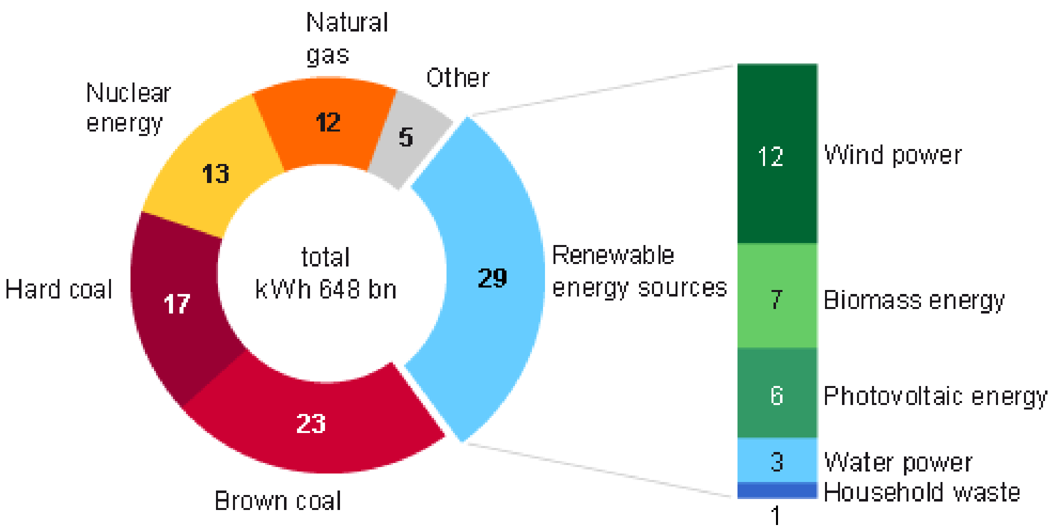
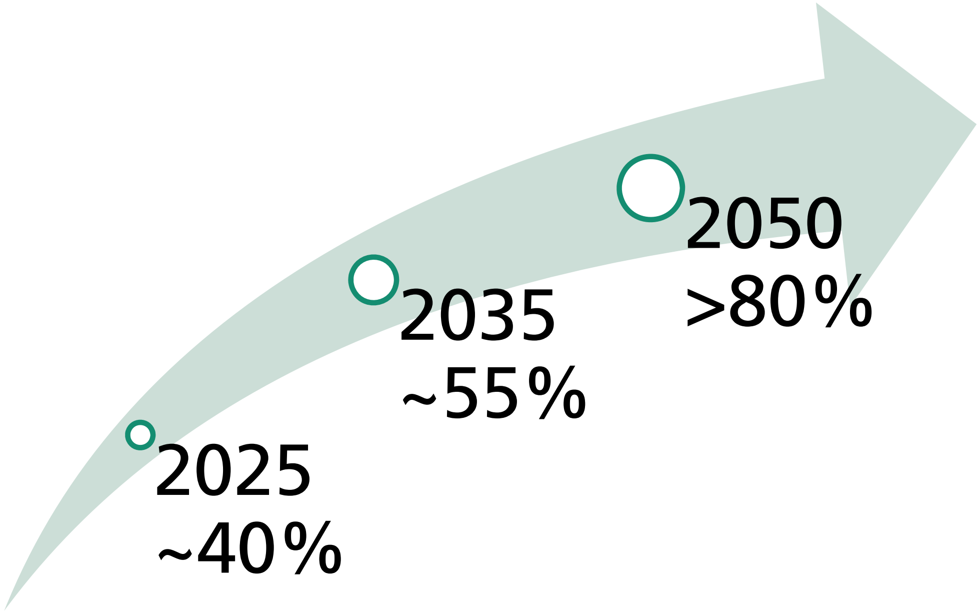
Introduction - German power system

Gross electricity production 2016
in %



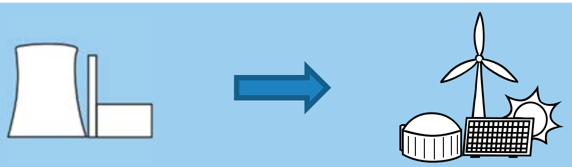
Preliminary result
Source: AGEE-Stat and AGEB.



Top-down → Optimization → Bottom-up

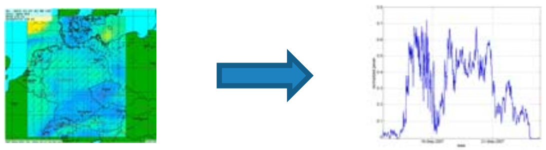
Introduction - The Challenges

Renewables replaces conventional power production



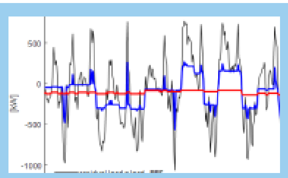
Intermittent character of wind and PV

- Grid operation more sophisticated
- Resource planning more sophisticated



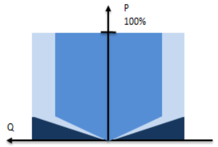
Security of supply

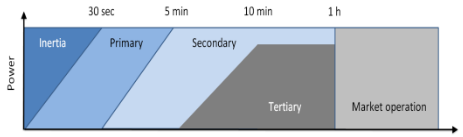
- Balancing of supply and demand
- Grid security



Ancillary services from RES

- reactive power (voltage stability)
- control reserve (frequency stabilization)





Holistic view on energy system

- Activation of flexibility
- sector coupling

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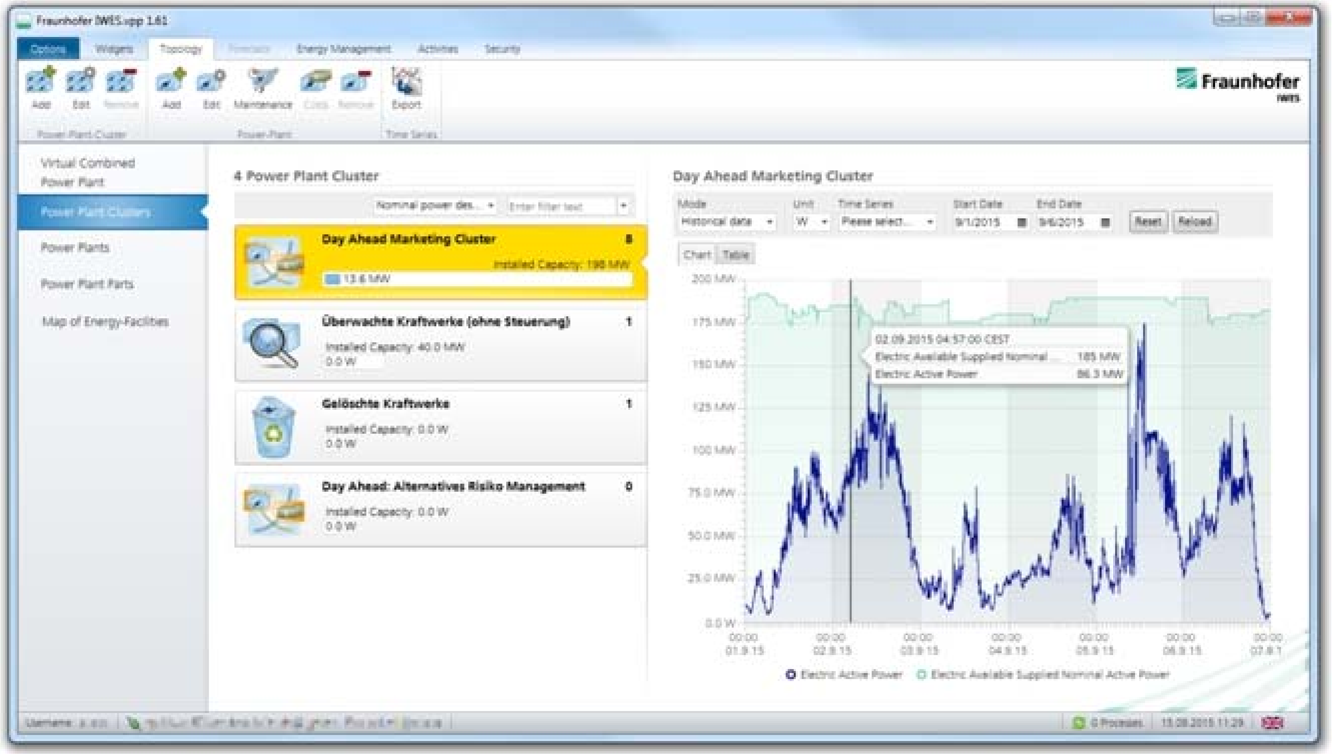
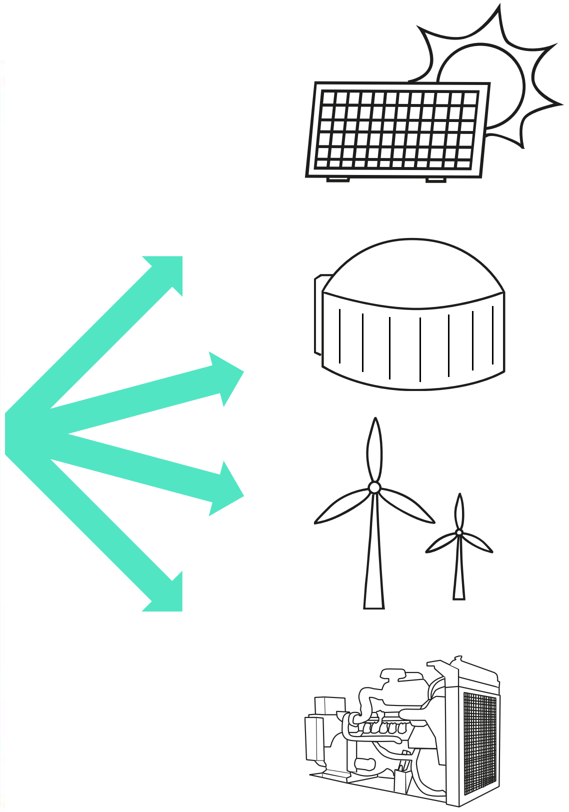
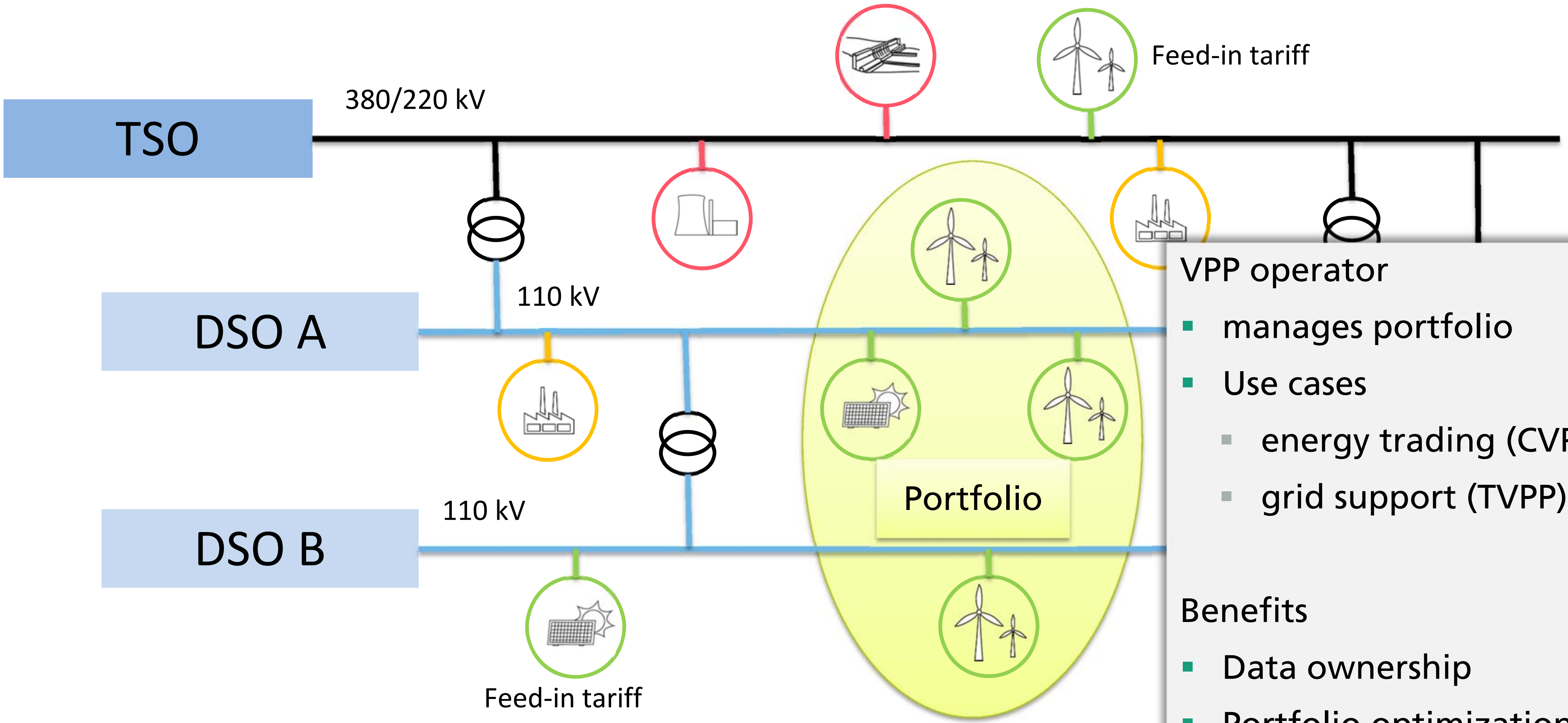
VIRTUAL POWER PLANT– RENEWABLE ENERGY PRODUCTION OF THE FUTURE





Introduction – New role portfolio manager (Energy trade)



VPP operator

- manages portfolio
- Use cases
  - energy trading (CVPP)
  - grid support (TVPP)

Benefits

- Data ownership
- Portfolio optimization

Roles: TSO, DSO, customer, plant operator, RE plant operator, energy trader

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Virtual Power Plant (VPP) - Definition

"A virtual power plant is a cluster of dispersed generator units, controllable loads and storages systems, aggregated in order to operate as a unique power plant. The generators can use both fossil and renewable energy source. The heart of a VPP is an energy management system (EMS) which coordinates the power flows coming from the generators, controllable loads and storages. The communication is bidirectional, so that the VPP can not only receive information about the current status of each unit, but it can also send the signals to control the objects."

