DANISH EXPERIENCES ON MARKET BASED INTEGRATION OF WIND POWER

April 2019

Peter Jørgensen, Vice President, Associated Activities

AGENDA

- Introduction to Energinet – the Danish TSO for electricity and gas
- Market based system operation with high shares of wind power
- Toolbox for efficient integration of variable renewable energy
- Towards a fossil fuel independent energy system by 2050

- Visit to Energinet's control center - 13:30-14:00 in 2 groups

ENERGINET

We own and operate the overall electricity and natural gas transmission system in Denmark.

Our tasks are to integrate renewable energy and ensure security of supply in Denmark

- Independent public enterprise owned by the Danish Ministry of Energy, Utilities and Climate
- ~ 1.300 employees – 8 locations and headquarter in Fredericia
- Mission to ensure reliable energy for society
- Vision to create balance in a renewable energy system

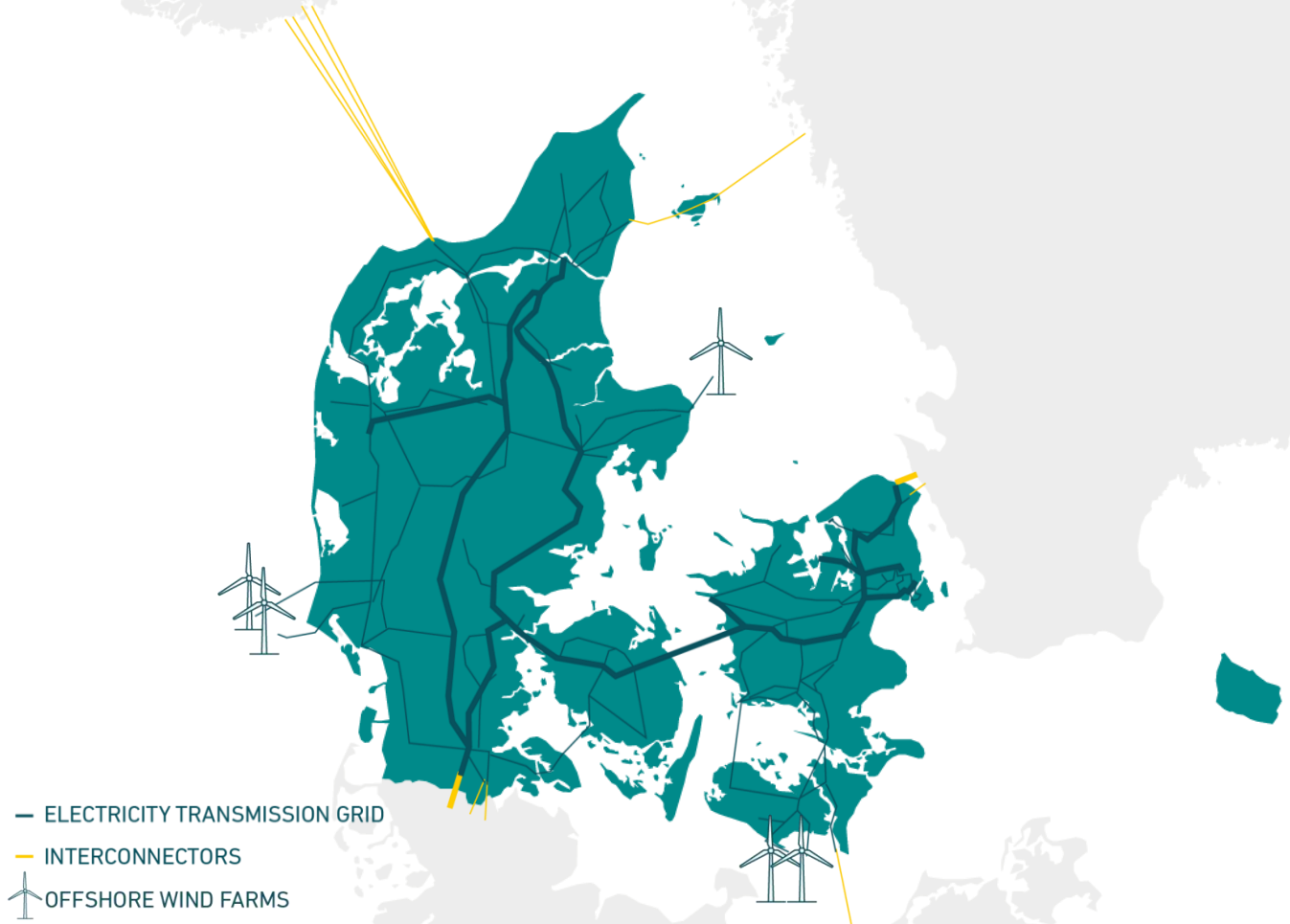
THE DANISH POWER GRID

6,913

km transmission grid

5

International interconnections



GAS GRID

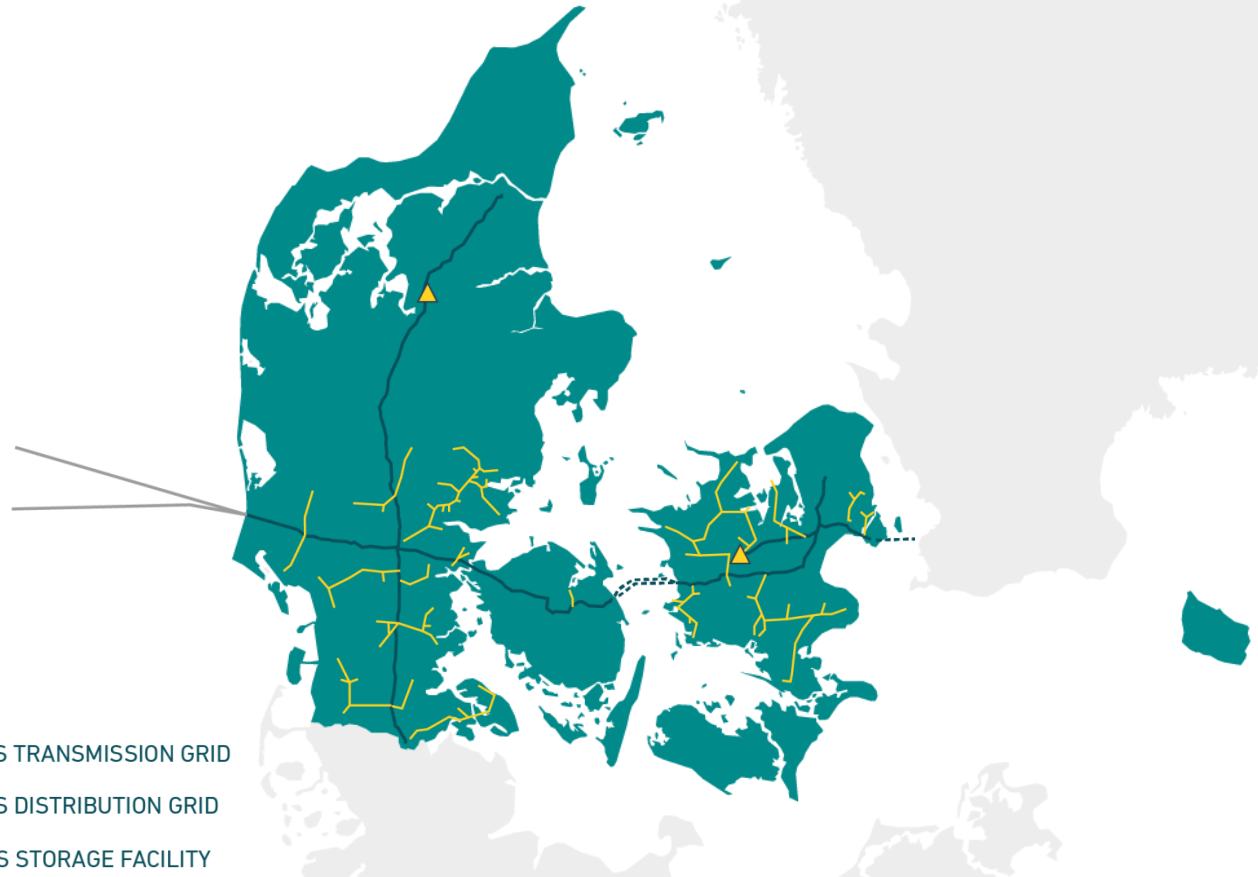
926

km gas pipelines and 2 interconnectors

3,4 billion Nm^3 transported

6,600 KM

Gas distribution network



BALTIC PIPE

- Baltic pipe will expand the gas transmission capacity by up to 10 billion cubic metres per year (Danish gas consumption in 2016 was 2.5 billion cubic metres)-
- Final investment decision in November 2018 and commissioning in October 2022
- Cost estimate € 1.6-2.1 billion equally split between GAZ-SYSTEM and Energinet

ENERGINET'S CORE TASKS

- Ensure short- and long-term security of supply for electricity and gas
- Ensure well-functioning markets for electricity and gas
- Own, operate and develop the gas and electricity transmission grids

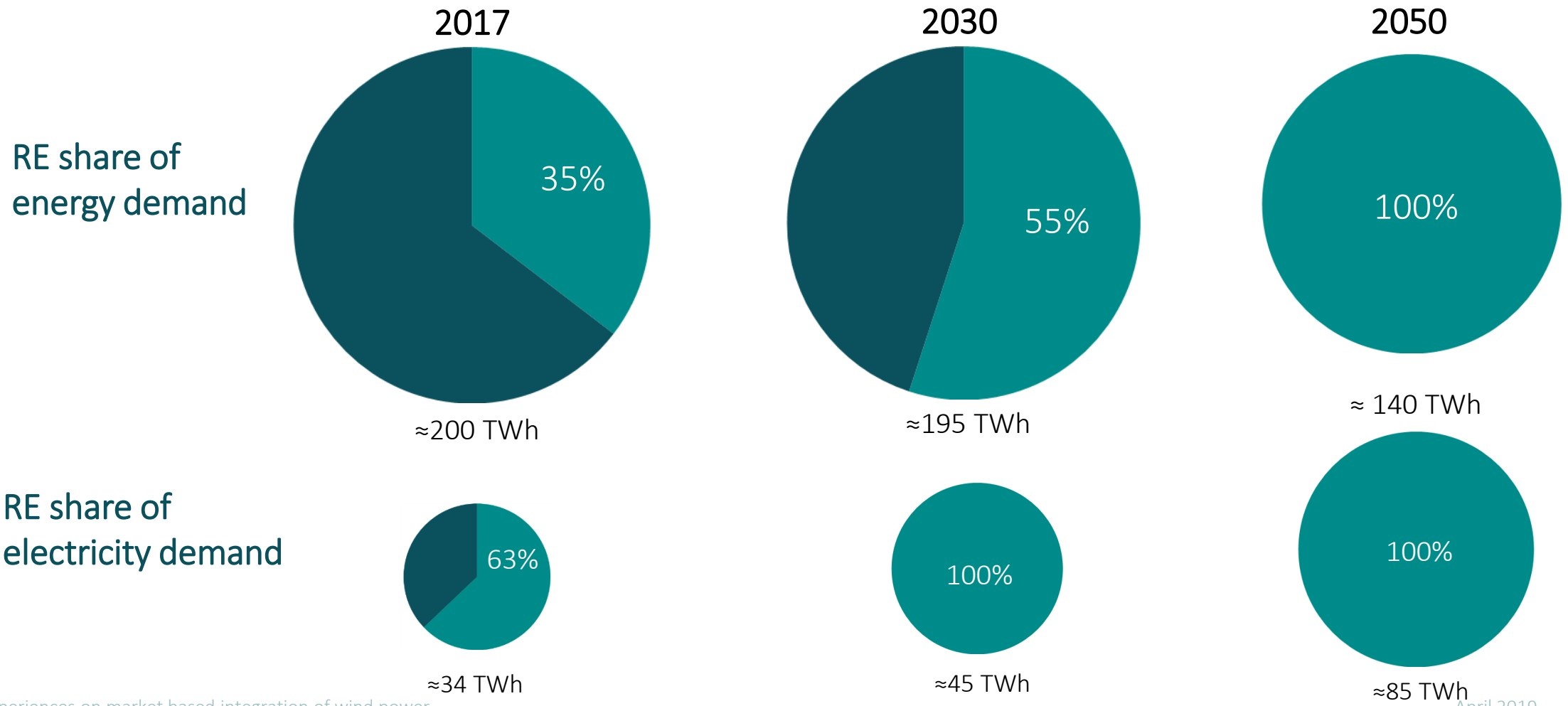
THE ENERGY SYSTEM IN DENMARK IS CHANGING

- By 2020, wind power will constitute 50% of the electricity consumption
- By 2030, renewable energy will constitute 55% of the energy consumption
- By 2050, Denmark will be independent of fossil fuels

Strategic commitments of Energinet:

