

# Development and role of flexibility

Four periods:

2000-2004

Period 1

2005-2009

Period 2

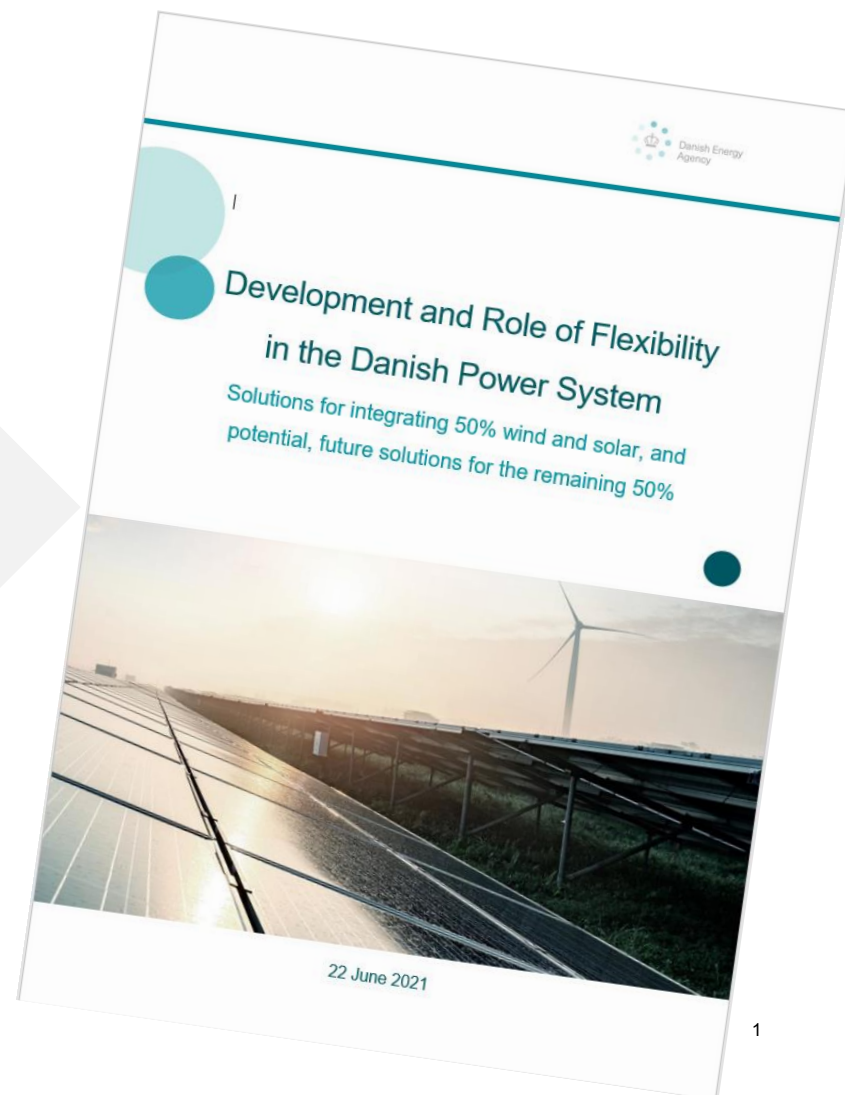
2010-2015

Period 3

2016-2020

Period 4

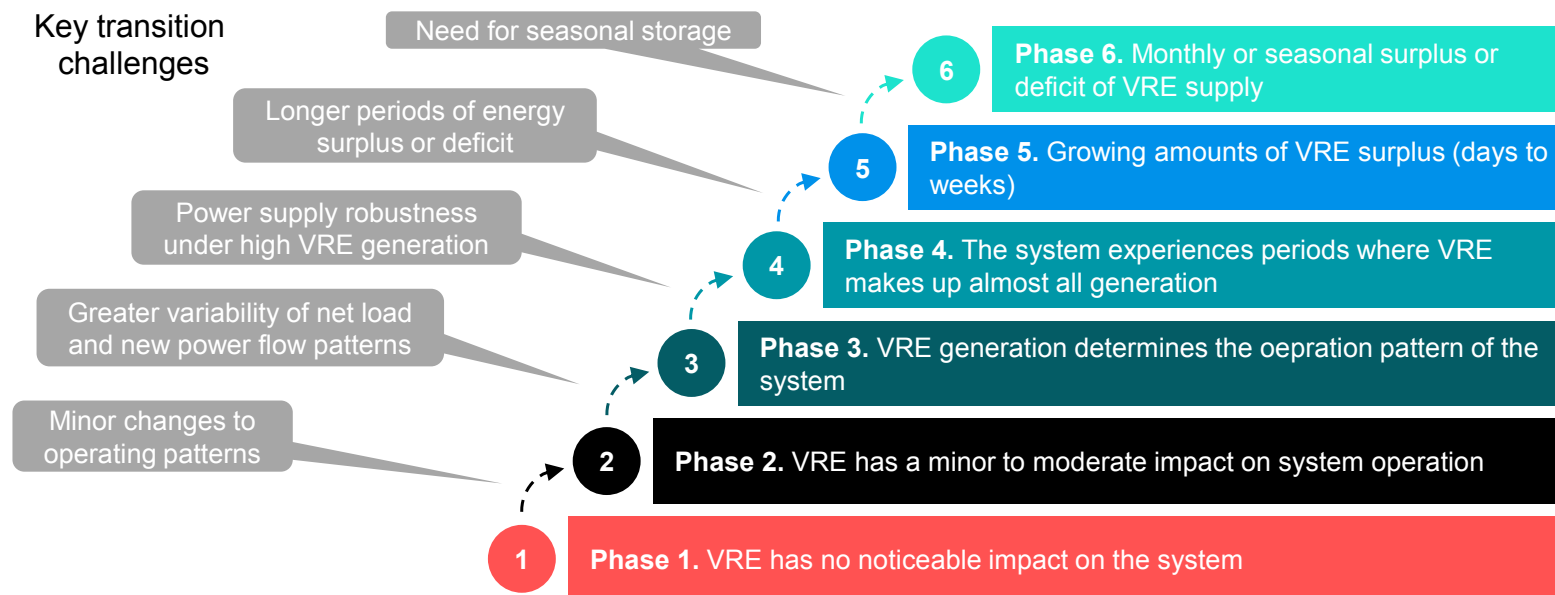
The historical development of the flexibility measures and the variable renewable energy share of the power mix in Denmark