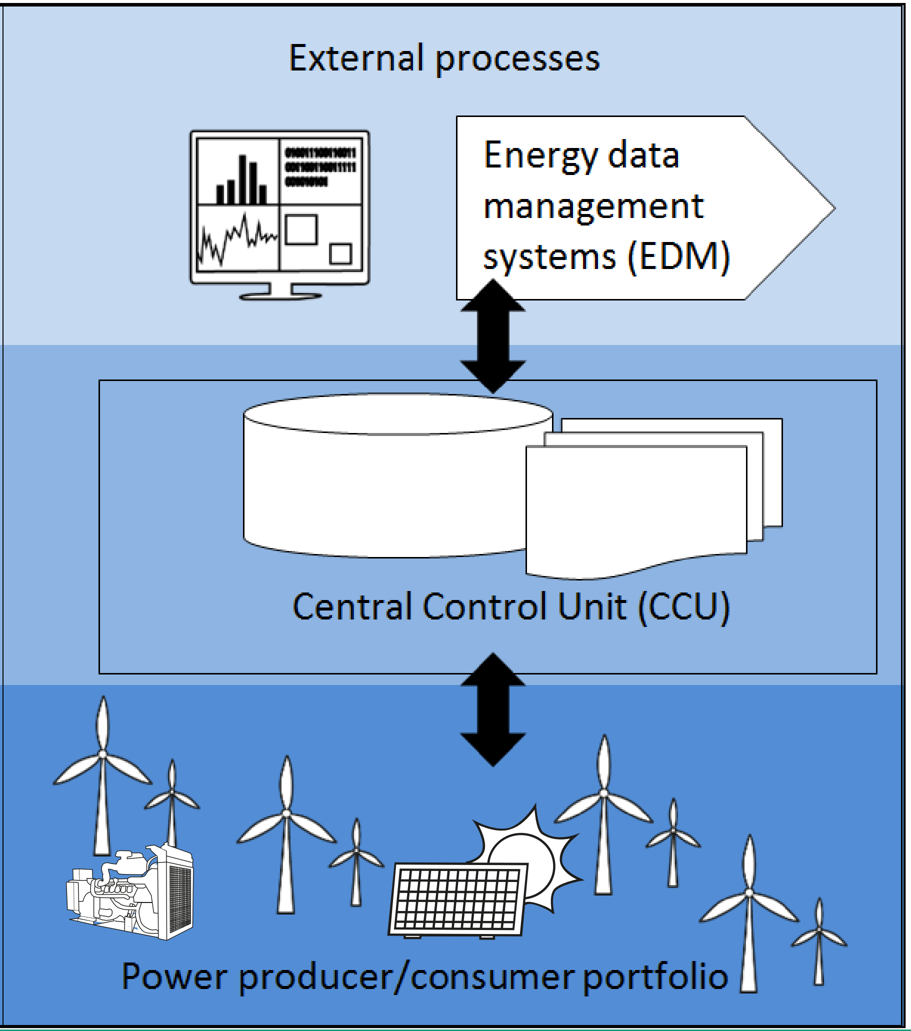
Source: Virtual Power Plant (VPP), Definition, Concept, Components and Types, Saboori, 2011, IEEE

Virtual Power Plant (VPP) - Architecture

Integration
- graphical user interface
- connection to external process
- acquisition of external data
- local communication

Use case/Business case
- logical/economical use case
- forecast processing
- interpretation of metering data
- creation of schedules

Portfolio aggregation
- communication with plants/portfolio
- metering
- scheduling
- calculation of operating point



Virtual Power Plant (VPP) – Aggregation level

Communication interface
- Standardization useful and needed

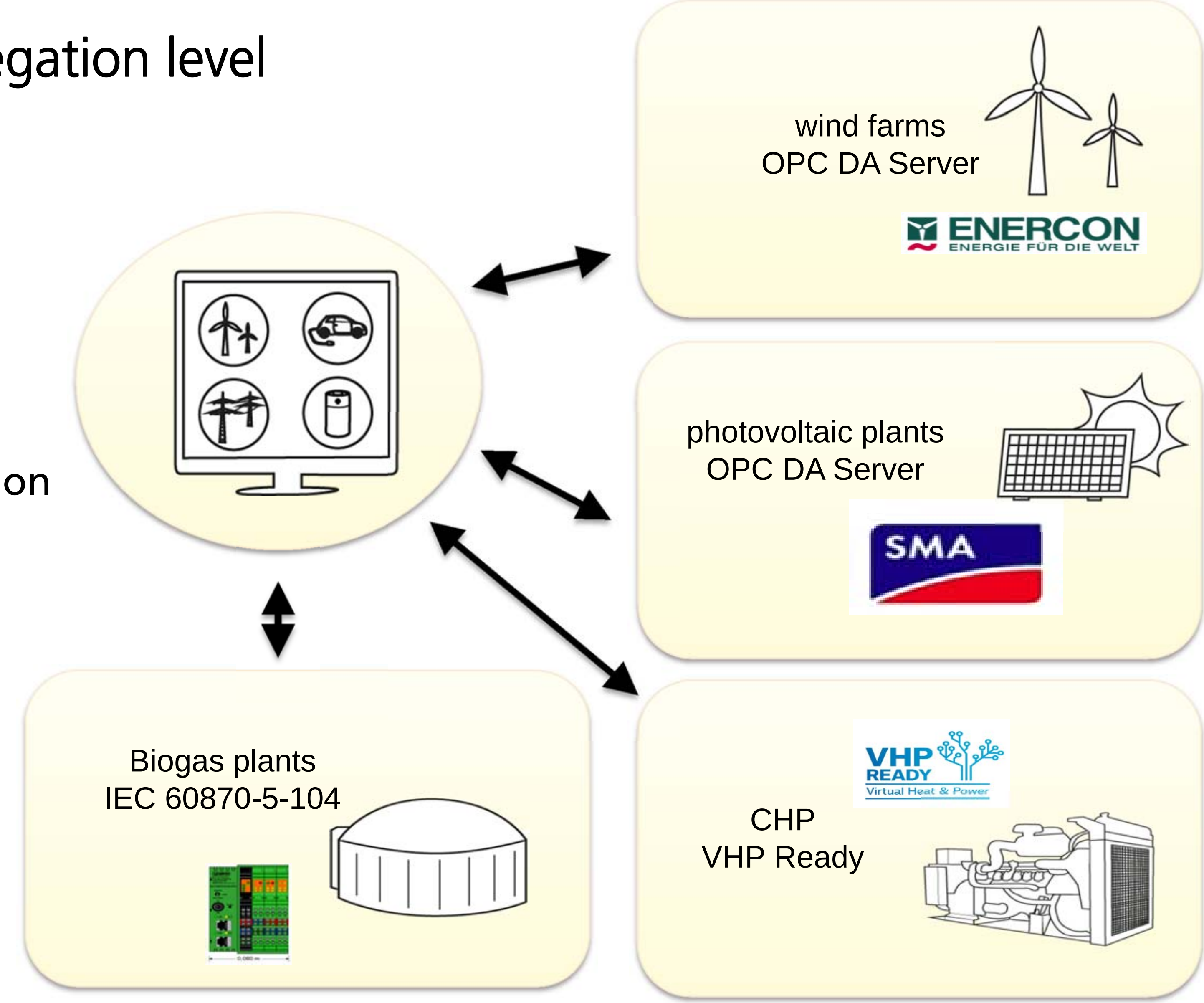
Communication protocols
- TCP/IP based

Communication technologies
- DSL, LTE, GSM, satellite communication

Communication security
- VPN
- Web security
- closed user groups
- point to point connections

Typical requested data
- P, Q, storage, weather information, possible power feed-in

Bidirectional connection, push/pull



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Virtual Power Plant (VPP) – Business logic level

Metering interface to portfolio

Database

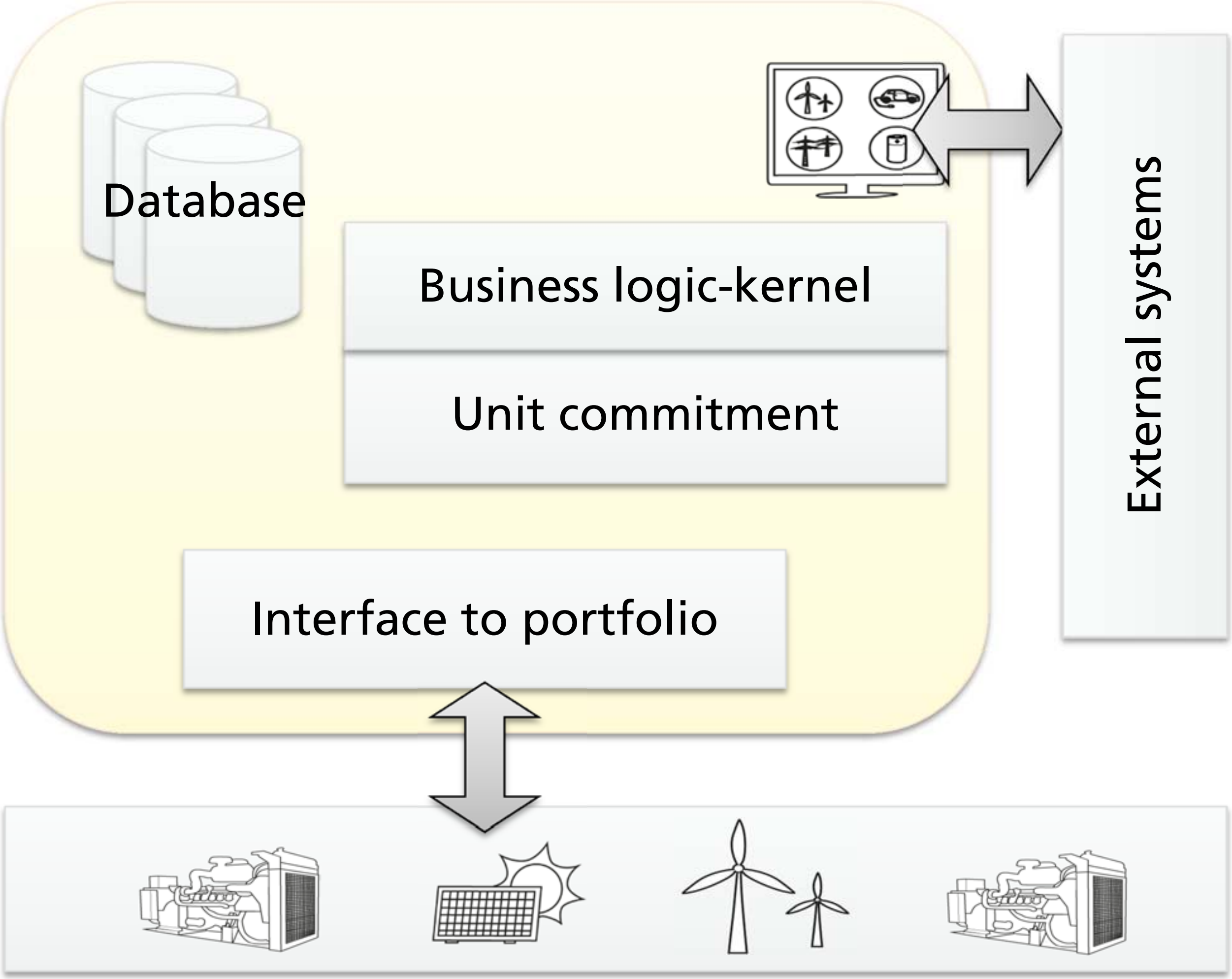
Business logic-kernel

- Optimization of business cases

Unit commitment

- Calculation of schedules
- Calculating of operating points

Interfaces to external IT-infrastructure,



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Virtual Power Plant (VPP) – Integration level