- Security of supply
- Efficient green transition
- Healthy investment climate

ELECTRIFICATION - INCREASED DEMAND FOR VRE IN THE POWER SYSTEM



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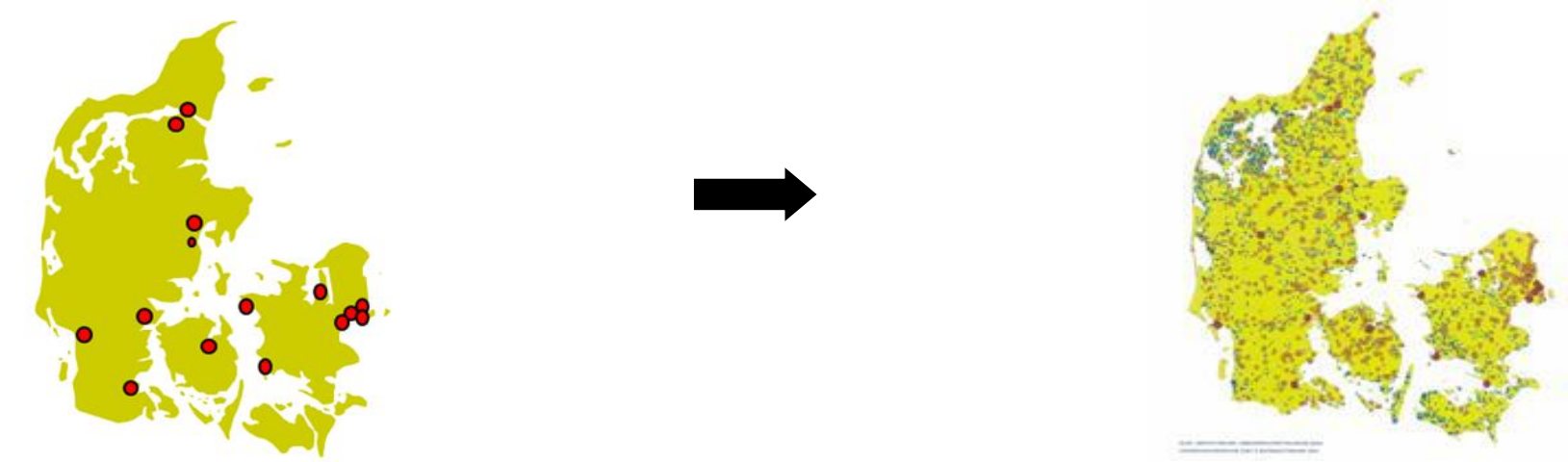
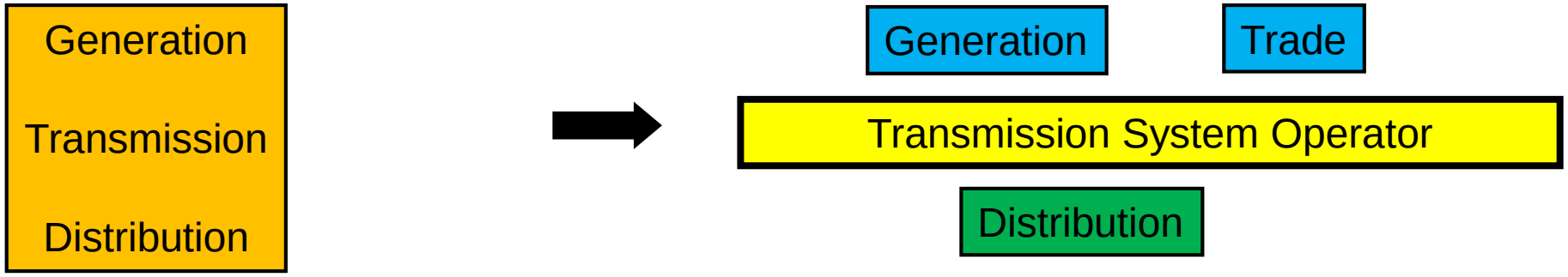
PARALLEL DEVELOPMENTS
- TOWARDS RENEWABLE ENERGY AND OPEN MARKETS



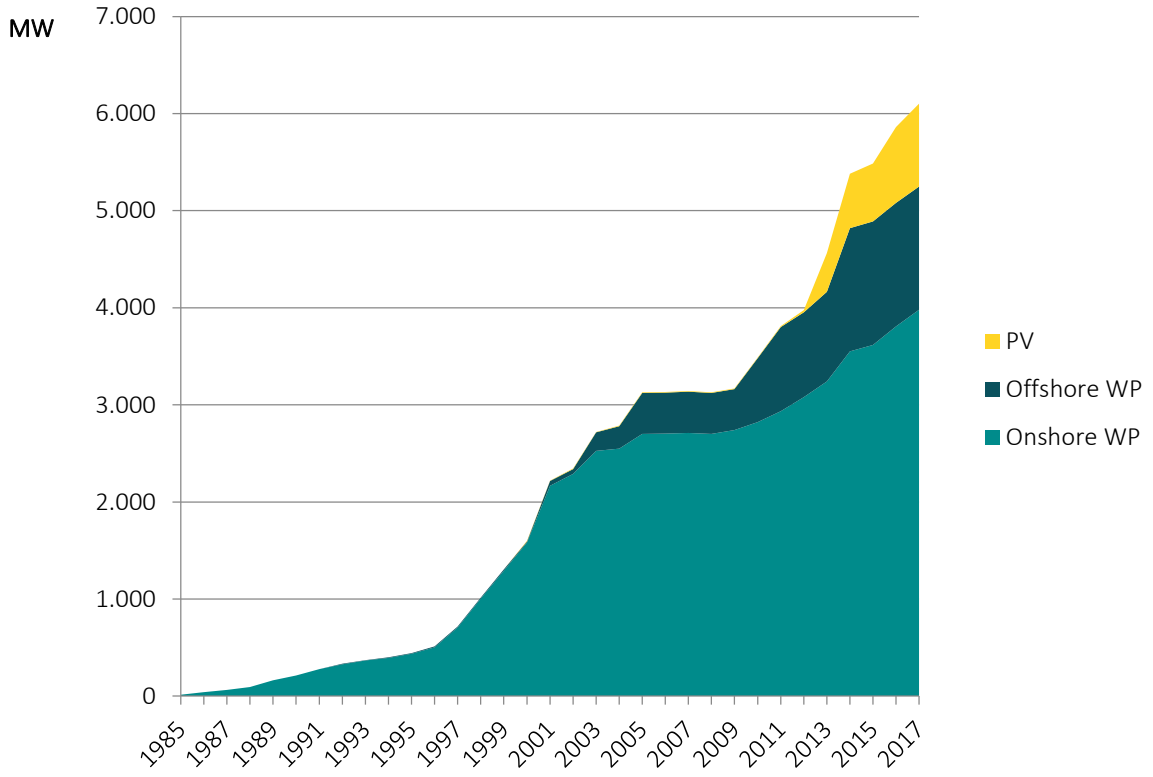
From primary coal fired to local CHP and wind power

2000

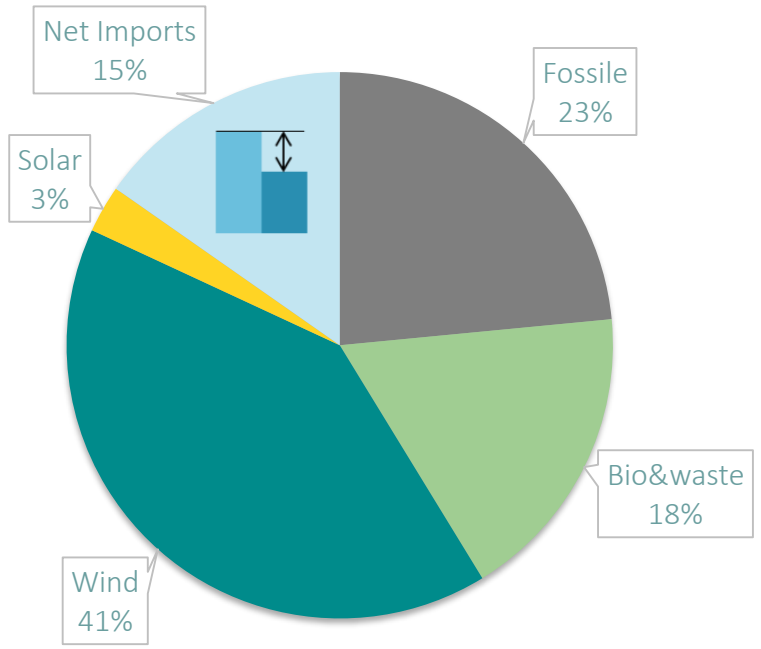
From vertically integrated monopoly to competitive electricity market



DANISH WIND POWER IN 30 YEARS – 41% OF DEMAND IN 2018

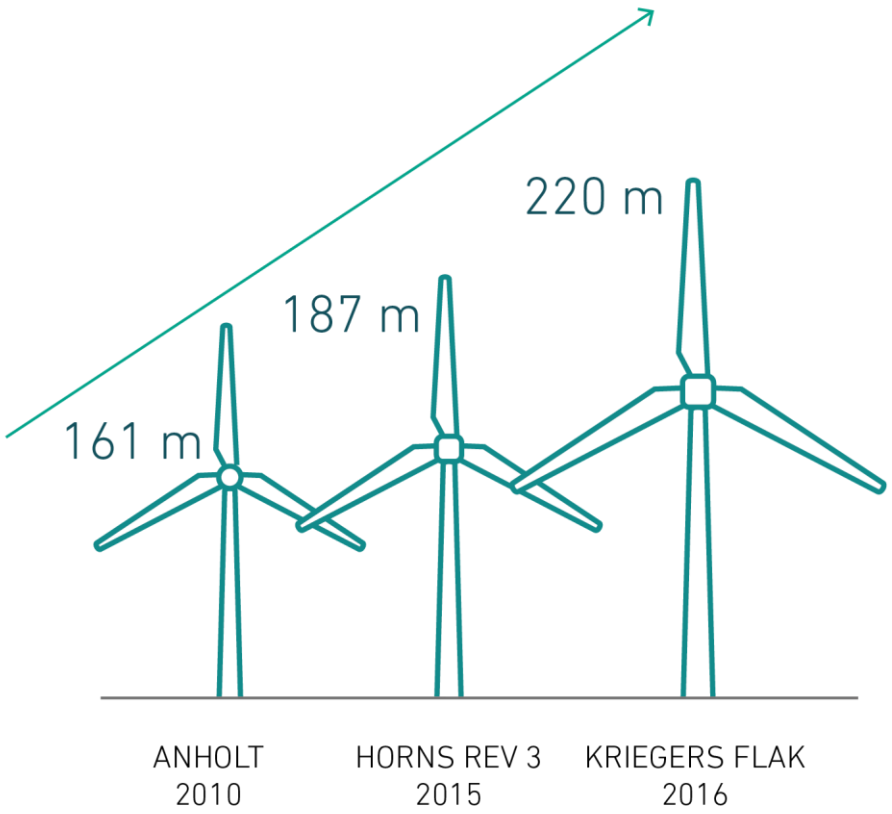


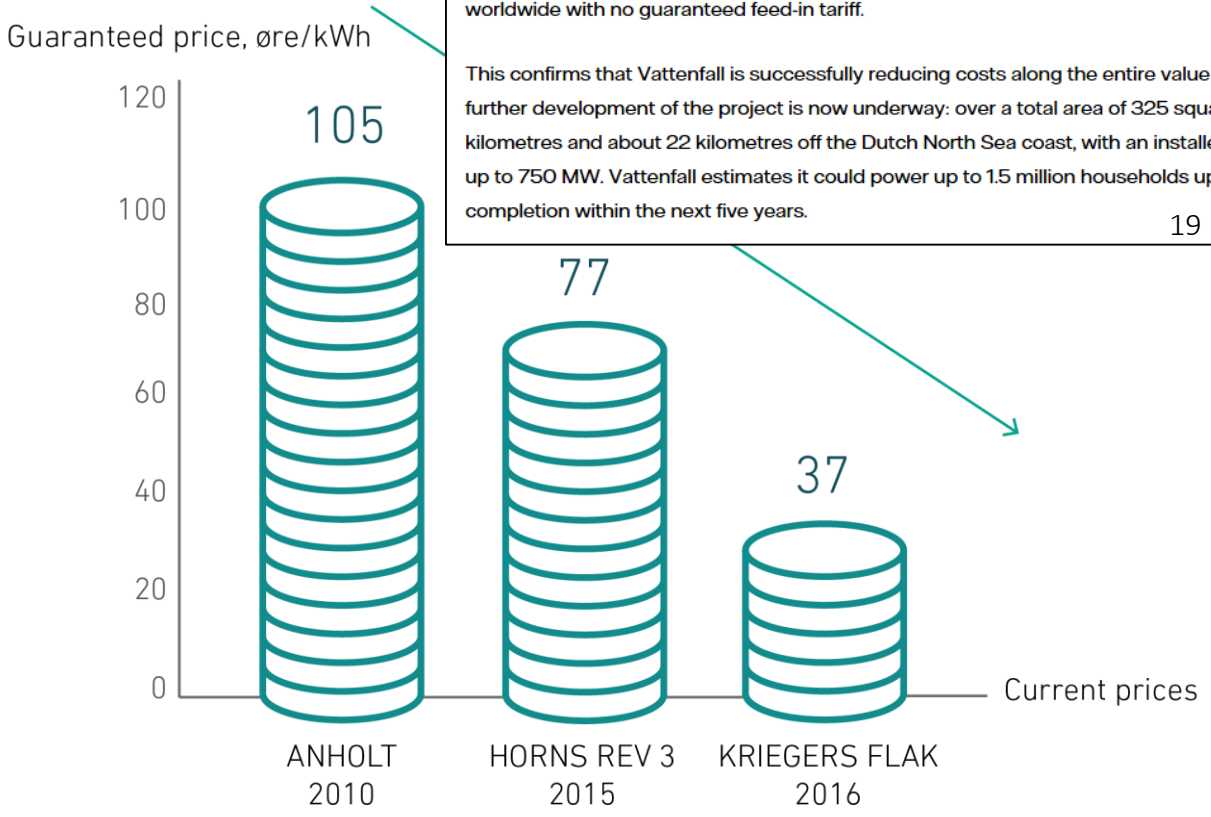
Installed wind and solar power



Energy balance 2018

WIND POWER BECOMES COMPETITIVE





Hollandse Kust, the world's first non-subsidised offshore wind farm

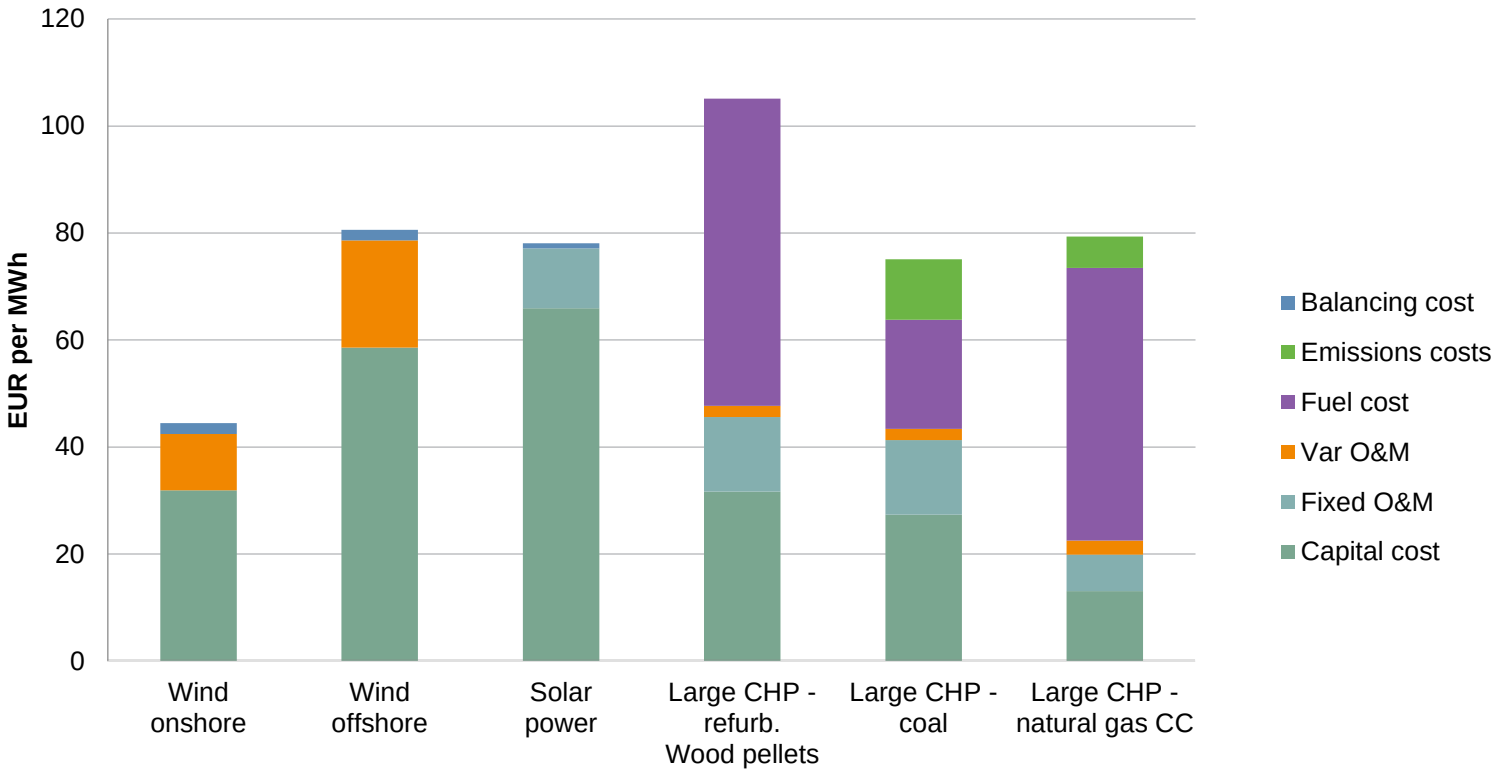
With the Hollandse Kust 1 & 2 offshore wind farm, Vattenfall is not only making a contribution to the sustainability of the Dutch energy system, but has also set new standards in terms of cost efficiency. Vattenfall is developing the first wind farm worldwide with no guaranteed feed-in tariff.

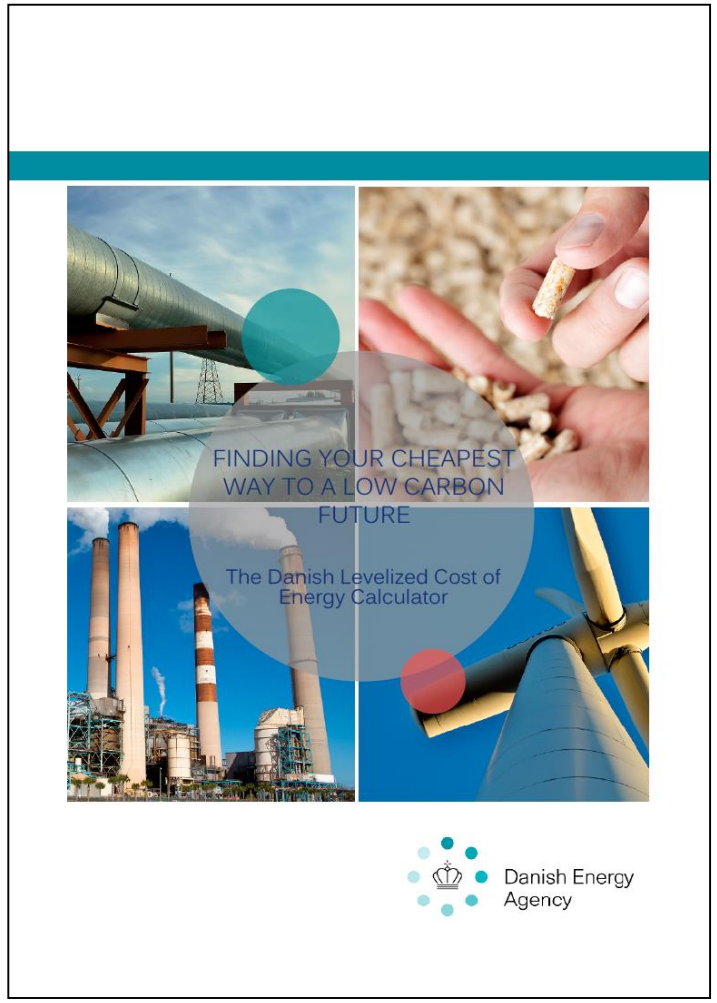
This confirms that Vattenfall is successfully reducing costs along the entire value chain. The further development of the project is now underway: over a total area of 325 square kilometres and about 22 kilometres off the Dutch North Sea coast, with an installed capacity of up to 750 MW. Vattenfall estimates it could power up to 1.5 million households upon completion within the next five years.

19 March 2018

WHY MORE WIND ENERGY?

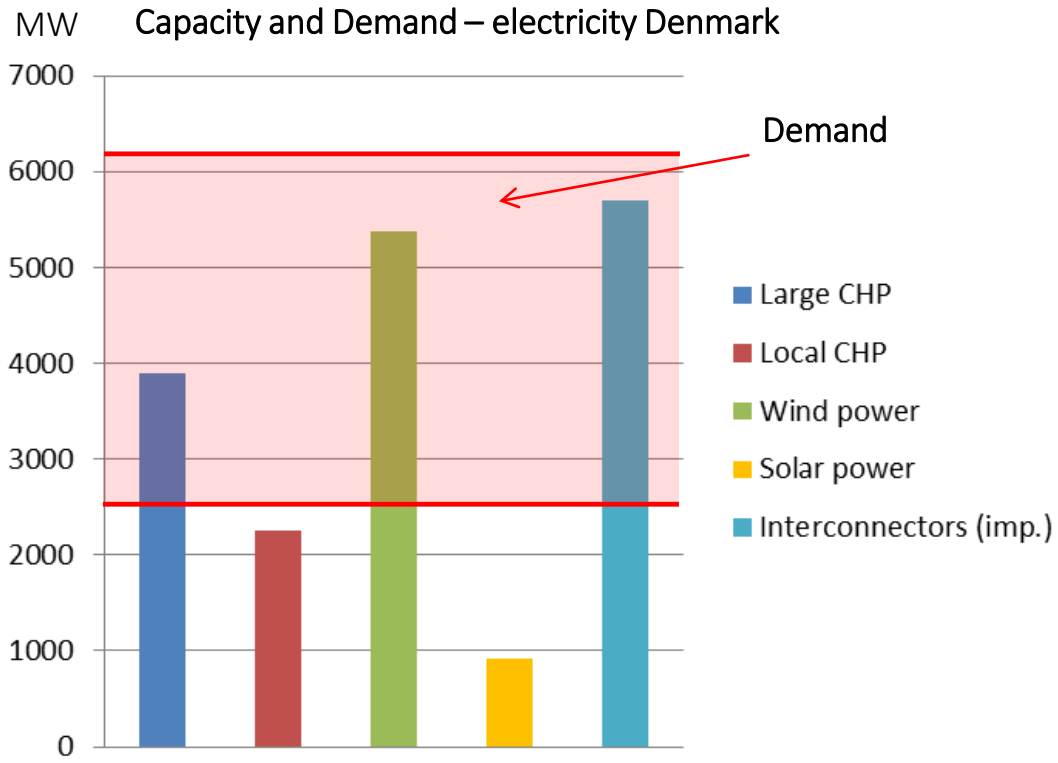
- CHEAPEST OPTION AND STILL GETTING MORE COMPETITIVE (LCOE)