Graphical user interfaces

Monitoring systems

External IT systems

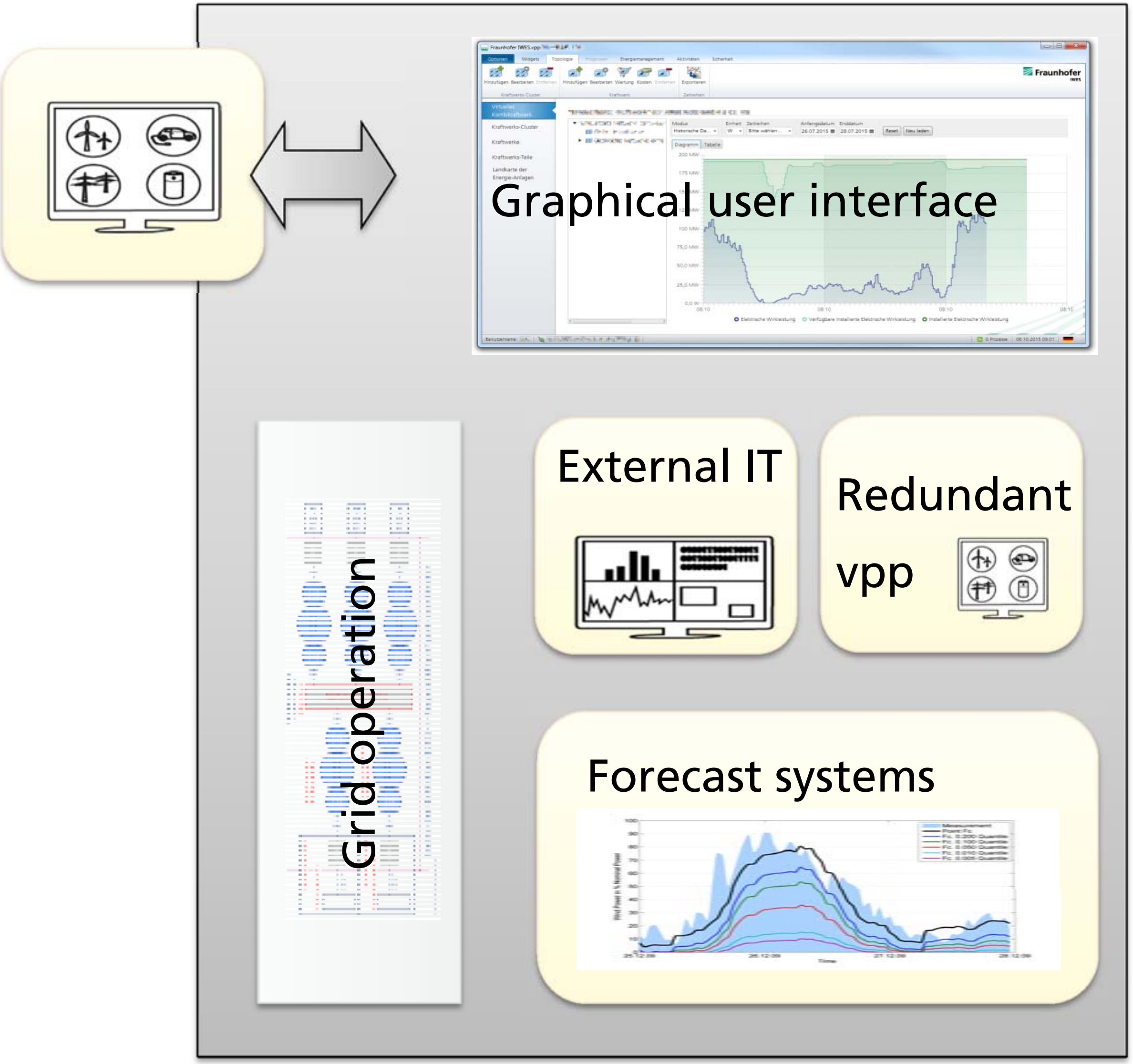
- Customer dependent (In case of utility SAP for accounting, etc.)

Forecast systems

- Power feed-in from fluctuating sources,
- load forecasts
- price forecasts for different markets
- External trading systems

Grid operation

- State information
- requests for control reserve power



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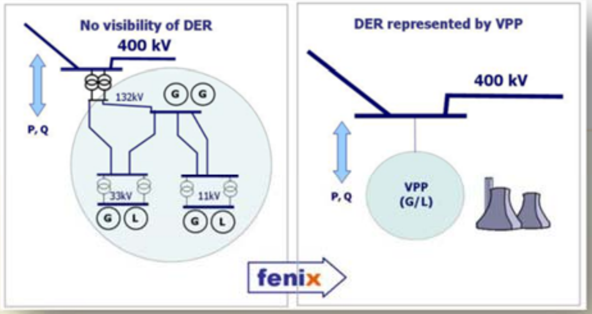
Virtual Power Plant (VPP) – Relevant research and cooperation projects (examples)

VPP as a substitution of conventional power plants

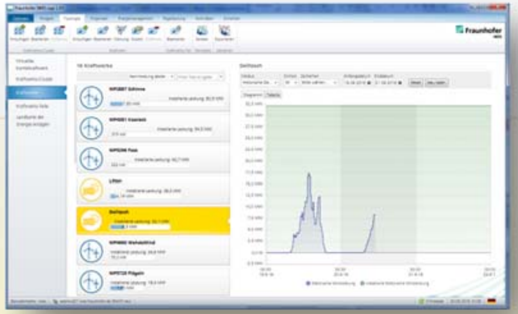
(European research – FENIX,)



Control reserve power with wind and PV,

Optimization of revenues

(National funded research – ReWP)



Aggregation of 700 MW renewable energies Portfolio in Germany

(Cooperation – ARGE-Netz GmbH)

Conceptualization of a Virtual Power Plant (VPP) in India

(International research/cooperation with ICF)

FORECAST SYSTEMS FOR THE INTEGRATION OF LARGE AMOUNTS OF WIND AND SOLAR POWER

Projects:

EWeLiNE (2013-2017)

Gridcast (2017-2021)

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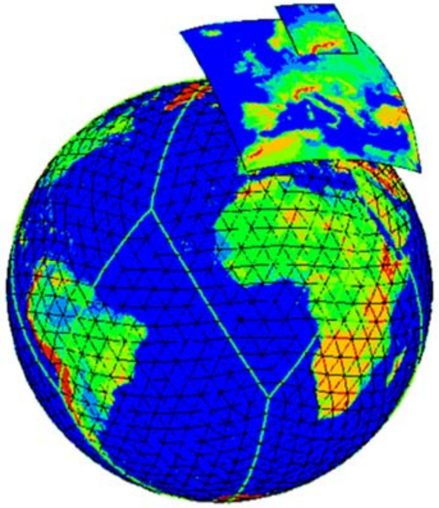
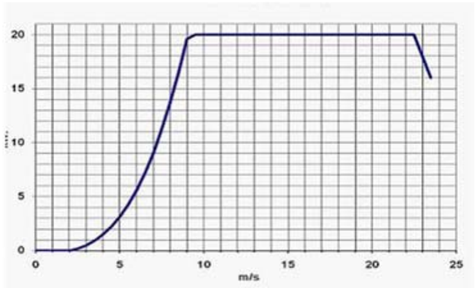
Cooperation between weather service and network operators

weather forecast



Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

power forecast



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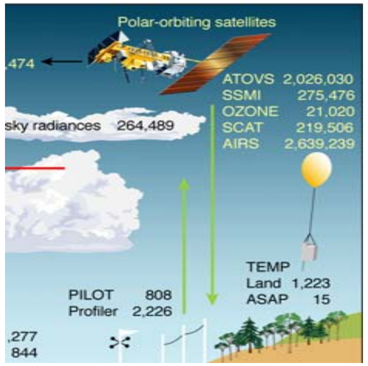
application of power forecast

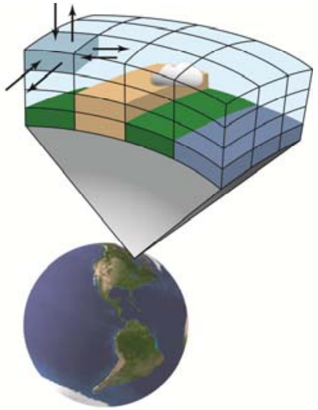
Francis McLloyd

50hertz
Energie für eine Welt in Bewegung
amprion
TenneT

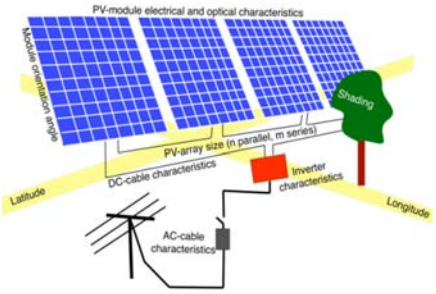
Improvements along the whole forecast chain



DWD



DWD



Francis McLloyd

assimilation → Weather forecast → Post processing → Power forecast → Post processing → application

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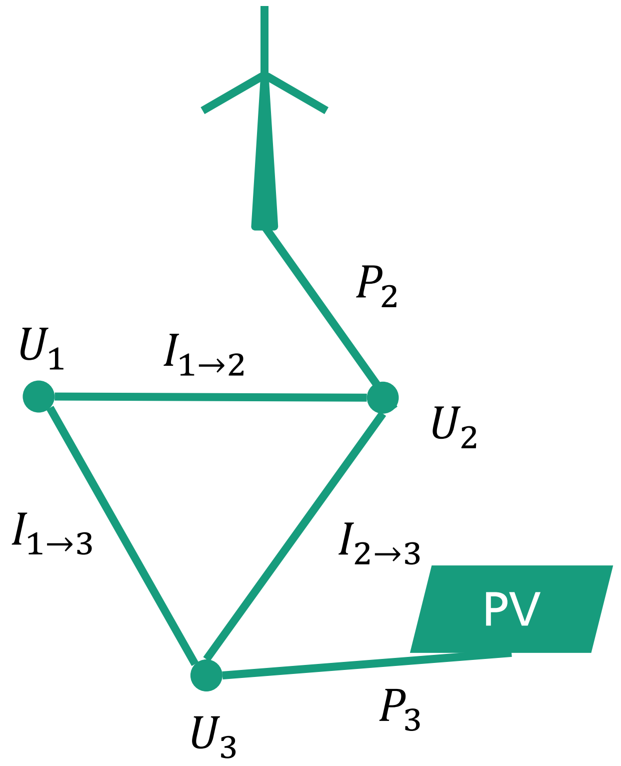
Problem description

- RES forecast for congestion forecast becomes one of the most important forecast for TSO in Germany
  - Operational planning: forecasting the future system state + actions
  - System state parameters: node voltage and branch current
- Risks can be captured with uncertainty information (risk for (n-1)-violation)
- Further Need: operational planning process which is capable of integrating uncertainties