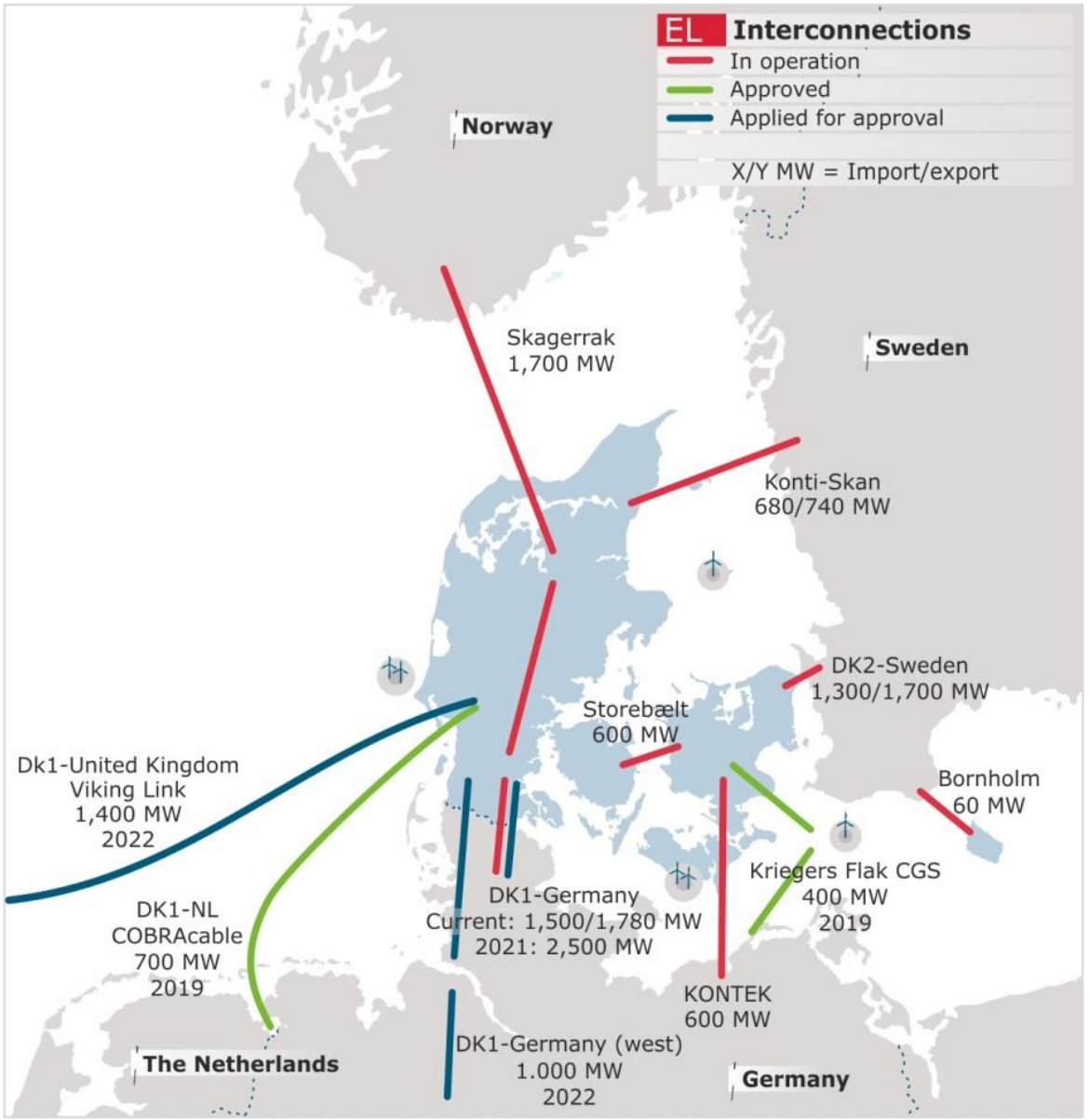




Source: Danish Energy Agency

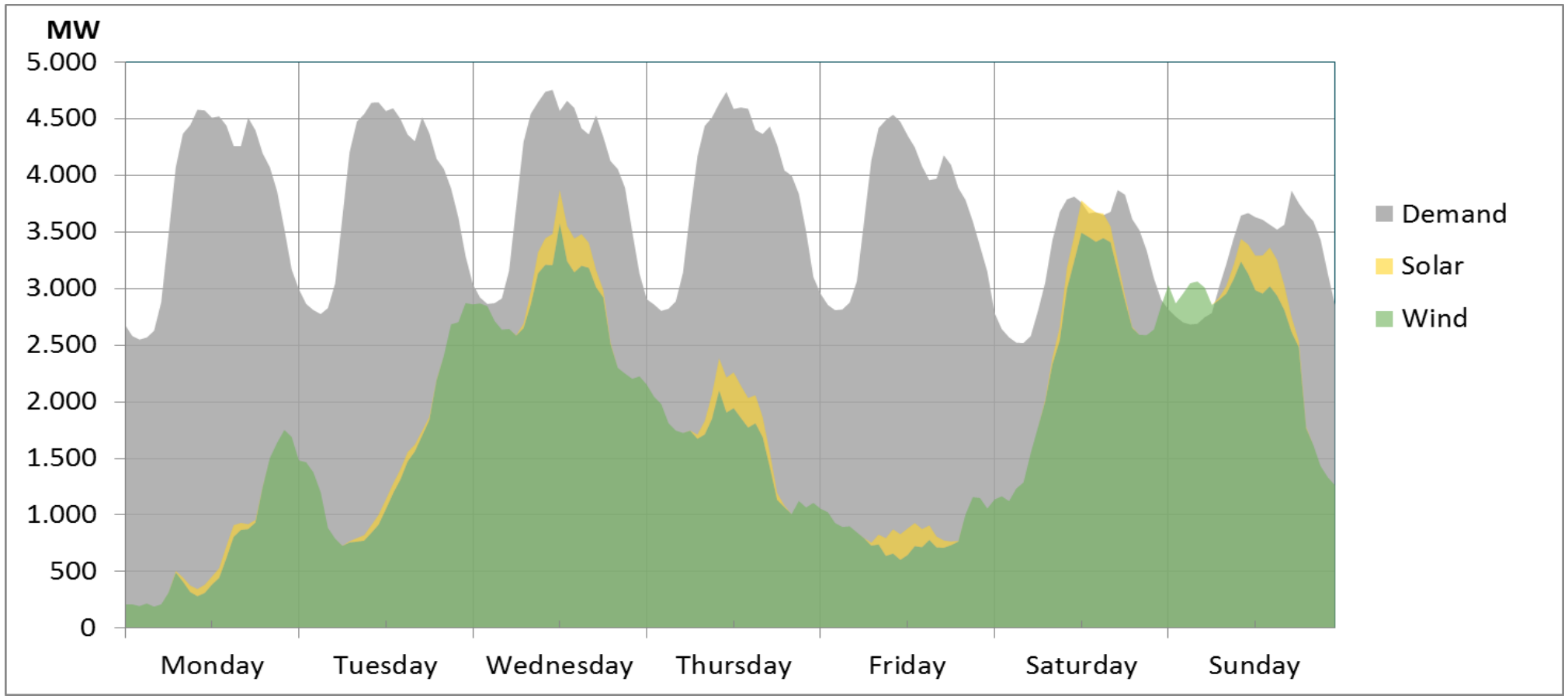
THE DANISH ELECTRICITY SYSTEM - CAPACITY BALANCE





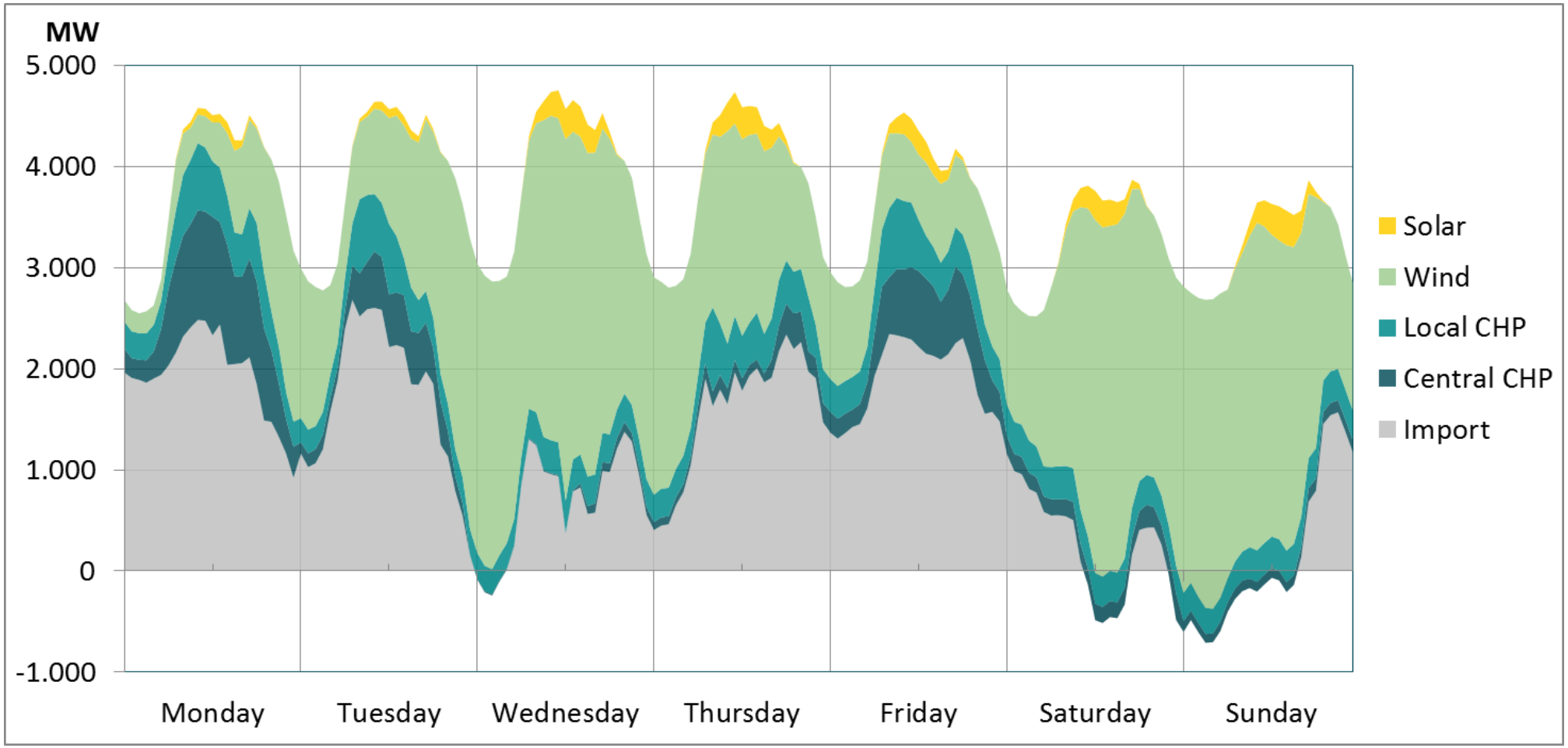
A WEEK IN SEPTEMBER

- 51% WIND AND SOLAR

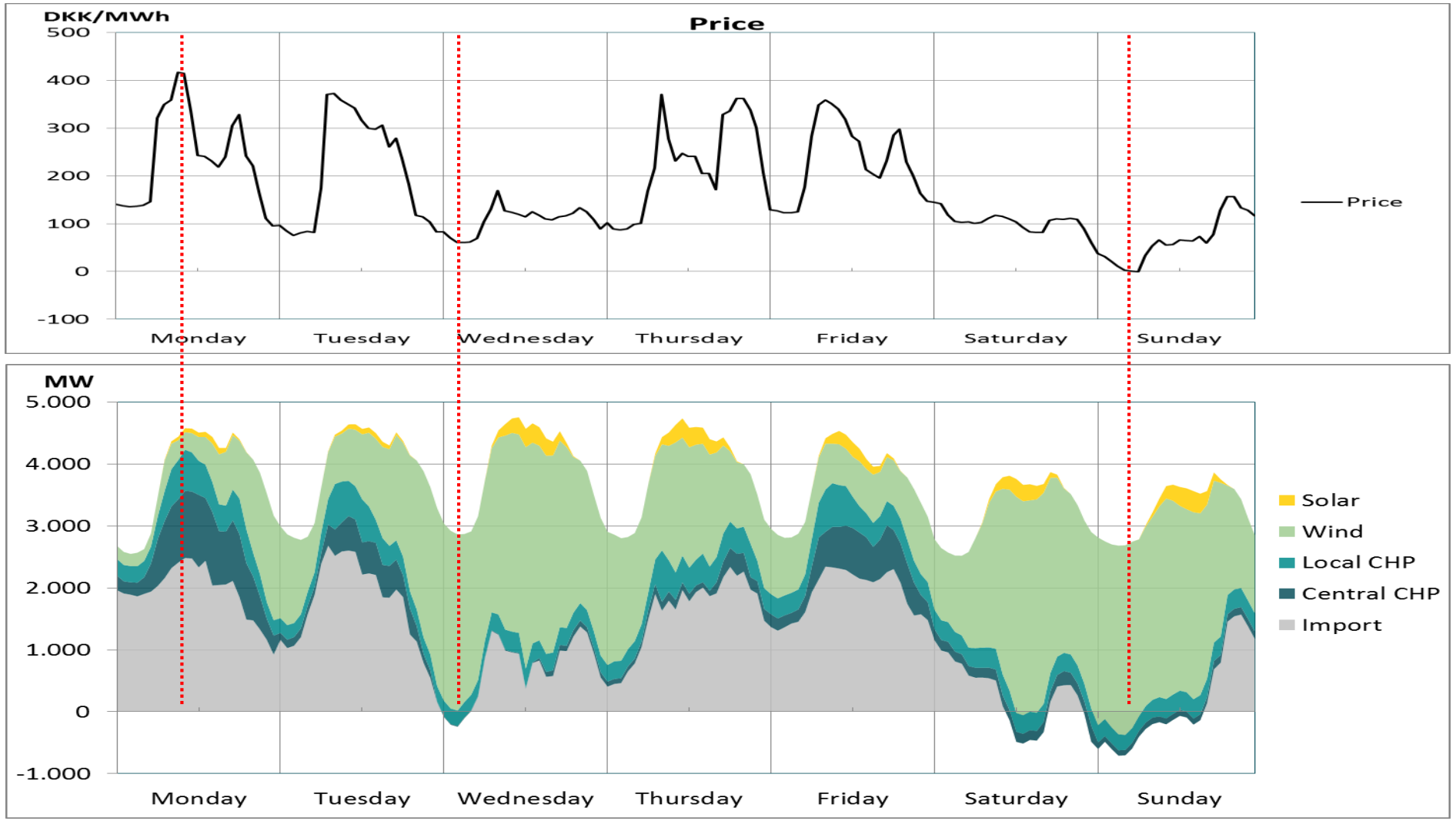


FLEXIBILITY IN THE ELECTRICITY SYSTEM

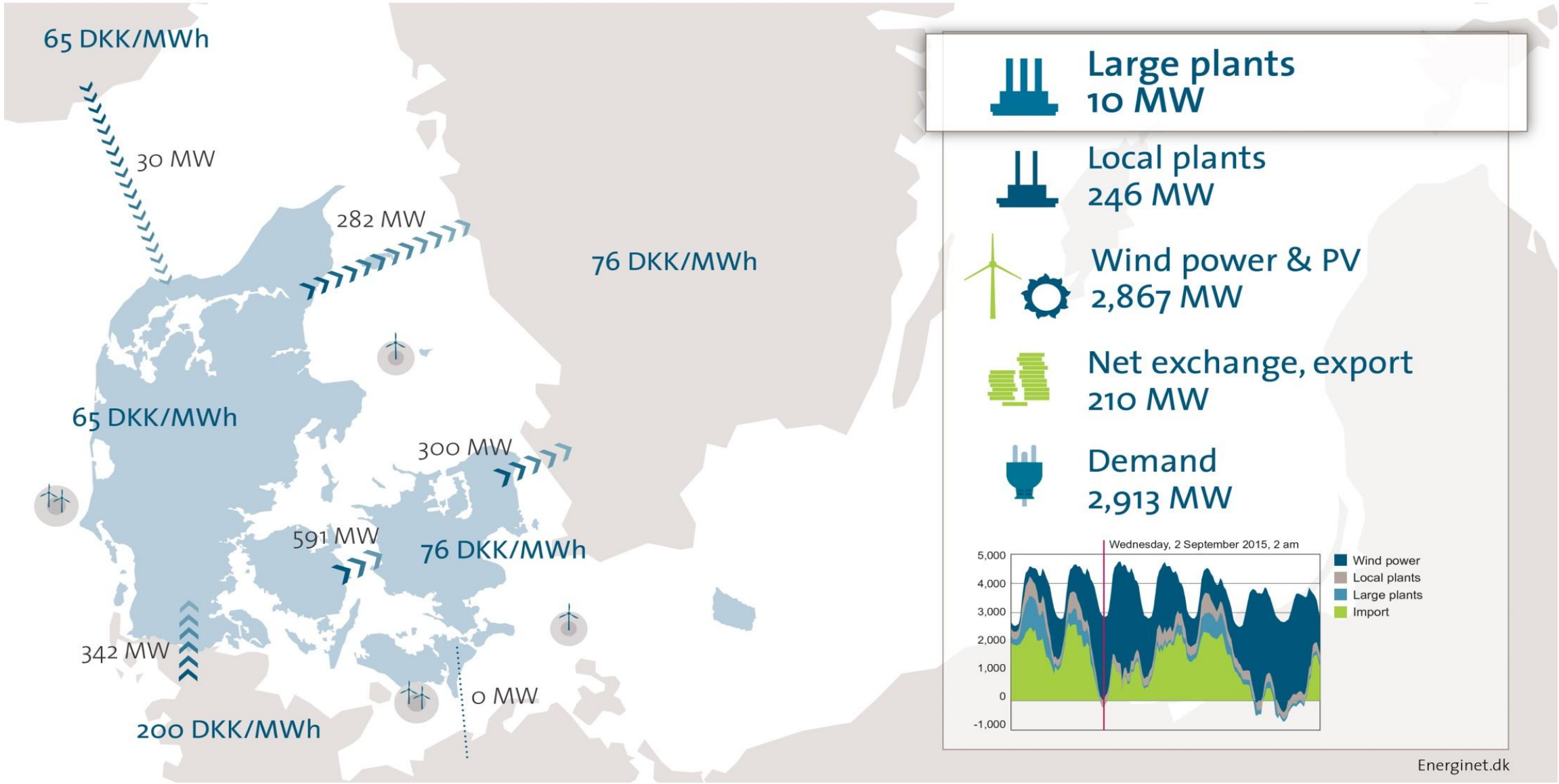
- HOURLY DISPATCH



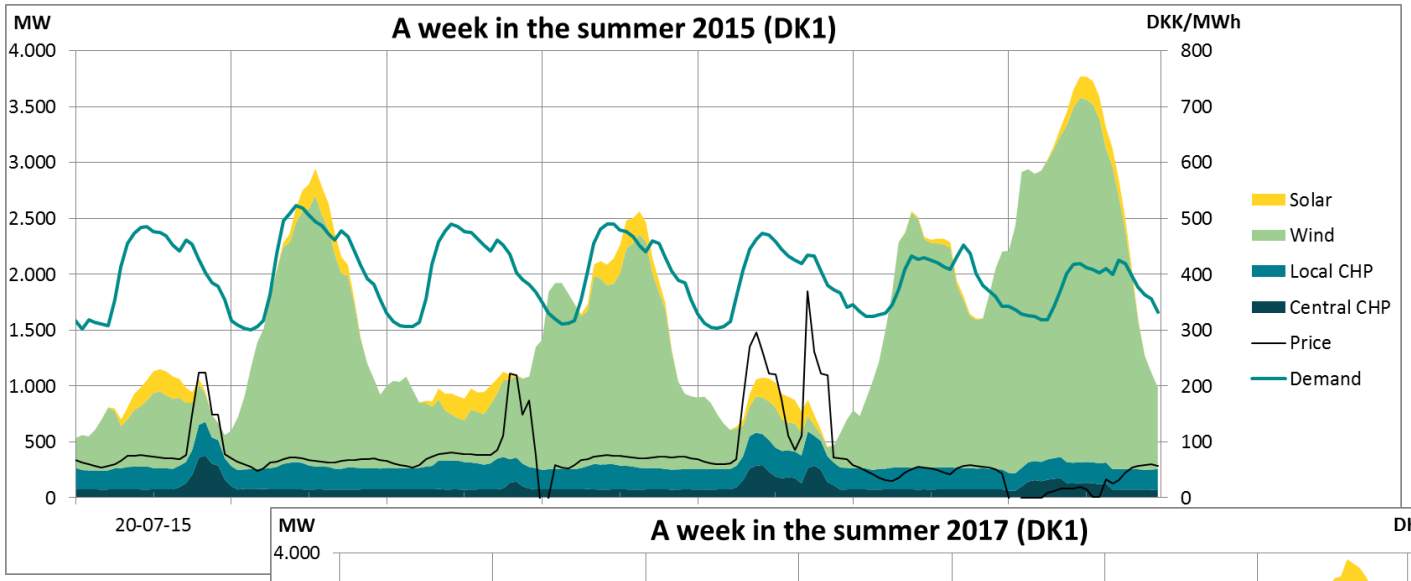
SPOT PRICE, WIND POWER AND MARKET DYNAMICS