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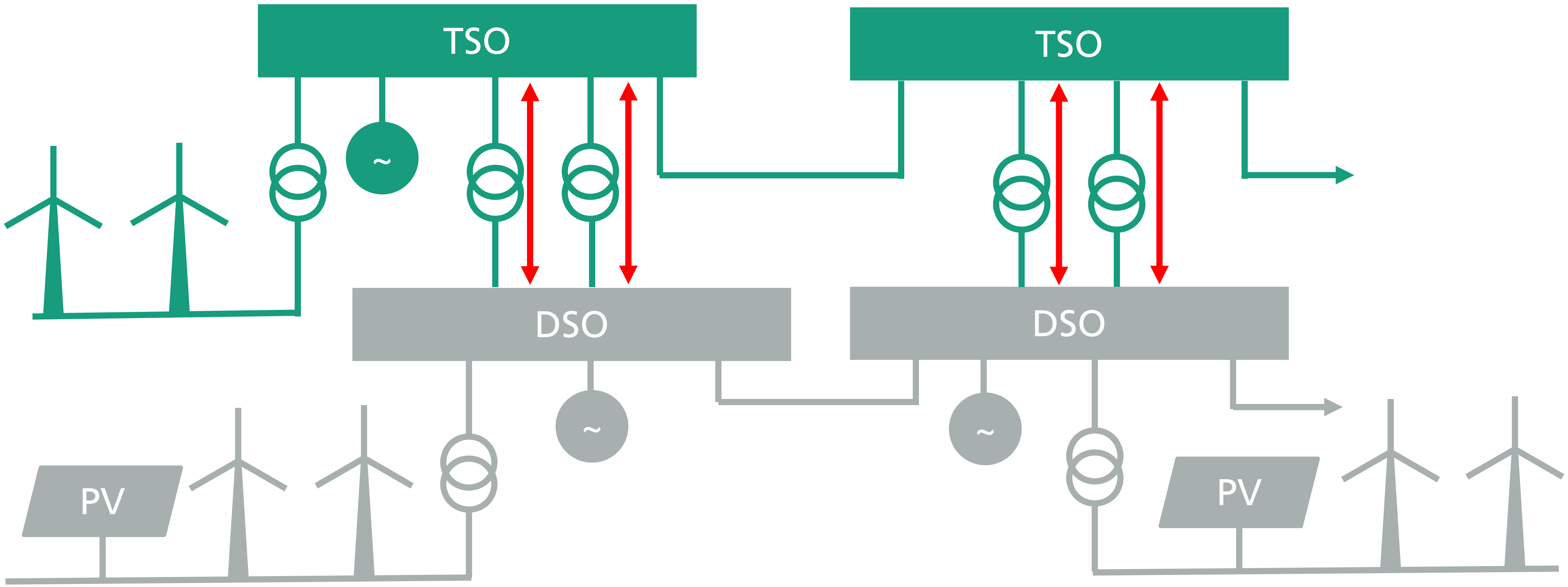
Most of the RES plants are connected to DSO-level



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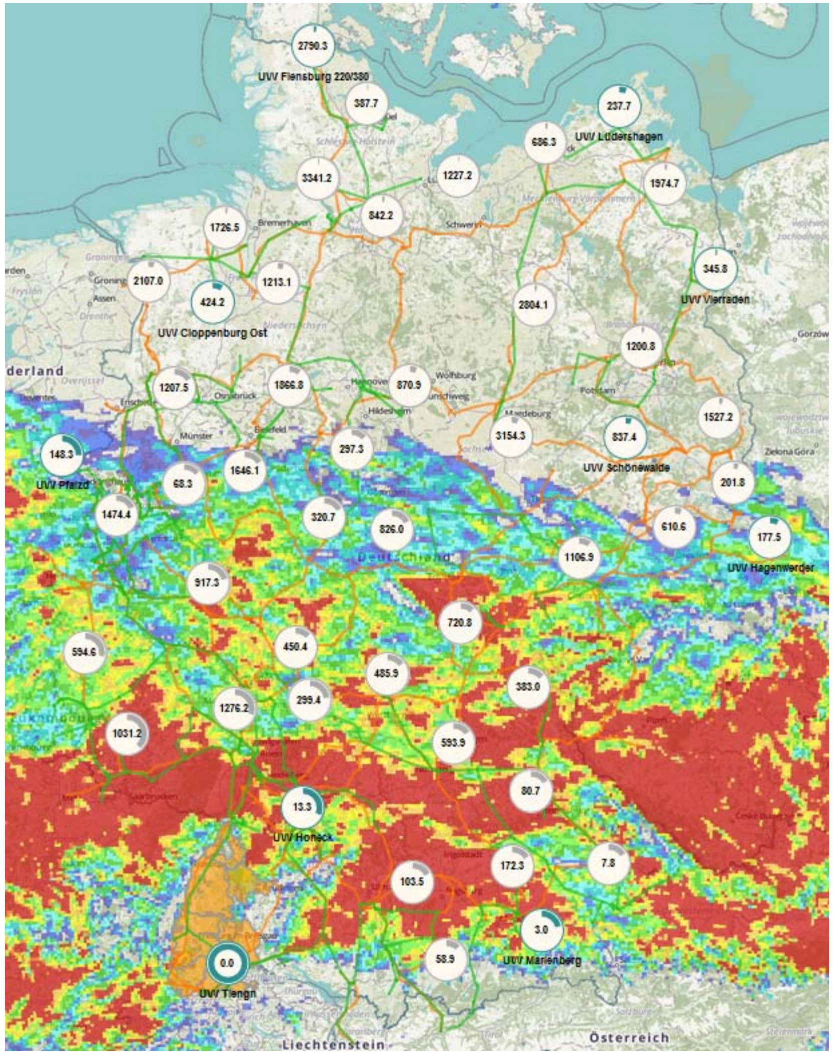
The challenge

1. Estimating the actual RES feed-in into transformer stations
2. Forecasting the RES feed-in into transformer stations
3. Estimating the reduced production of RES plants
4. Improved allocation of RES plants to transformer stations and integration of the grid sate
5. Quantification of the forecast uncertainties
6. Testing the results by functional models



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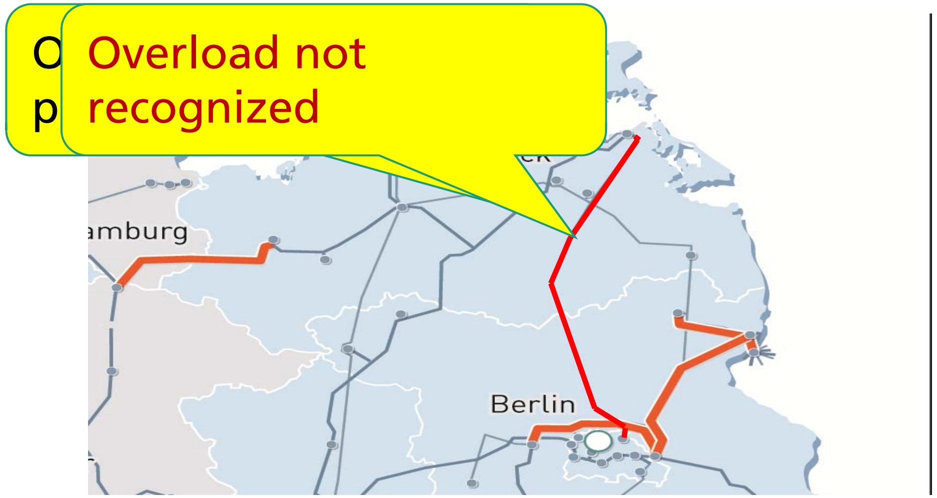
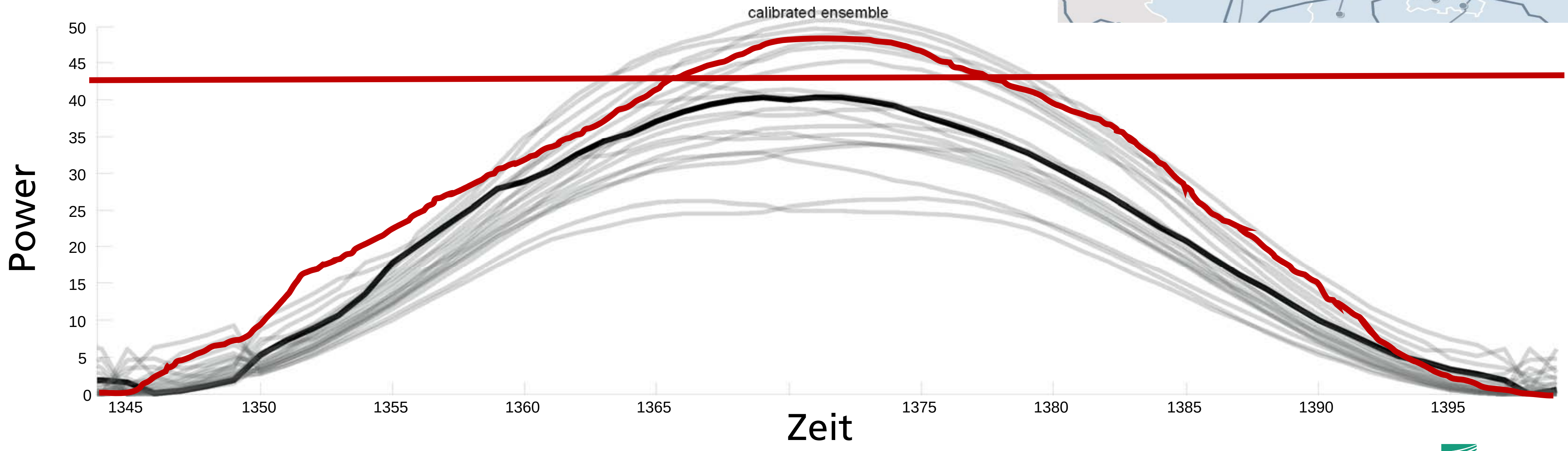
Uncertainty Forecast for Congestion Management

- Thermal overload?
- Deterministic forecast: „No“.
- Reality: „Yes“.
- Ensemble recognize possible overload.





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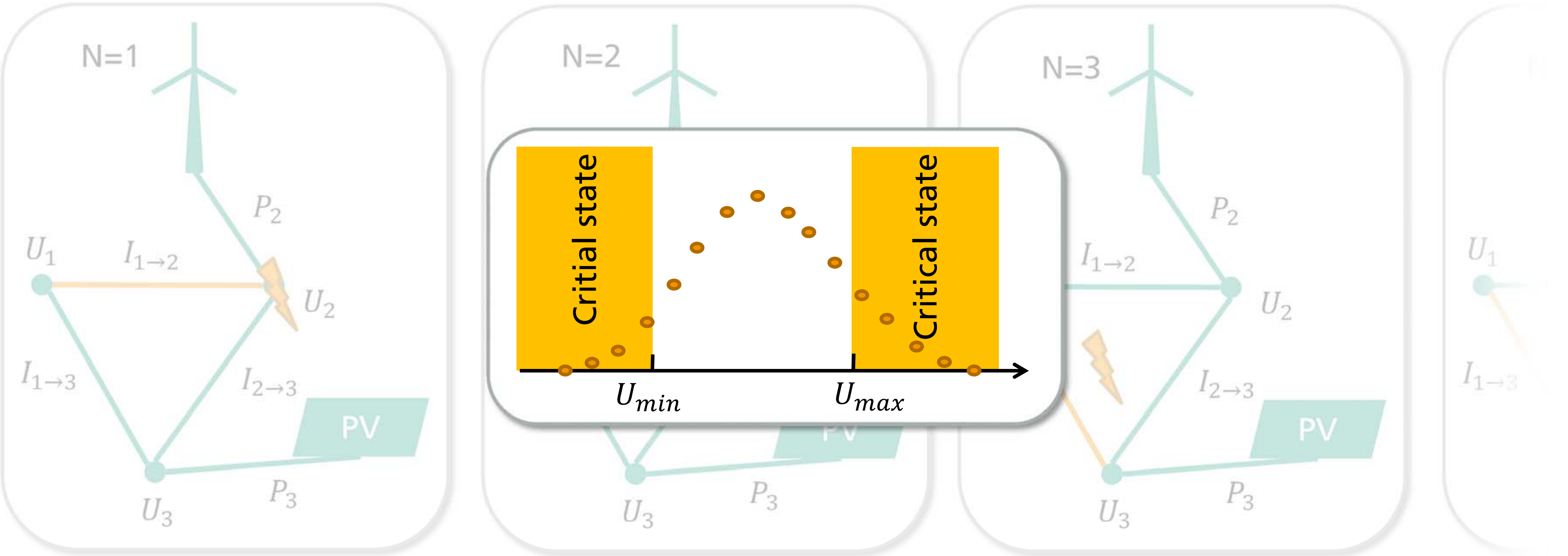
One congestion forecast for each scenario
→ estimation of critical system states