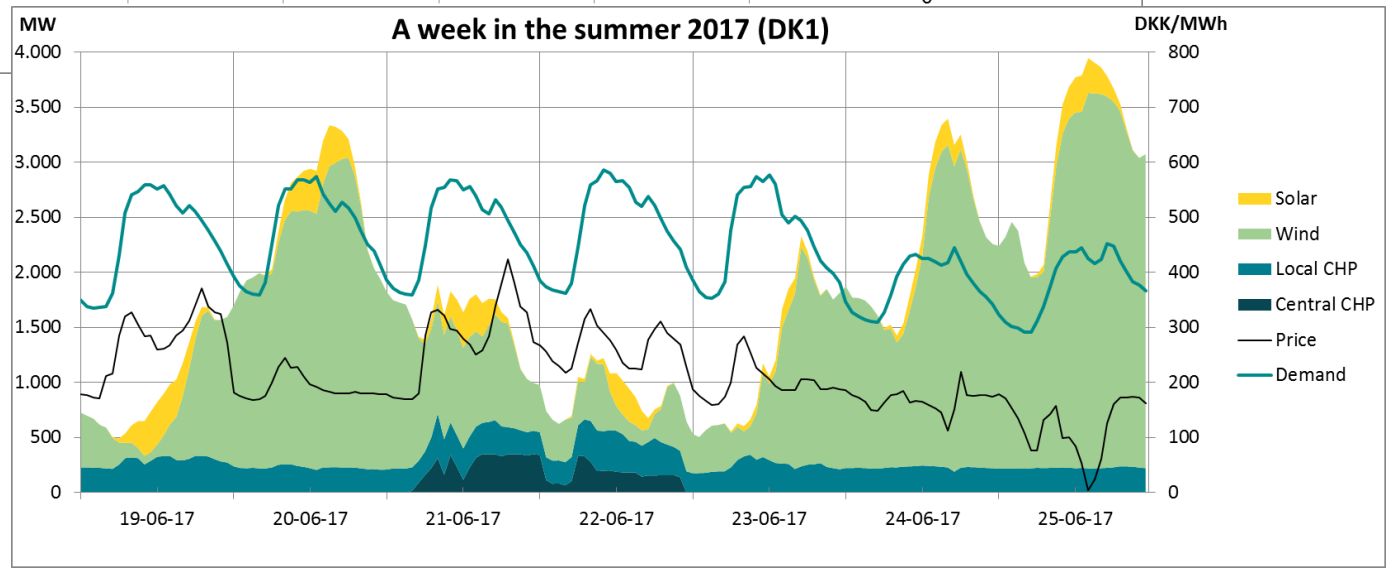


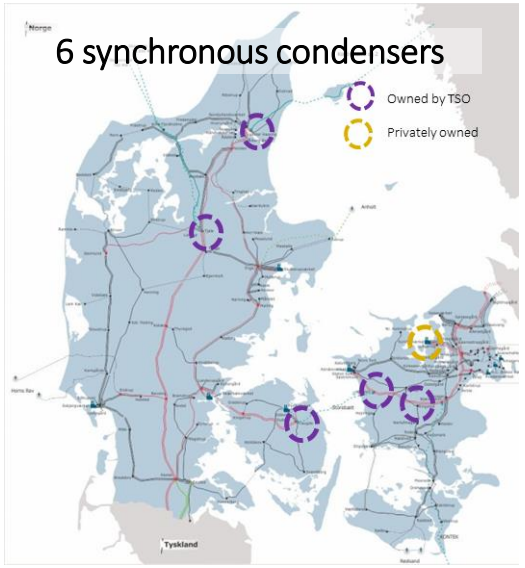
Example 2: High winds – low price - no large power plants



OPERATION WITHOUT CENTRAL POWER PLANTS







OUTAGE MINUTES IN EUROPE

- VERY HIGH SECURITY OF SUPPLY IN DENMARK IN PERIOD WITH INCREASING SHARE OF RENEWABLES

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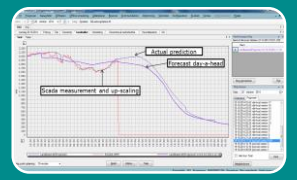
TOOLBOX FOR EFFICIENT LARGE SCALE RES INTEGRATION

Strong transmission grids and interconnectors

International electricity markets

Flexible generation system



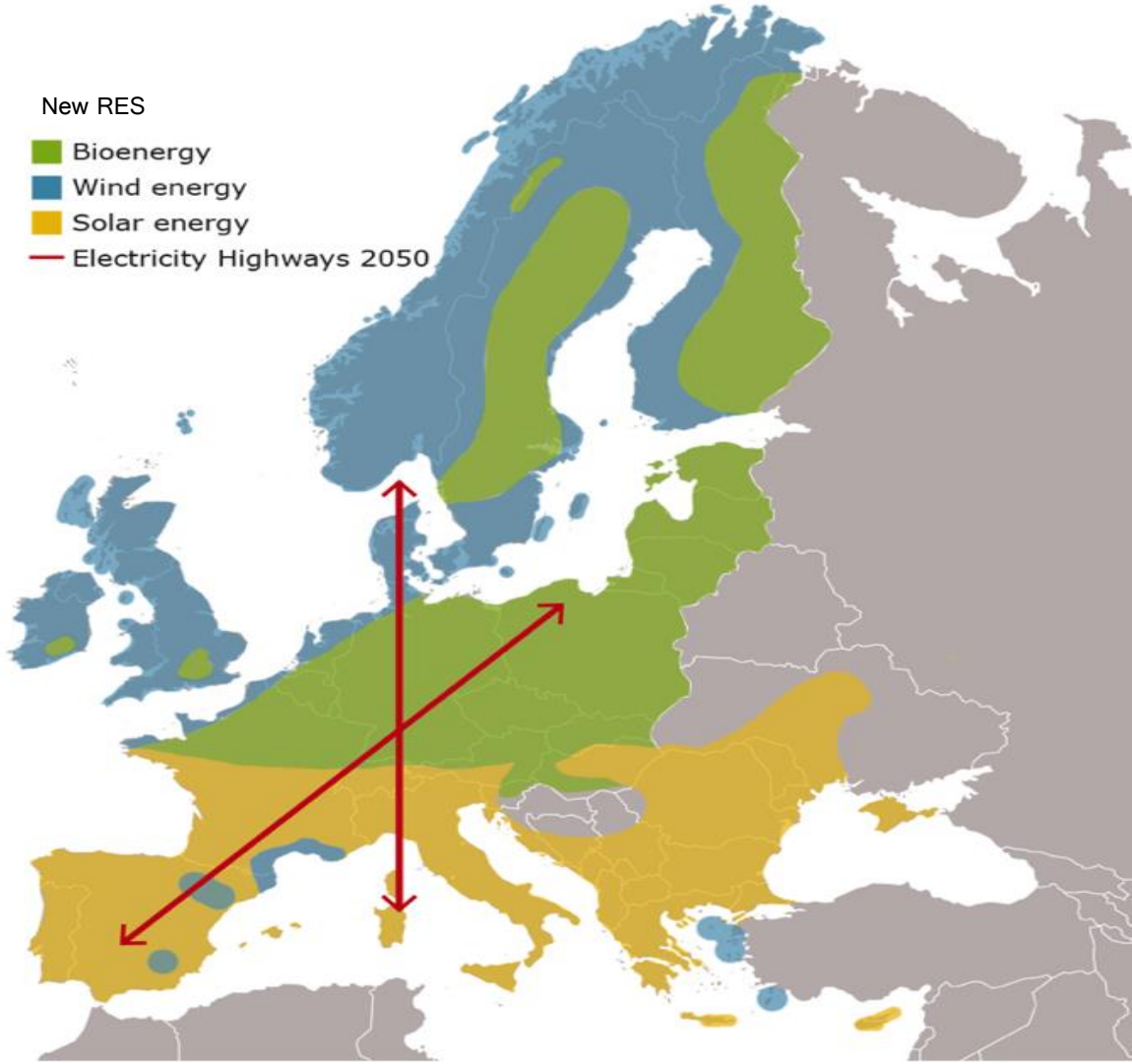
Specialized forecasting and operational planning tools

TRANSMISSION GRIDS

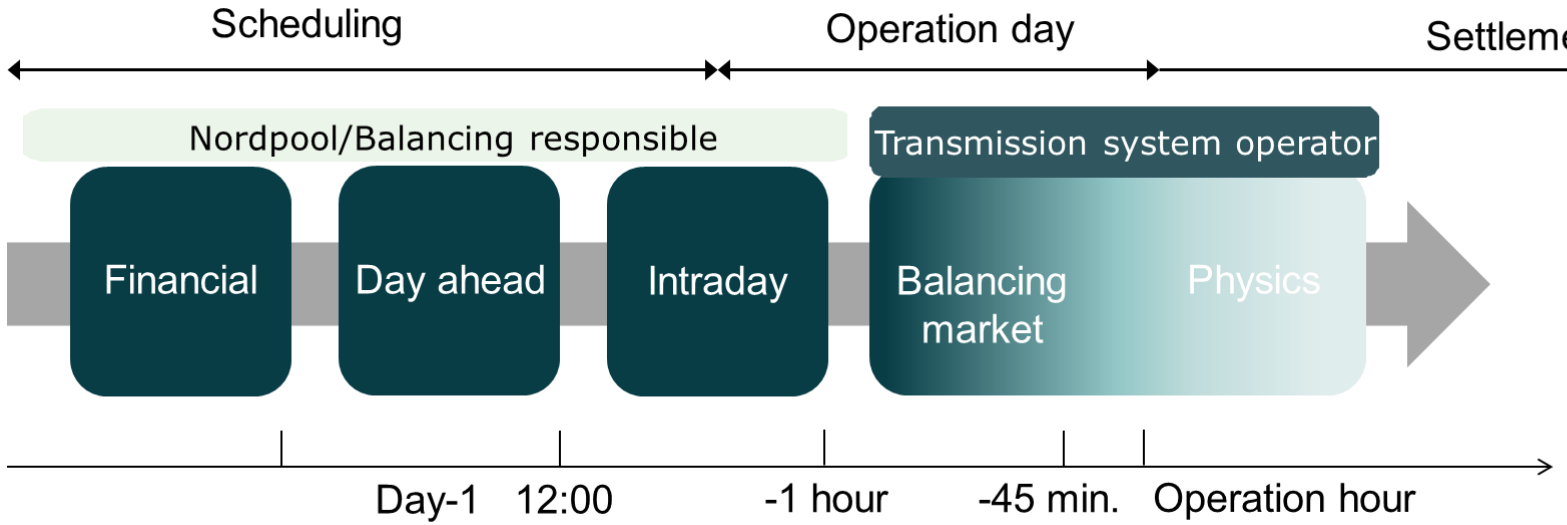
- Variable RES drives grid investments

- Strong grids enable
  - Optimal utilization of generation capacity
    - merit order dispatch
  - Balancing in larger diversified areas
  - Sharing of reserves

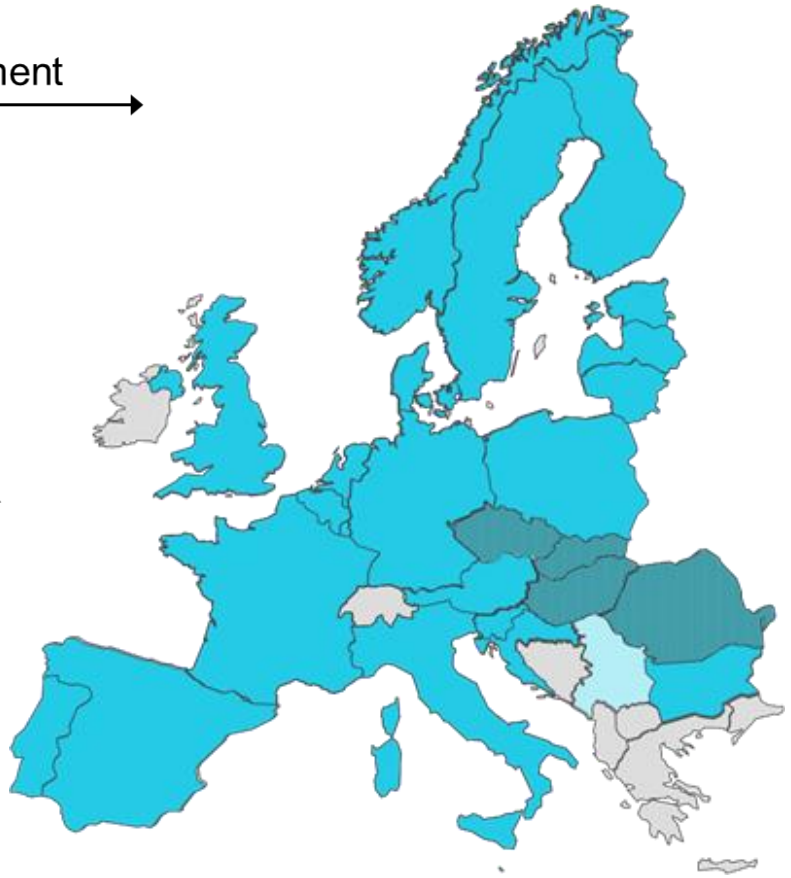
⇒ **A positive business case for grid investments**