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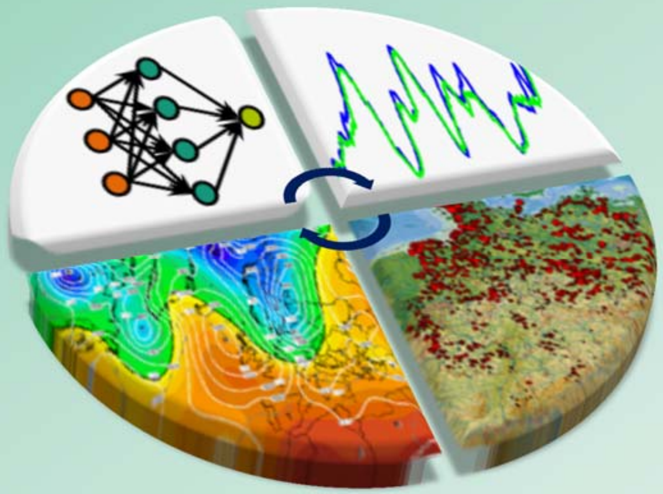
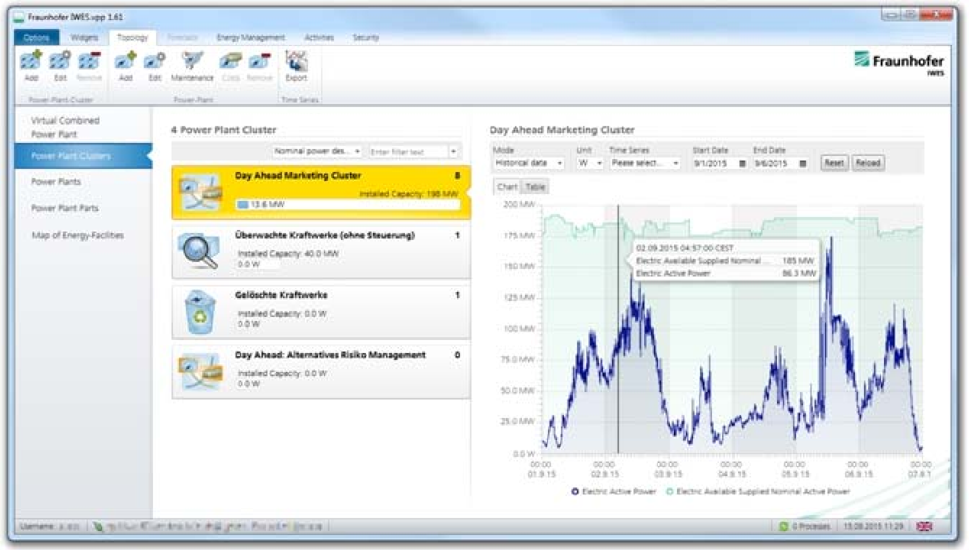
Fraunhofer is Europe’s largest application-oriented research organization.

- Our research results are proven in practice

Forecast Systems



Virtual Power Plant



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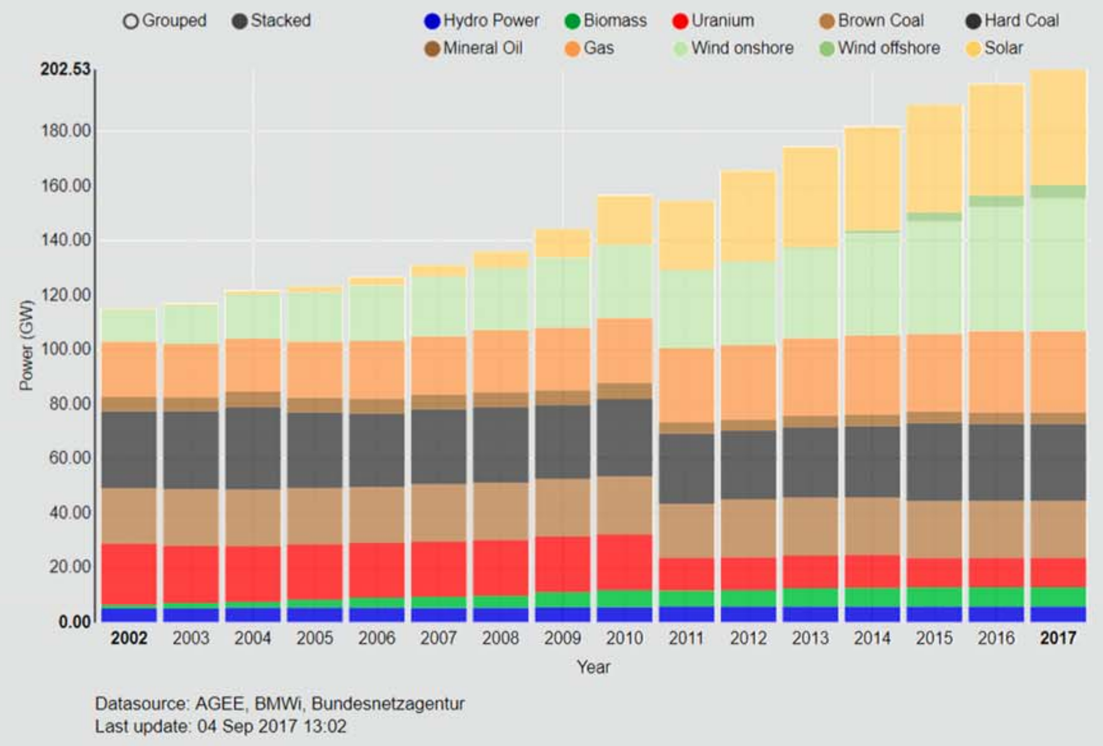
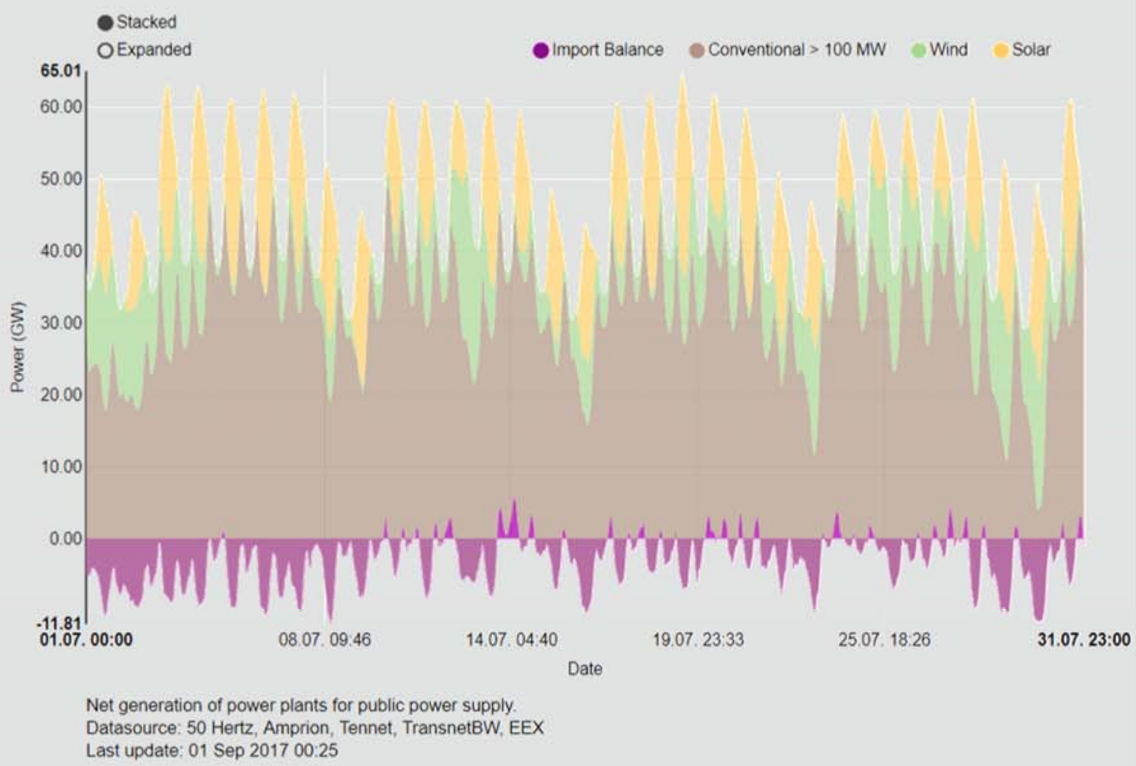
Renewables in the German power system

Installed capacity



Power supply (August 2017)



- Installed capacity of renewables sharply increased in recent years
- Installed capacity constant respectively slightly decreasing (changing to cold reserve)
- Varying share of renewables in power supply due to intermittend primary resources

Source: https://www.energy-charts.de. Accessed September 25, 2017.

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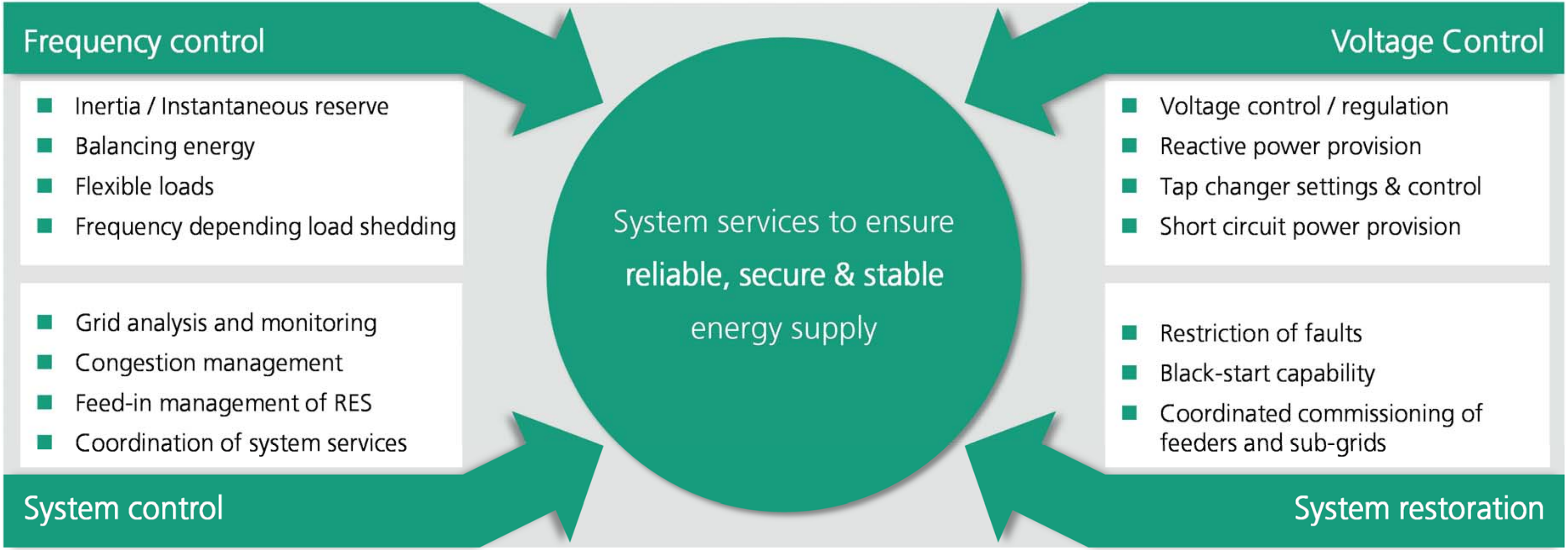
System ancillary services – classical provision and new challenges

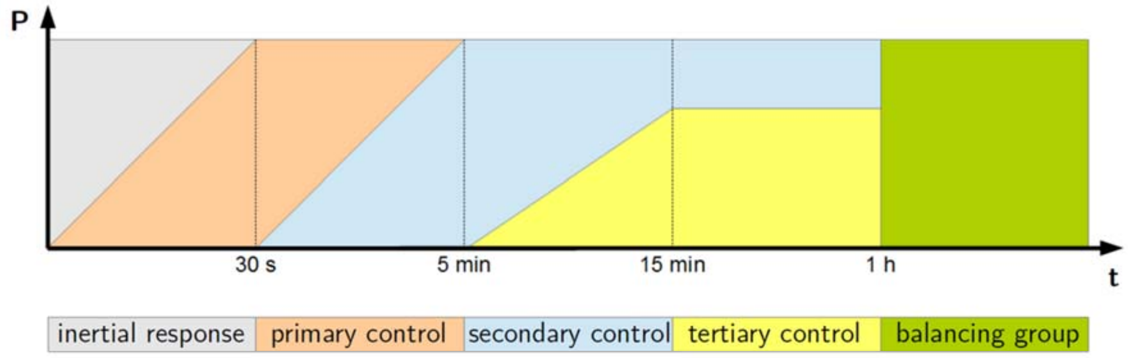


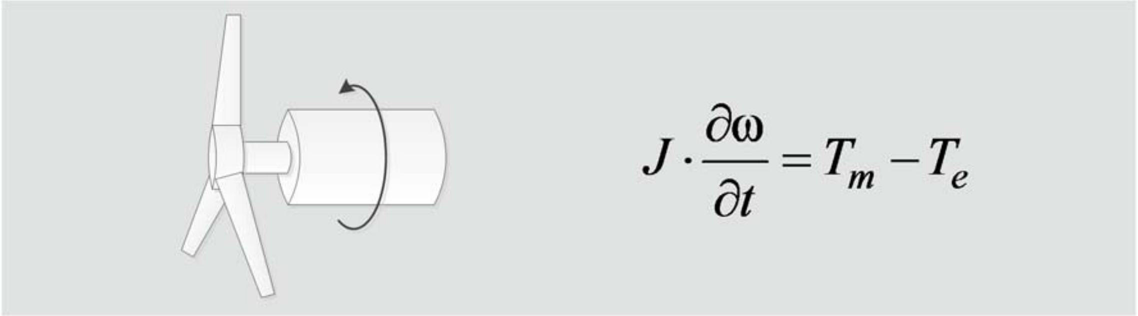
- System services classically provided by conventional power plants, but oftentimes not yet required by RES
- RES need to participate in system services to keep system qualities up

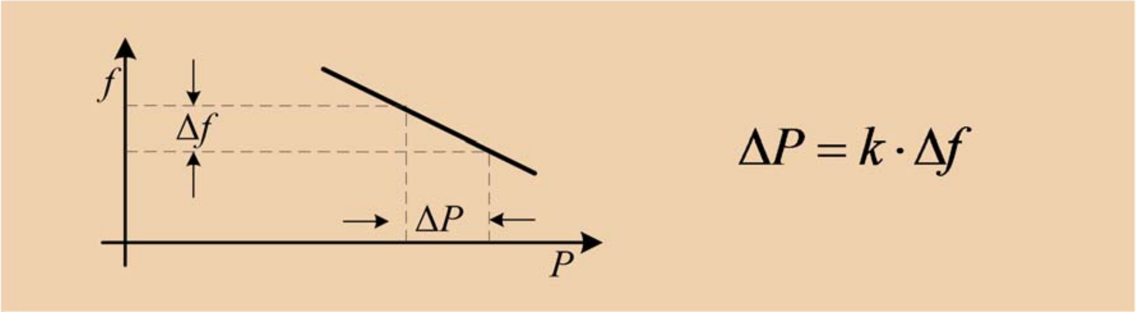
Source: dena Ancillary Services Study 2030. https://www.dena.de/en/topics-projects/projects/energy-systems/dena-ancillary-services-study-2030. Accessed September 25, 2017.

Frequency control in power systems with high penetration of renewables (I/III)

- Frequency control ensured by conventional generators
  - Rotating masses lead to instantaneous frequency support
  - Primary control ensures new stable operating point due to increased power output
  - Further control leads to constant frequency at nominal value
- RES decoupled from grid frequency due to inverter-based grid connection
  - No direct coupling to frequency
  - Only over-frequency support (reduction of power)
  - Under-frequency support would mean active power reserves
- Investigations on frequency control and frequency supporting functionalities become more and more essential
- Examples
  - Demonstration of control reserve with renewables: Project Combined Power Plants: http://www.kombikraftwerk.de
  - Challenges in grid modeling (next slide)
  - Frequency supporting functionalities (inertia & primary control) in wind turbines (2 slides ahead)







Source: According to https://commons.wikimedia.org/wiki/File:Schema_Einsatz_von_Regelleistung.png. Accessed September 25, 2017. Own drawings.

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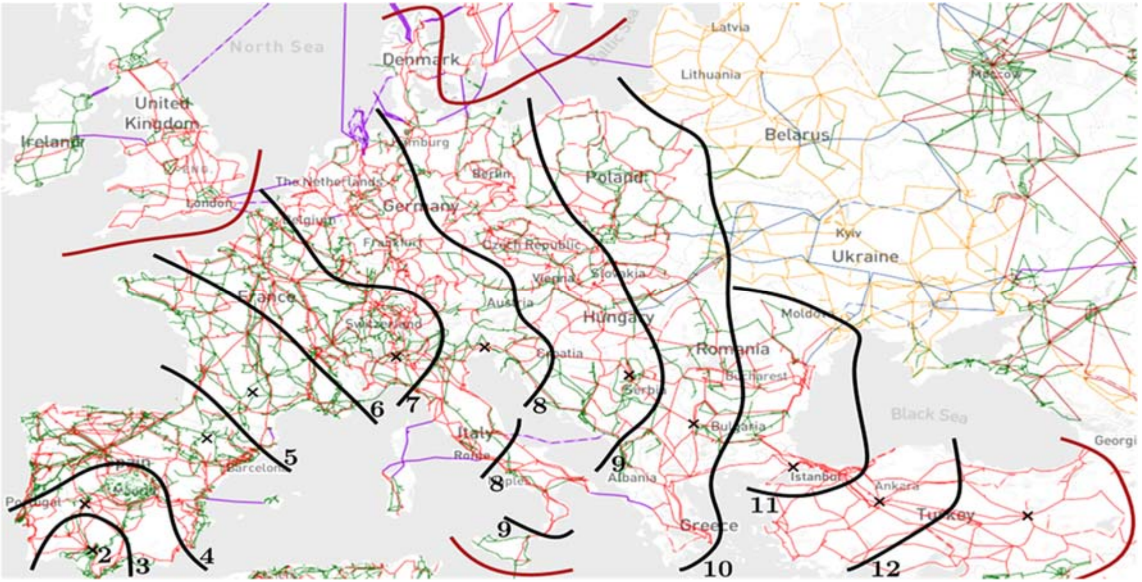
Frequency control in power systems with high penetration of renewables (II/III)

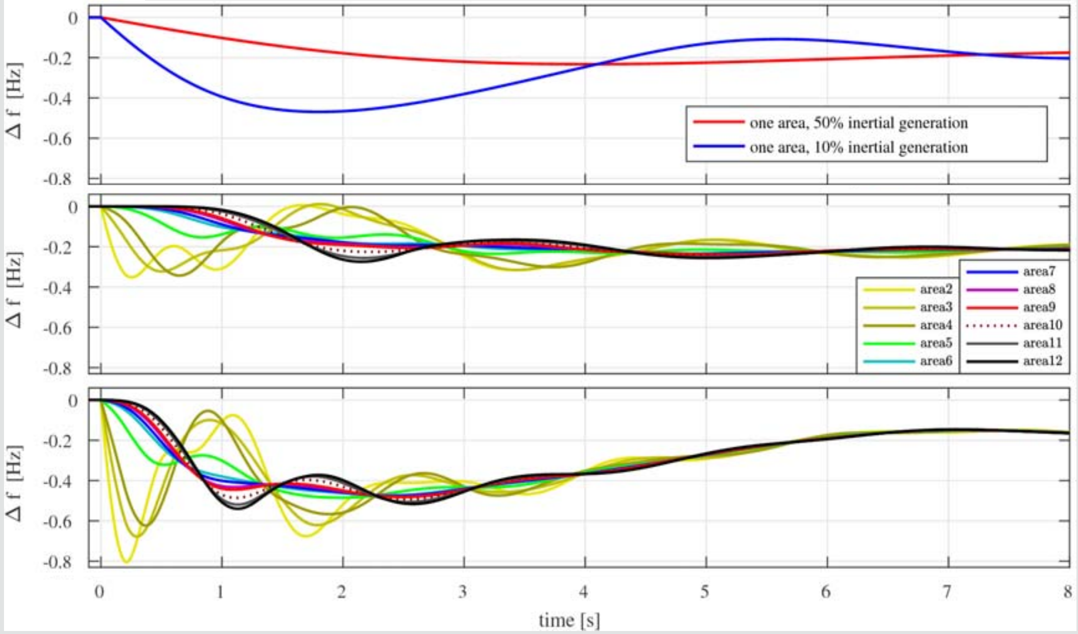
- Challenges in power system modeling
- Example
  - Reduced inertia leads to increased requirements to power system models
  - Balancing model vs. enhanced modelling of large power systems
- Reduced system inertia calls for enhanced models and new modeling concepts



Above
- Balancing model (one rotating mass, no tie lines)

Middle
- 12 „balancing“ models with tie lines and enhanced modeling (rotor angle, …)
- 50 % inertial generation

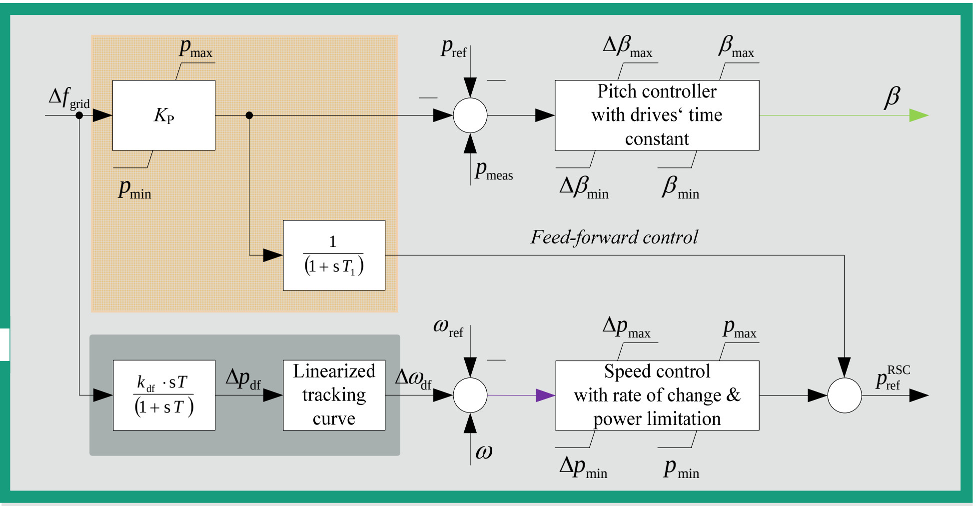
Below
- 12 „balancing“ models with tie lines and enhanced modeling (rotor angle, …)
- 10 % inertial generation