THE ELECTRICITY MARKETS



Trade in Nordic area:	500 TWh	4TWh	2TWh

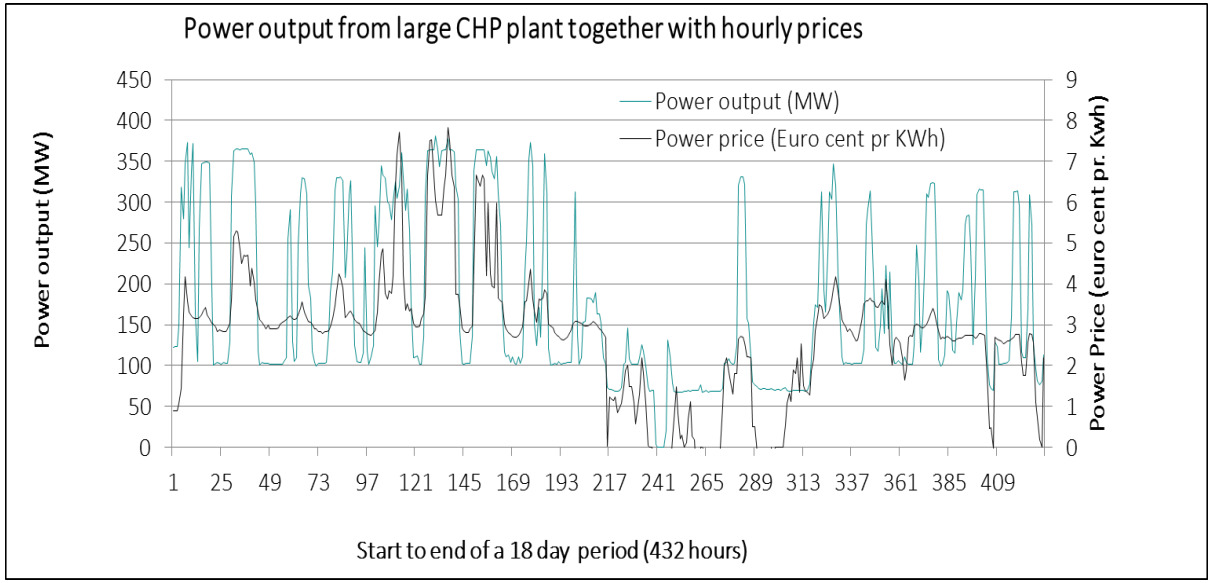


European market coupling

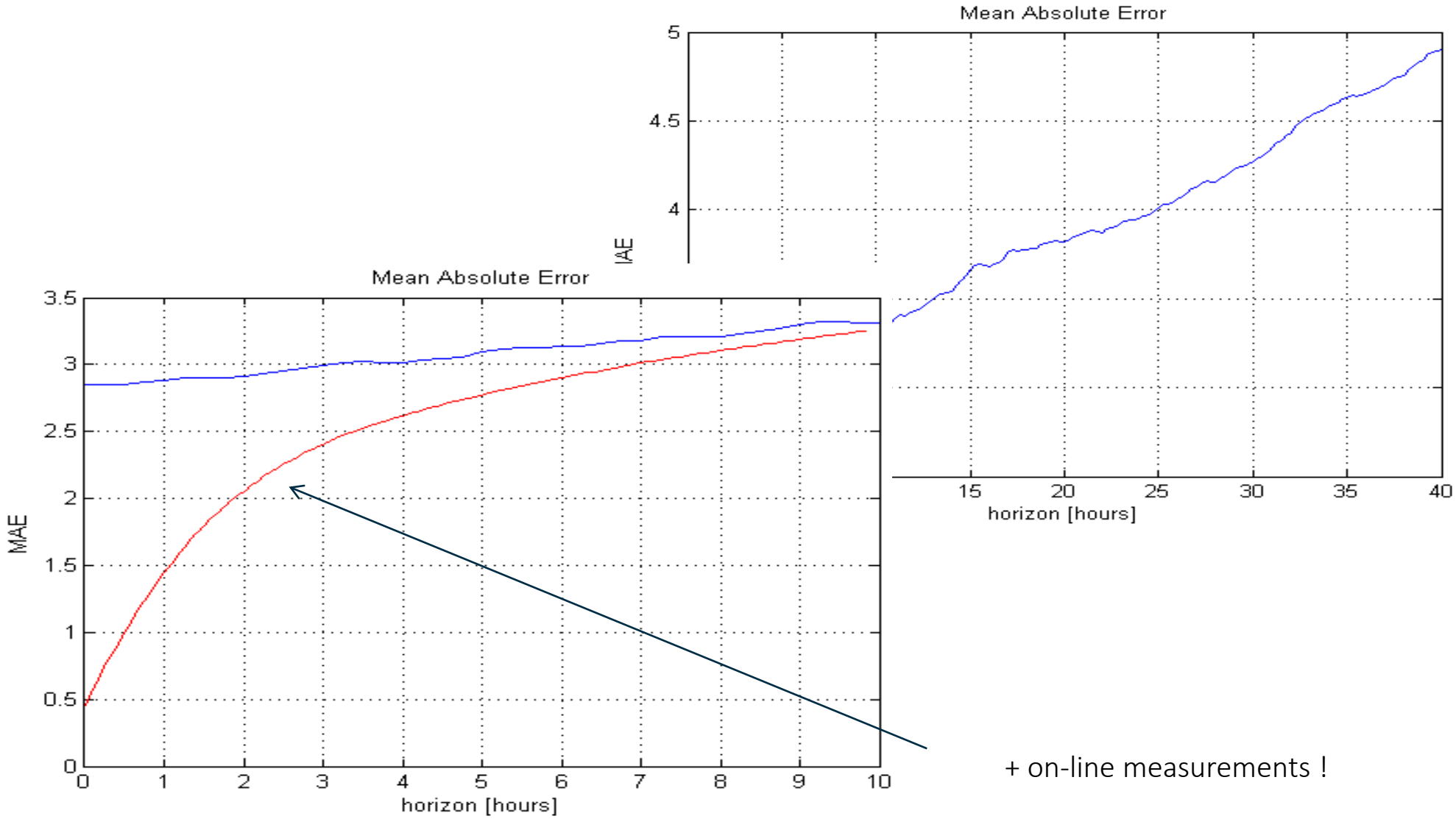
FLEXIBILITY OF POWER PLANTS

Operational range: 10 - 100%
Regulating rate: 3 - 4% per minute

+ Heat accumulators and electric boilers



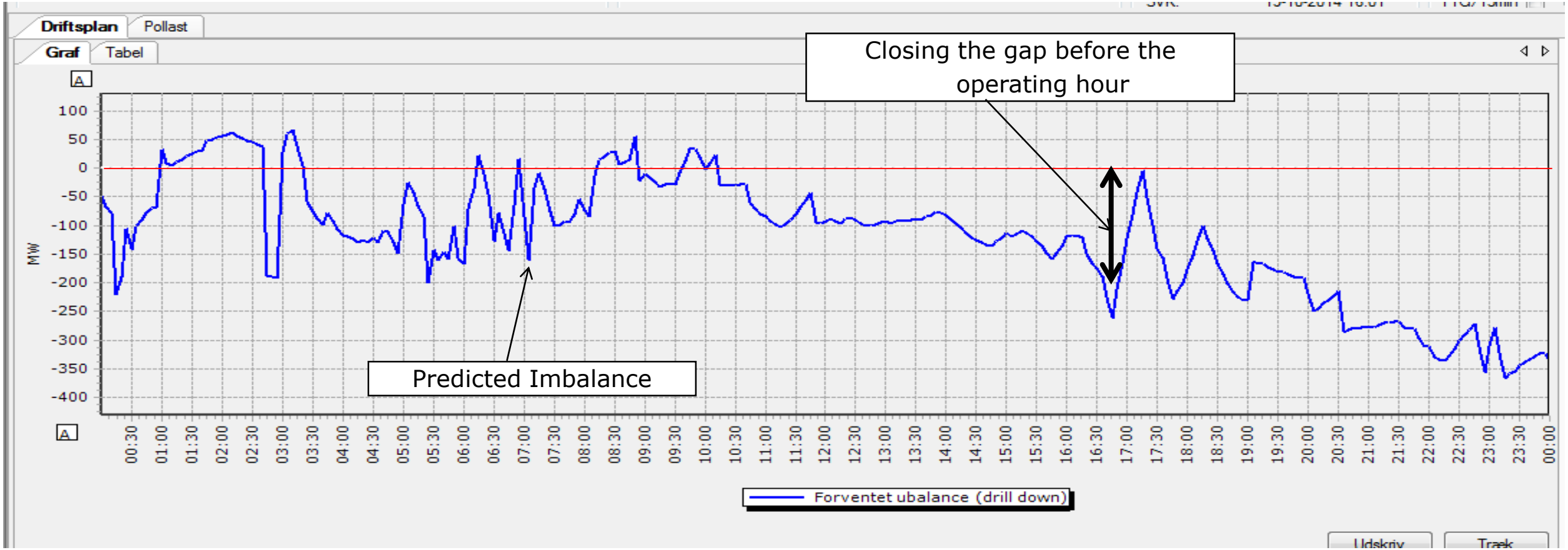
WIND POWER FORECASTING



+ on-line measurements !

PROACTIVE SYSTEM BALANCING

- Predicted imbalance – on-line up-dated



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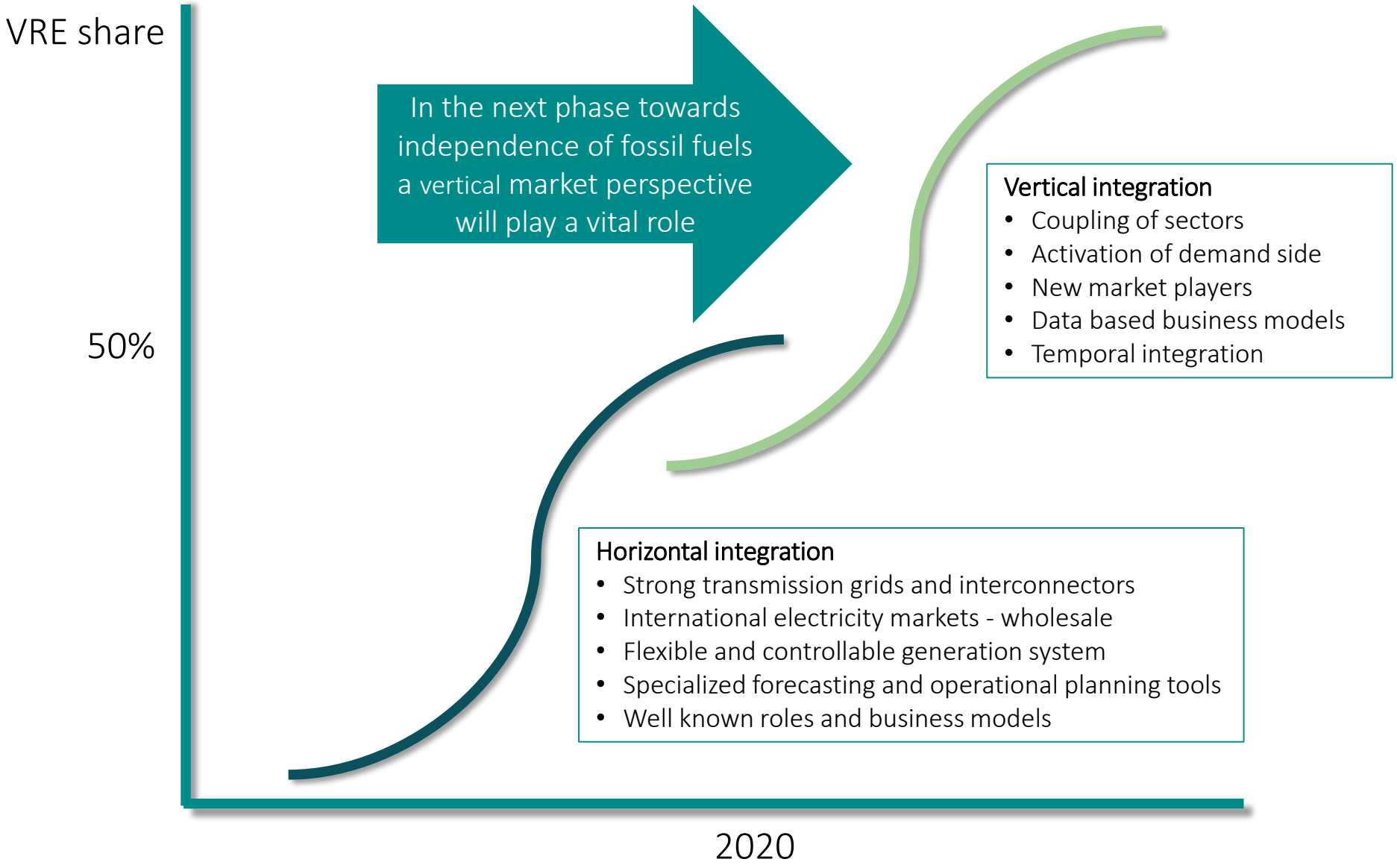
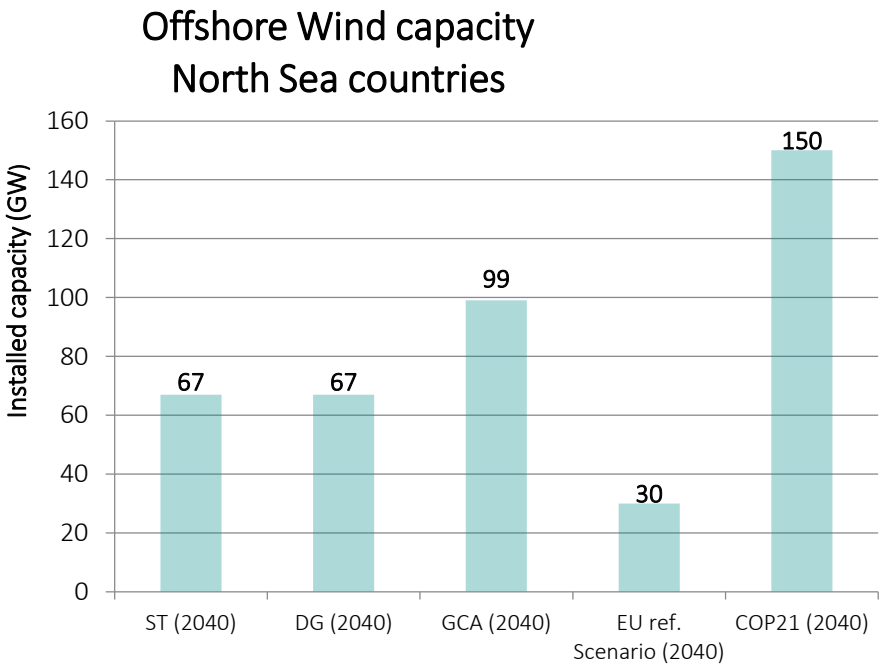
MARKET BASED INTEGRATION OF VRE