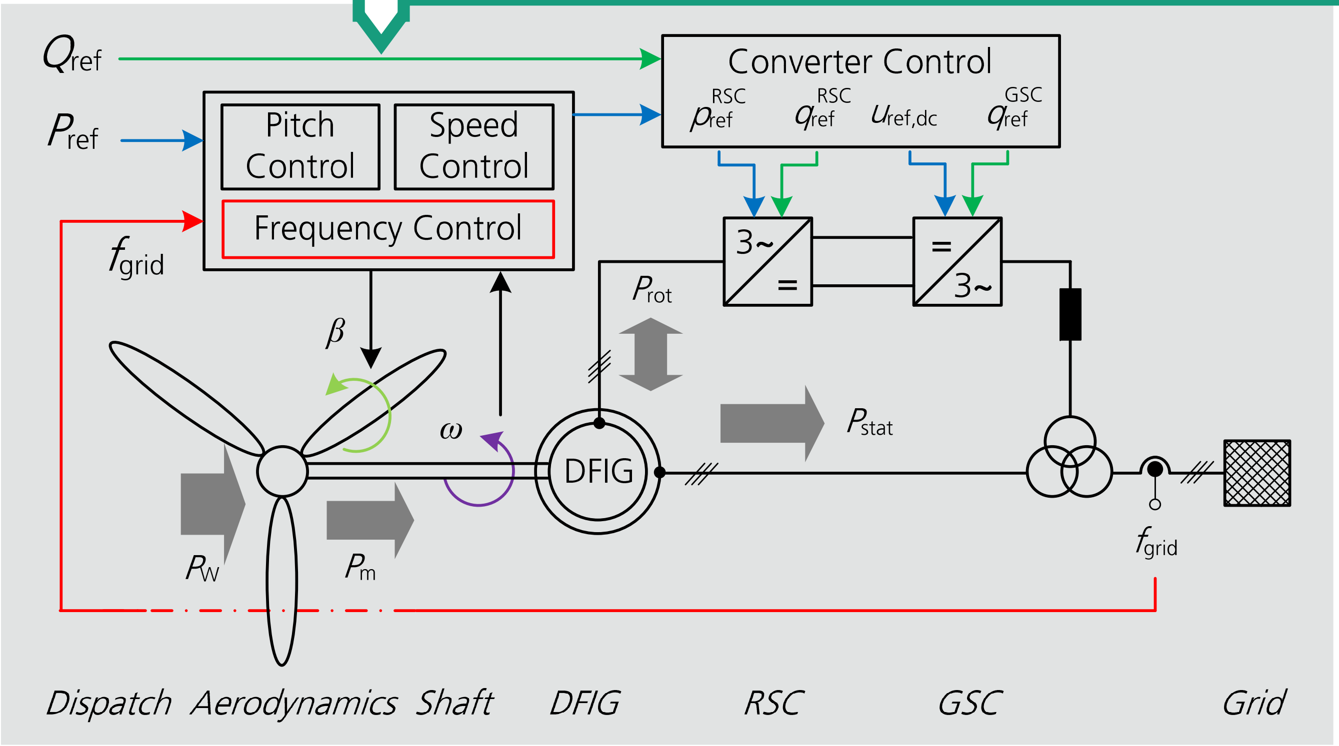


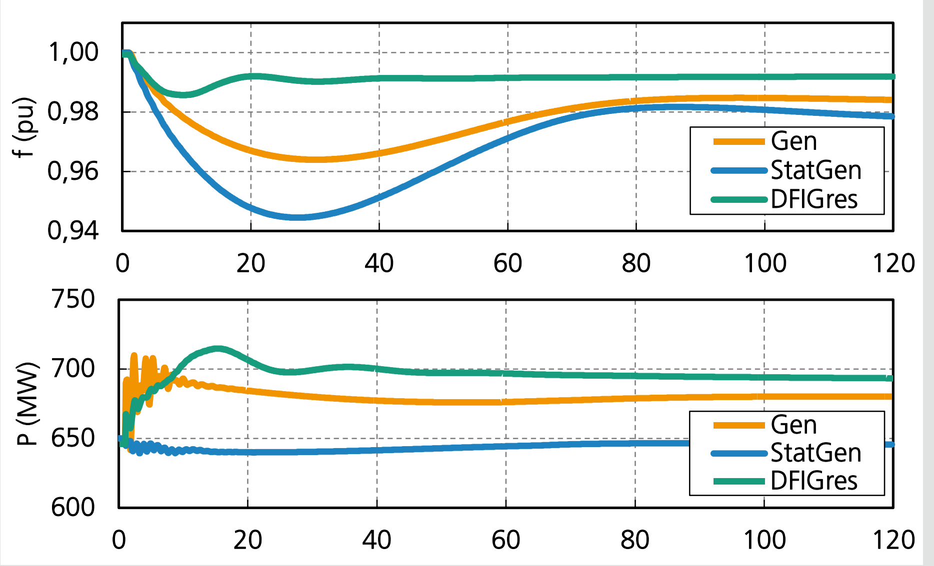
Pictures from: Schittek: Augmented block diagram model for investigating primary-control performance at low inertia, Master's thesis, Fraunhofer IWES, 2017. In Progress.

Frequency control in power systems with high penetration of renewables (III/III)

- Frequency supporting functionalities of RES
  - Modelling of wind turbines with frequency supporting functionalities (FSF)
  - Study cases in power system models
- Example: IEEE 39 bus system, Generator outage, RES w/o FSF (StatGen, DFIGres)







See also: Mende, Hennig, Akbulut, Becker, Hofmann: Dynamic Frequency Support with DFIG Wind Turbines – A System Study', IEEE EPEC, Ottawa, 2016. DOI: 10.1109/EPEC.2016.7771694.

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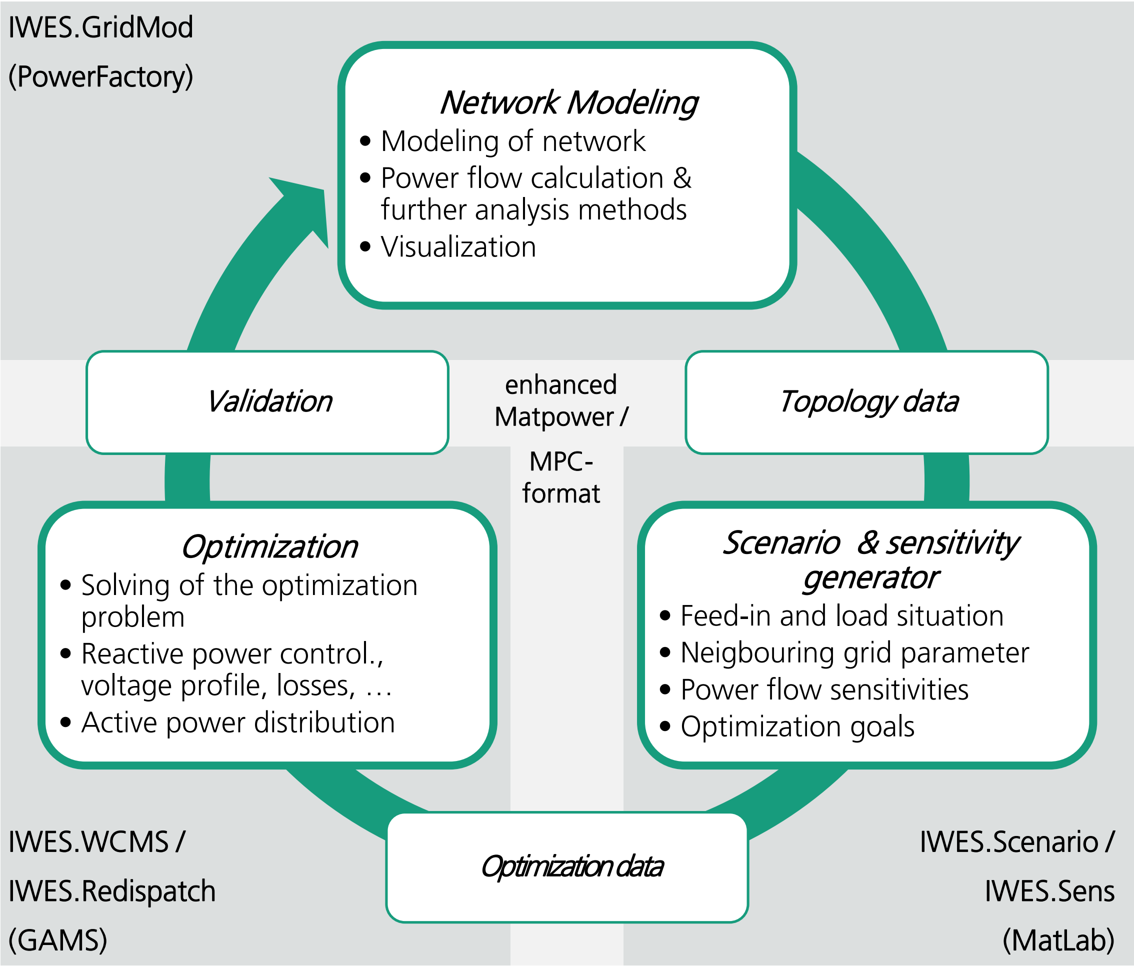
Optimized grid operation in power systems with high penetration of renewables (I/III)

- New challenges in grid operation due to increased flexibility of generation and demand
  - Volatile RES generation profiles
  - Changing power flow patterns
  - Increased ramping requirements (e.g. as known in the US as „Duck curve")
  - Increased demands on coordination between TSO & DSO due to changed generation location
    - wind on HV-level
    - solar pv on MV- and especially LV-level

- Optimization approaches allow facing different challenges
- Example:
  Implementation of optimization algorithms in flexible modules to with possibility of result validation
  - Network modeling (PowerFactory)
  - Scenario / Sensitivity generator (MatLab / Matpower)
  - Optimization environment (GAMS)

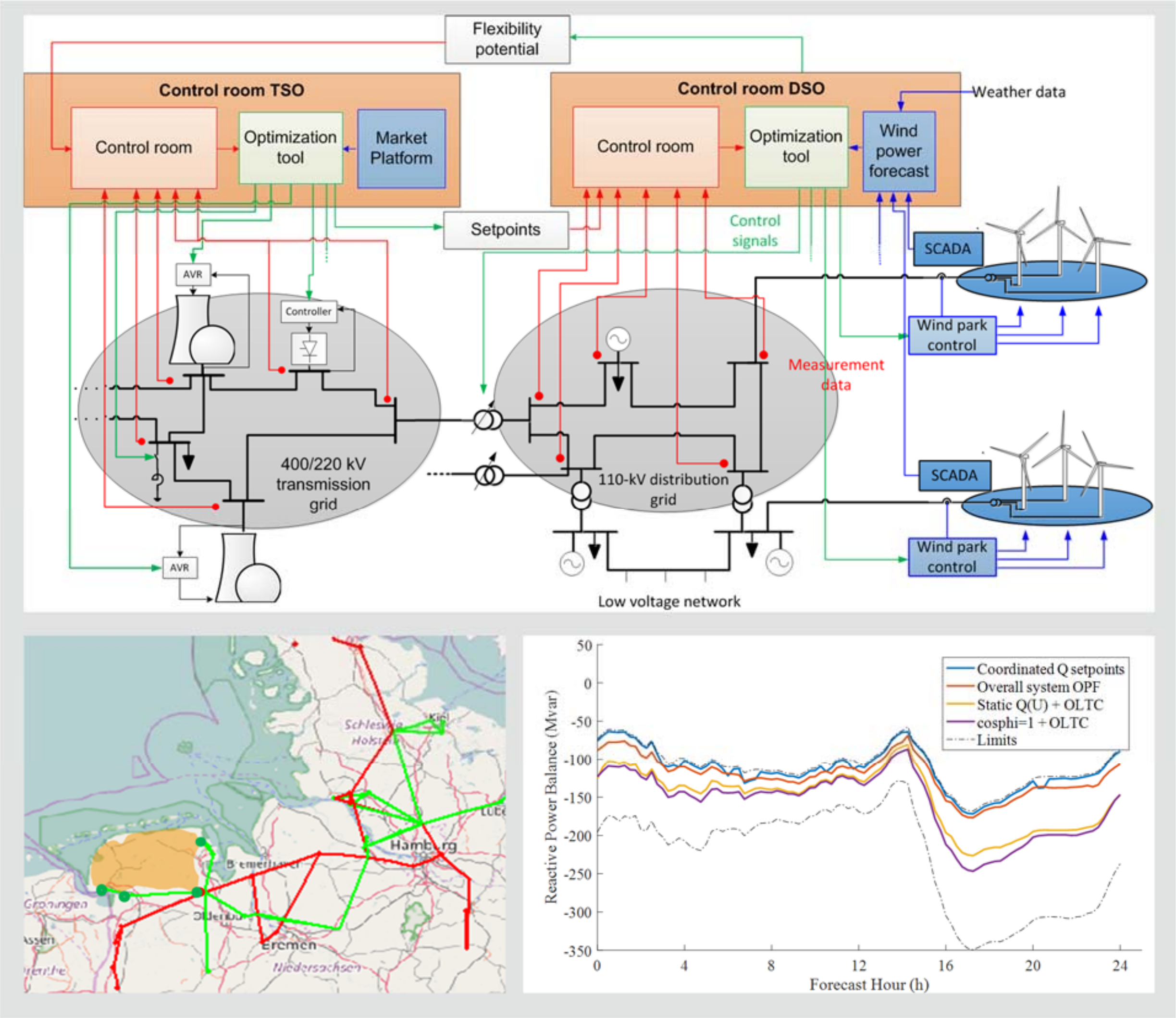


Optimized grid operation in power systems with high penetration of renewables (II/III)

- Example:
  Increased demands on optimization and coordination between TSO & DSO due to changed generation location

- Implementation of optimization tool to coordinate and enhance TSO-DSO-interface
  - Optimization on DSO-level to provide flexibility potential at interface to TSO
  - Optimization on TSO-level using own and TSO-flexibilities and giving setpoints to DSO
  - DSO uses RES flexibilities to provide setpoints and new flexibility potentials

- Study case
  - Larger DSO area in northern Germany with high share of RES
  - (Part of) Northern Germany Transmission Grid
  - Reactive power provision in given limits using different approaches



Pictures from: Sala: Optimal Reactive Power Management of Wind Farms for Coordinated TSO-DSO Voltage Control, Master's thesis, Fraunhofer IWES, 2017. In Progress.

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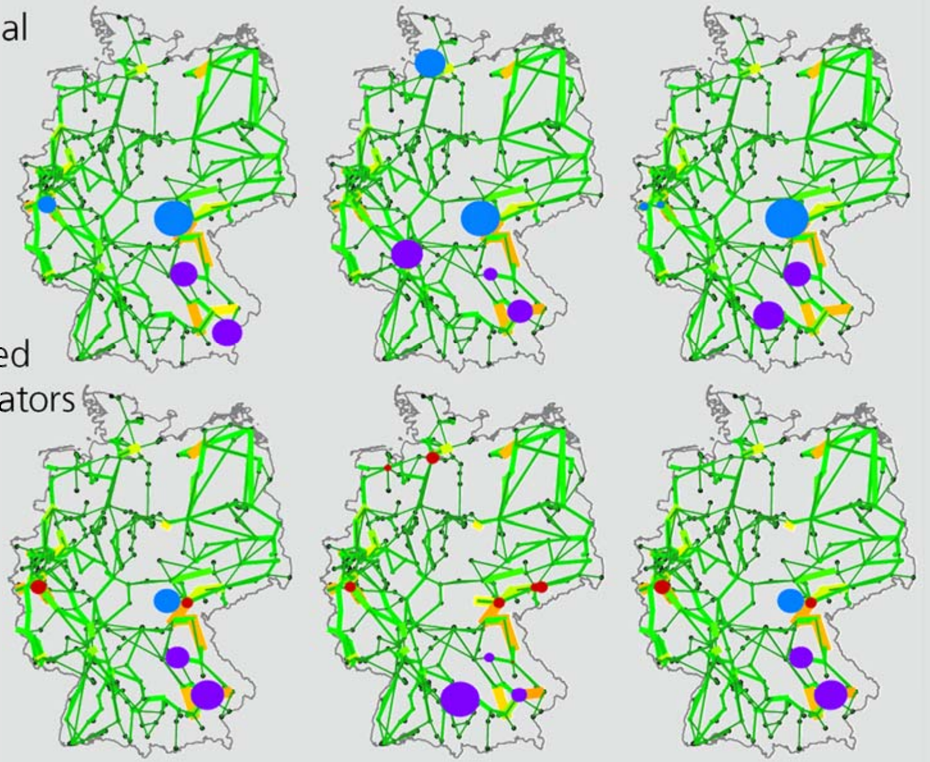
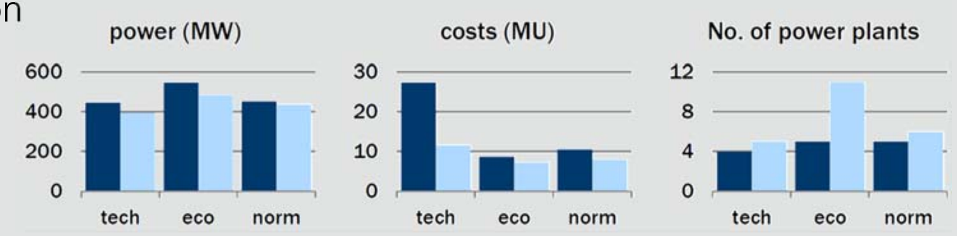
Optimized grid operation in power systems with high penetration of renewables (III/III)

- European liberalized energy market
  - Energy trading doesn‘t take grid restrictions into account → „Trading on a copper plate“
  - Possibility of large power transmission needs
- RES often far away from load centers
  - RES installation in rural areas with low load
  - Example: Offshore wind energy
- Modular optimization tool to find optimal solution for „re-dispatching“ power plants
  - Optimization of costs, powers or multiobbjective goals including several optimization criteria
  - Possibility to freely include flexibilities of generation and load units
- Example:
  - Redispatch according to overloading of lines
  - Scenario w/o incorporating wind power plants
  - Redispatched powers (tech), costs (eco) and combined optimization using normalization approach (norm)

- Conventional
- Incl. assumed wind generators



- Comparison



See also: Akbulut, Mende: Congestion Management Strategy in Combined Future AC/DC System, Fraunhofer IWES, 2017. In: IRP-Wind: Deliverable 81.5 – Congestion Management in combined future AC/DC System.

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Restoration in power systems with high penetration of renewables

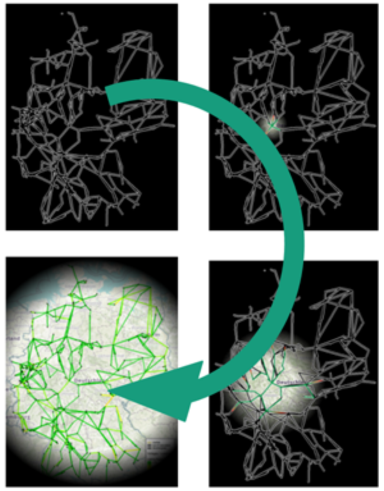
- Integration of renewable generators in system restoration concepts: Project Netz:Kraft

- Classical restoration
  - Opening and enhancing grid island
  - Start of large conventional power plants
  - Provision of loads
  - RES not considered in restoration concepts or are strictly limited/shut down

- Enhanced concepts including RES
  - Integration of renewable generators in system restoration concepts
  - Improved planning using forecasts (renewables and load)
  - Increased flexibility and possibilities through frequency supporting functionalities and reactive power capabilities of modern renewable generators
  - Increasing of robustness of restoration paths

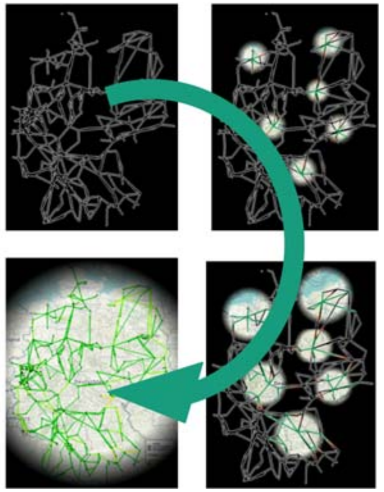
Concepts for system restoration

- (conventional) black start units
- Large (conventional thermal) blocks
- Loads



Concepts for system restoration with RES

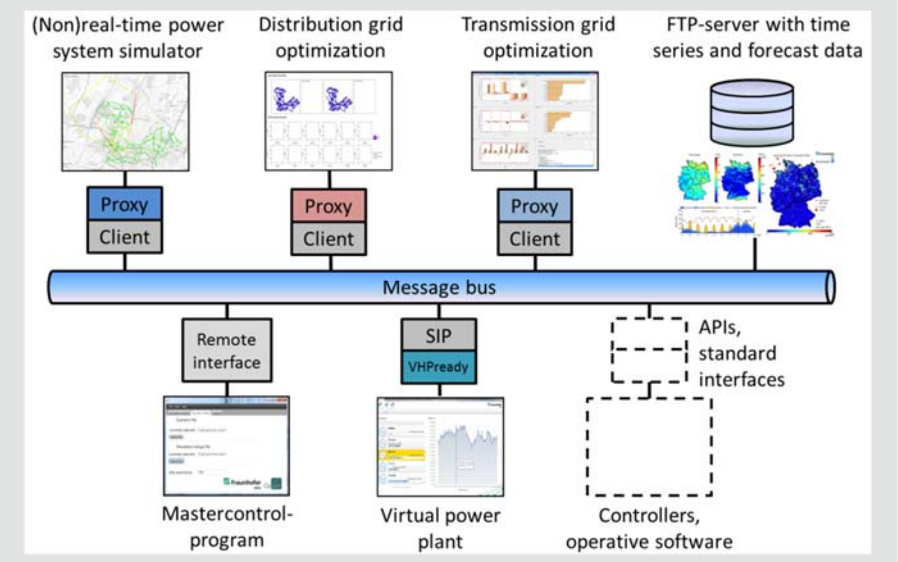
- (conventional) black start units
- Large (conventional thermal) blocks
- Loads
- Renewable generators



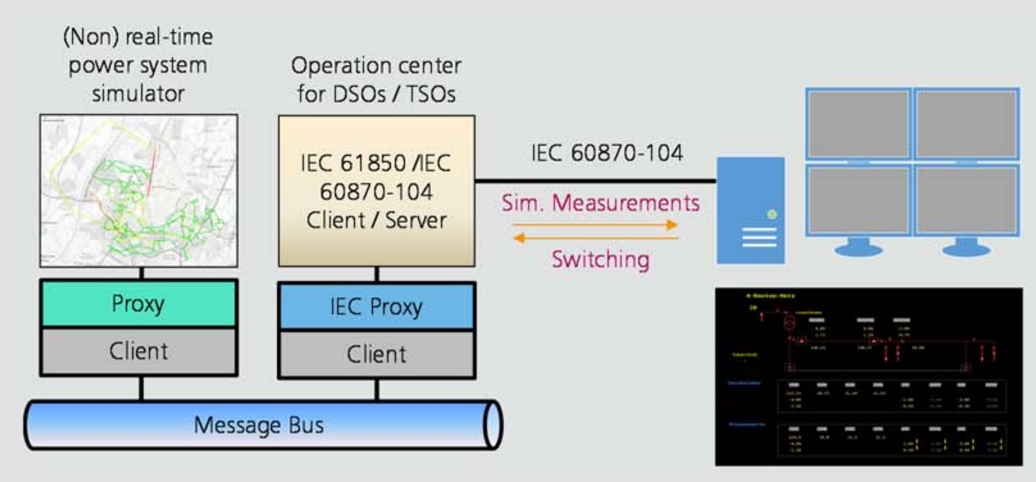
See also: https://www.energiesystemtechnik.iwes.fraunhofer.de/de/projekte/suche/laufende/Netzkraft.html. Accessed on September 25, 2017.

Demonstration of solutions - OpSim

- Test- and simulation-environment for grid control and aggregation strategies
- Applications ranging from developing prototype controllers to testing operative control software in the smart grid domain
- Features
  - APIs to connect various simulation tools such as Opal-RT, pandapower, PYPOWER, MATPOWER or custom scripts in Matlab, Java and Python.
  - Standard interfaces: VHPready, CIM and IEC 61850.
  - Scalable environment - runs on desktop PCs and clusters.
  - Interfaces for hardware-in-the-loop (HIL) tests.



- Example
  - Implementation of DSO / TSO operation center
- Further Information
  - www.OpSim.net



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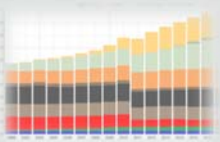
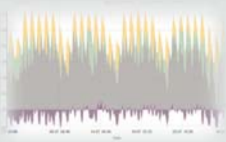
Summary

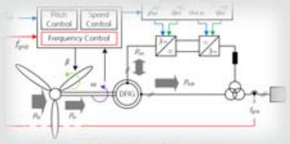
- Transition in electrical energy systems lead to various challenges
  - Sharp increase in installations as well as in power provision
  - Varying penetration of renewables & conventional generation



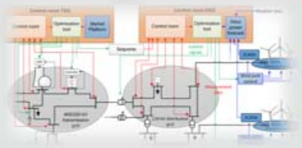


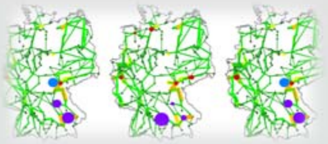
- Renewables need to participate in system services such as
  - frequency control
  - voltage control
  - system operation
  - system restoration

- Frequency control as challenge due to reduced rotating masses
  - Challenges for modelling
  - Frequency supporting functionalities and power reserves by RES

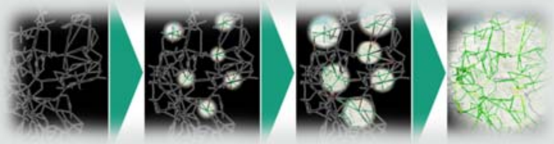


- Optimization and coordination at the interface of DSO / TSO
  - Flexible optimization implementations and algorithms
  - Improved solutions in grid operation and congestion management





- Integration of renewable generators in system restoration concepts
  - Increasing of flexibility and robustness of restoration paths
  - Using frequency supporting functionalities and reactive power capabilities of RES



- Demonstration of system operation strategies and optimization algorithms
  - OpSim environment

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Agenda

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Training and Knowledge Transfer at Fraunhofer IWES (I/II)

- We offer our "know-how pool" in different arrangements.
- Our target groups include decision-makers, specialists and executives from business and administration as well as students.
- With our IWES experts and with our broad network of experts from industry, consulting and universities, we provide basic and detailed knowledge on the use of renewable energies.

Characteristics

- National as well as international trainings / workshops
- Day or week seminars regarding various aspects of renewable energy sources
- Online master program and certificate programs *Wind Energy Systems*
- Customer-oriented specific trainings on demand

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Training and Knowledge Transfer at Fraunhofer IWES (II/II)

Example: Online-training for engineers of TSOs

- Wind and Solar Energy Sources Integration in Power Systems
  - 6 Modules
  - 50 lessons

Introduction: Basic Concepts of Wind and Solar PV Energy	Market Models and System Balancing	Planning considering Wind and Solar PV Power Integration	Long-Term Planning
4 lessons	6 lessons	12 lessons	10 lessons
Wind and Solar PV Forecasting	Operational Analysis	Homework / Exam	Certificate
10 lessons	8 lessons		

Thank you very much for your attention!

I	What is Fraunhofer-Gesellschaft and Fraunhofer IWES?	
II	Developing Long-Term Scenarios with High Levels of Decarbonisation	(Philipp Härtel)
III	Current Challenges of the Integration of Large Amounts of Wind and Solar Power	(Dr. Malte Siefert)
IV	Technical Challenges and Prospects in Power Systems with High Penetration of Renewable Energies	(Denis Mende)
V	Training and Knowledge Transfer at Fraunhofer IWES	

Thank you very much for your attention!

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