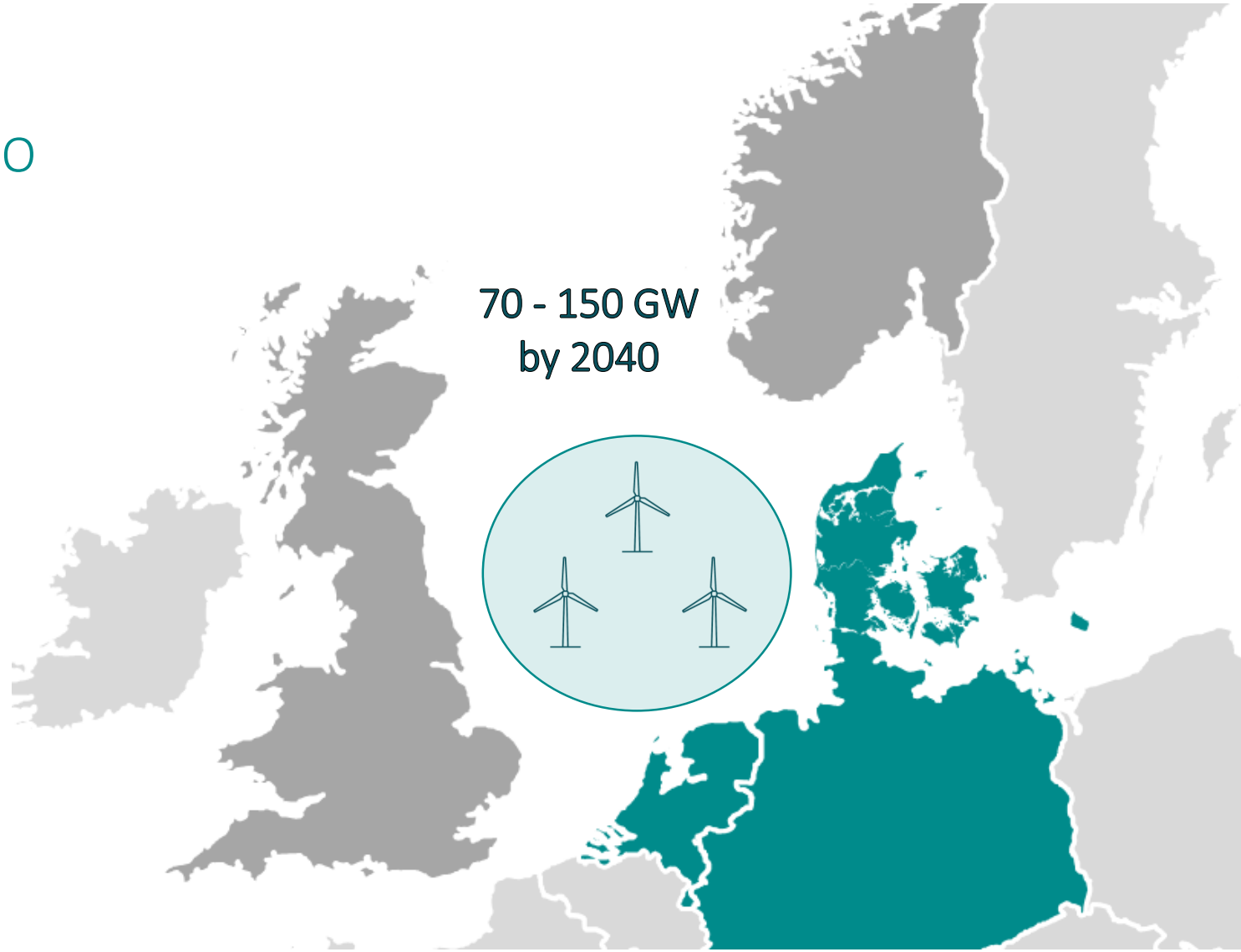
After the first 50% VRE new challenges and options arise



THE NORTH SEA FUTURE SCENARIO

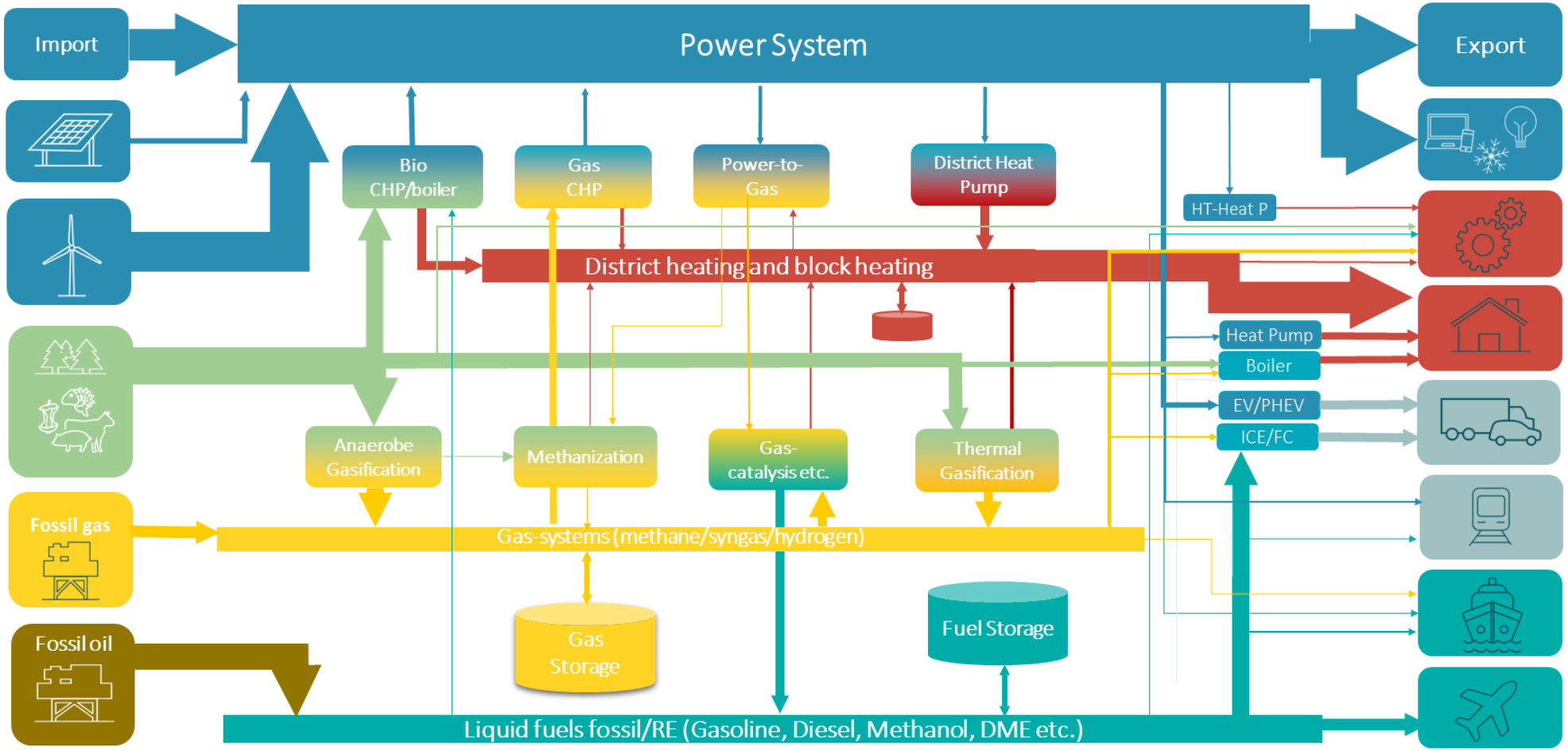
… Much more offshore wind power





COUPLING OF SECTORS

Simulated annual energy flows in Denmark 2035



Eurelectric : Max 40-60% of energy demand in 2050 can be covered by electricity directly

WHAT IS POWER-TO-X (PTX)?

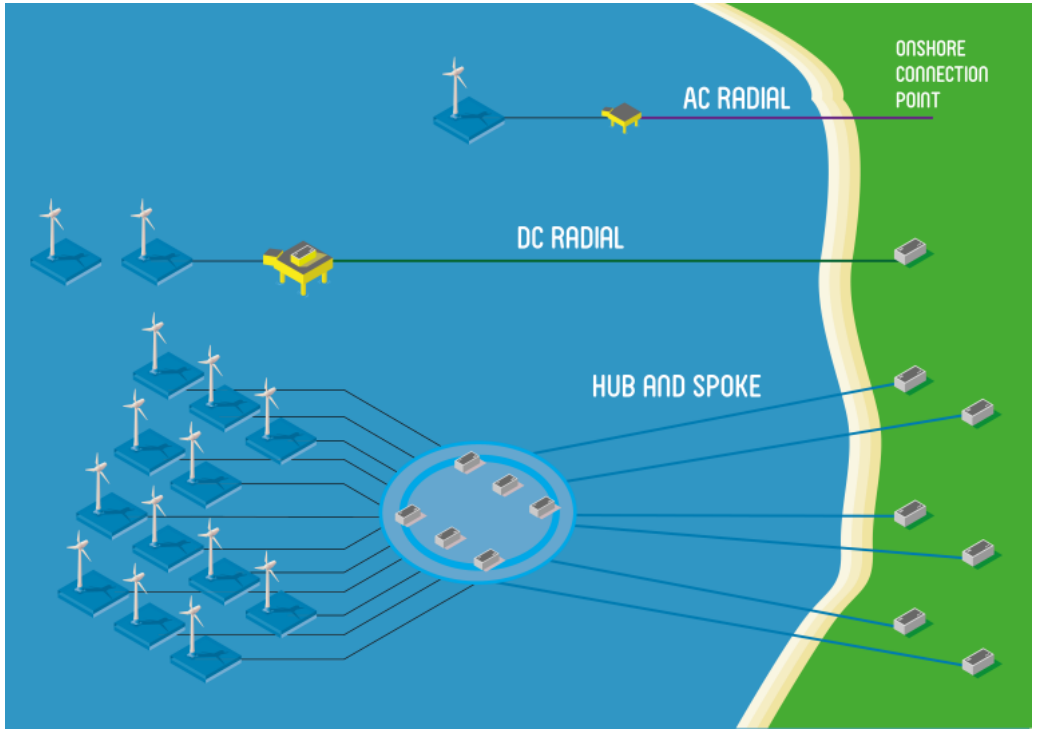
Conversion of (RE-)electricity via electrolysis to hydrogen, fuels, chemicals

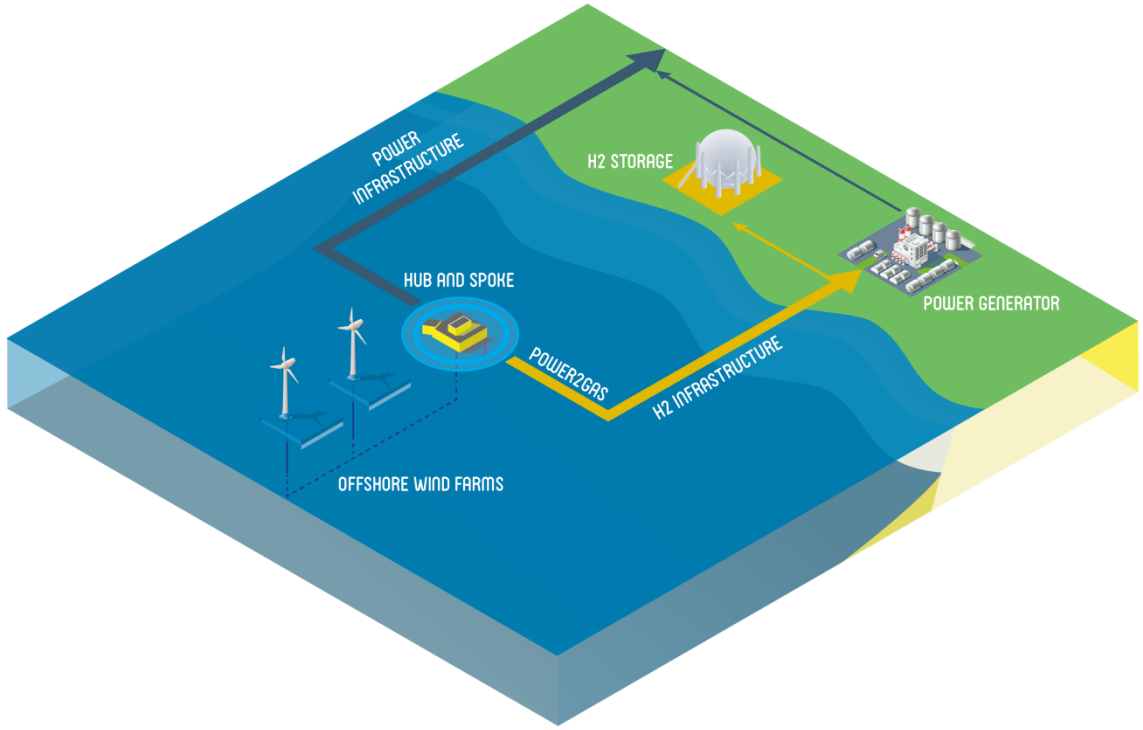
From green electrons to green molecules!

Examples of PtX-products

- **Hydrogen (electrolysis)**
- **Synthetic gaseous fuels (PtG) as for instance methane/**SNG
- **Synthetic fluid fuels (PtL)** as for instance methanol, kerosene (jet fuel), DME, gasoline, diesel
- **Ammonia (PtC): Basic element in fertilizer**. Can also be used directly as fuel. Does not need a carbon source and does not emit CO_2 during combustion.

FROM INDIVIDUAL POWER GRID CONNECTIONS TO HYBRID SOLUTIONS

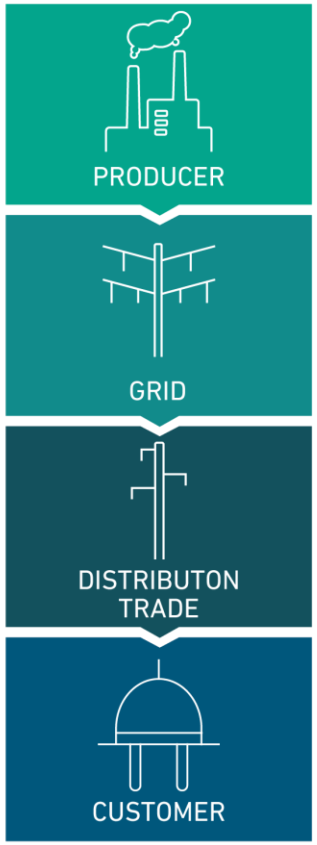




www.northseawindpowerhub.eu

THE ENERGY VALUE CHAIN IS TRANSFORMING
- and traditional assumptions are challenged

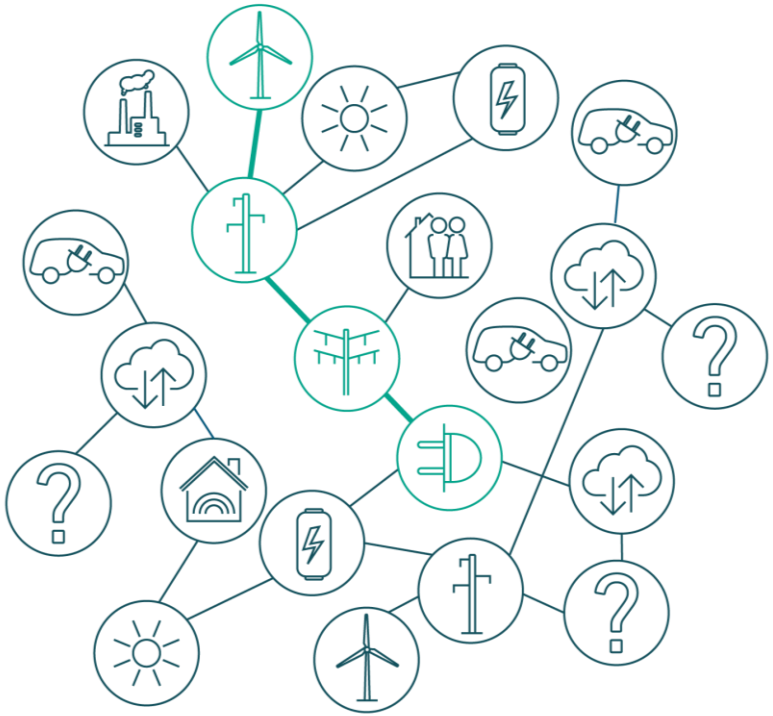
BEFORE



- Green energy has to be subsidized
- Electricity can ~~not~~ be stored
- Electricity and gas consumers are
  active and flexible
  ~~passive and inflexible~~
  do not demand and
- All consumers receive the same product

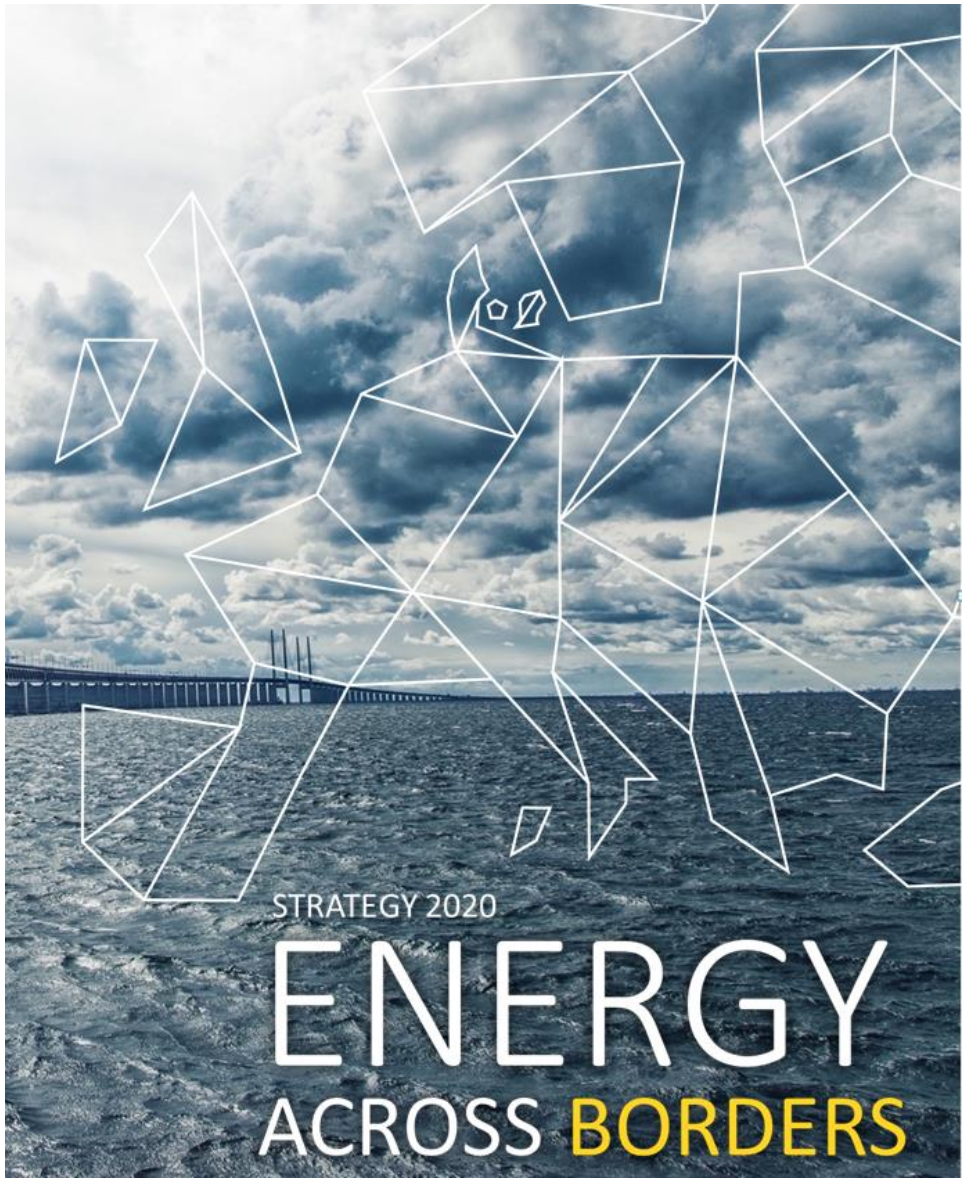
And it will require a lot of software !

IN THE FUTURE

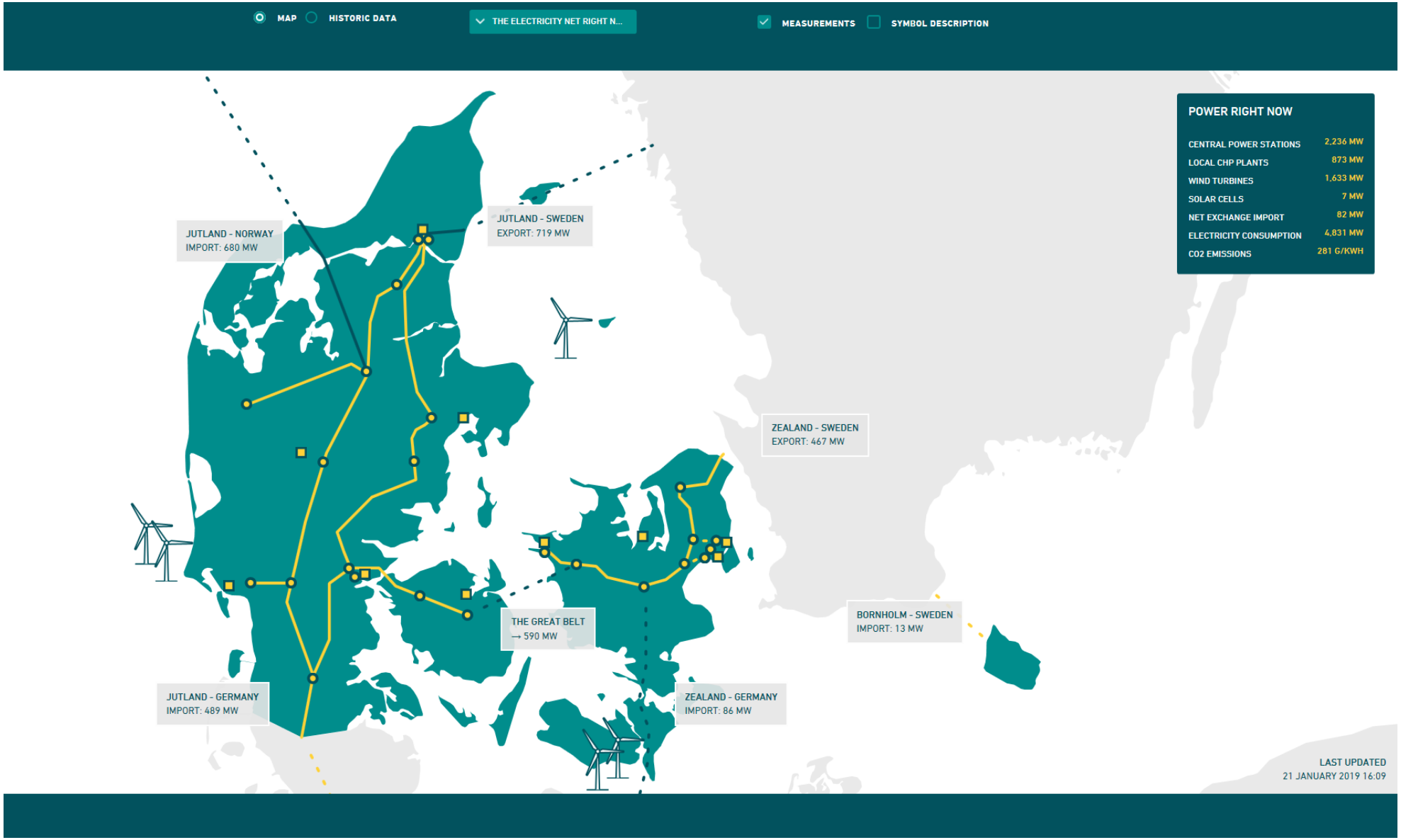


SUMMING UP

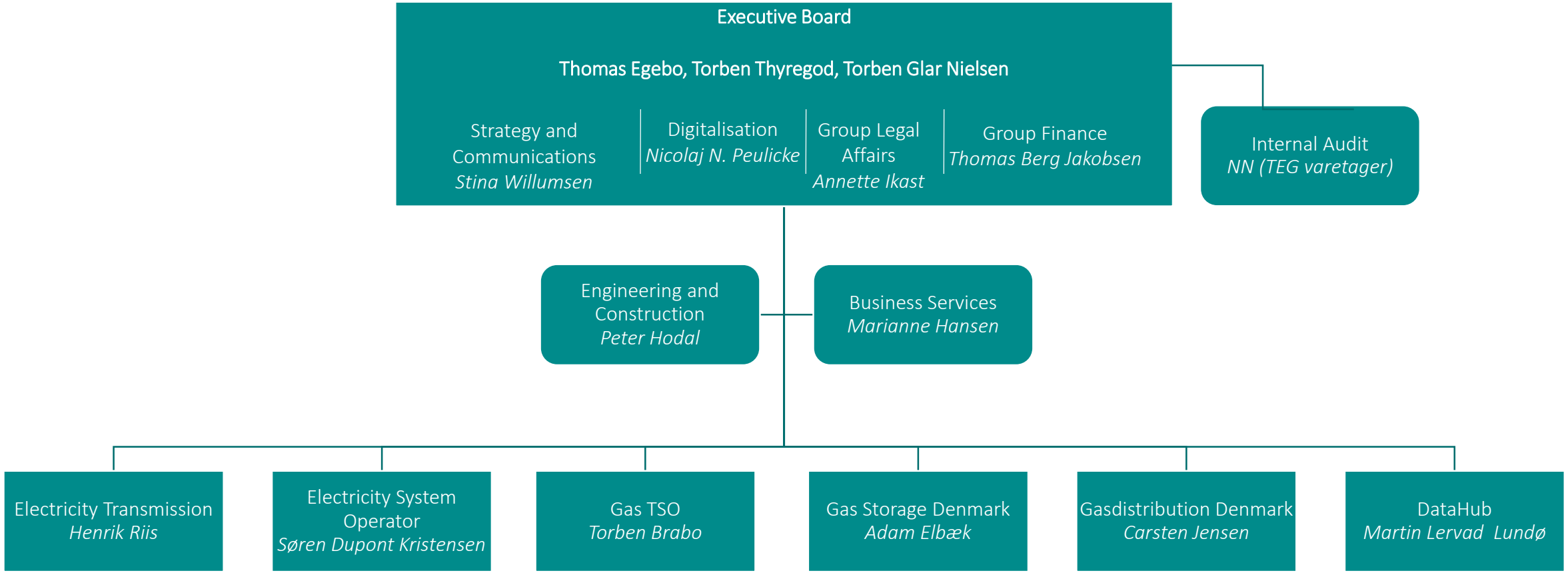
- Danish plans and goals:
  - 2020: Wind power will constitute 50% of the electricity consumption
  - 2030: RES will constitute 100% of the electricity consumption and 55% of the energy consumption
  - 2050: Denmark must be independent of fossil fuels
- Toolbox until now – horizontal integration:
  - Strong transmission grids and interconnectors
  - International electricity markets
  - Flexible and controllable generation system
  - Specialized forecasting and operational planning tools
- Long term enablers – vertical integration:
  - Flexibility in a coherent energy system – sector coupling
  - Transformation of the energy value chain – data driven business models
  - Demand side flexibility
  - Both local and large-scale solutions




THANK YOU FOR THE ATTENTION
WWW.ENERGINET.DK


MAP
HISTORIC DATA
THE ELECTRICITY NET RIGHT N...
MEASUREMENTS
SYMBOL DESCRIPTION
POWER RIGHT NOW
CENTRAL POWER STATIONS 2,236 MW
LOCAL CHP PLANTS 873 MW
WIND TURBINES 1,633 MW
SOLAR CELLS 7 MW
NET EXCHANGE IMPORT 82 MW
ELECTRICITY CONSUMPTION 4,831 MW
CO2 EMISSIONS 281 G/KWH
JUTLAND - NORWAY
IMPORT: 680 MW
JUTLAND - SWEDEN
EXPORT: 719 MW
ZEALAND - SWEDEN
EXPORT: 467 MW
THE GREAT BELT
→ 590 MW
BORNHOLM - SWEDEN
IMPORT: 13 MW
JUTLAND - GERMANY
IMPORT: 489 MW
ZEALAND - GERMANY
IMPORT: 86 MW
LAST UPDATED
21 JANUARY 2019 16:09

ENERGINET GROUP



ENERGINET'S INTERNATIONAL KNOWLEDGE SHARING

Large and small projects since 2010

ENERGINET
ENERGY CONSULTANCY