# Project background:

- **Input to ERI model and study**
- **Mapping flexibility in Chinese provinces**

In IEA's terminology, Denmark is now in the 4th category





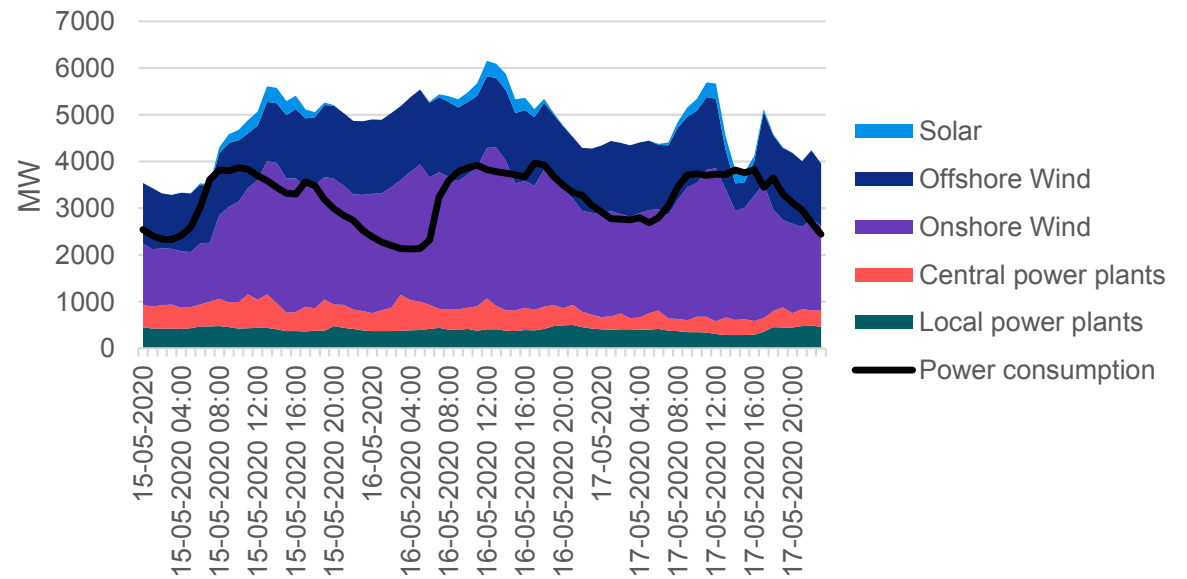
Explaining the term

# Flexibility



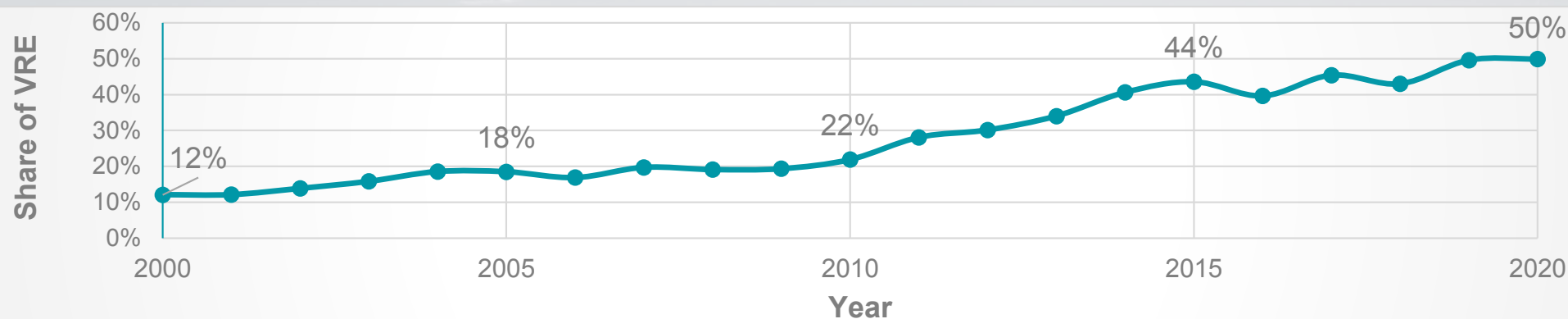
Noun [U]

**Definition:** *The ability of a power system to cope with variability and uncertainty in both generation and demand, while maintaining a satisfactory level of reliability at a reasonable cost, over different time horizons” (Ma, 2013).*



# Report structure: Chronologically reviewing flexibility solutions

*5 main categories of flexibility with market as a key driver*



	2000-2004	2005-2009	2010-2015	2016-2020	After 2020
Flexible thermal power plants					
Utilisation of interconnectors					
Forecasting and scheduling systems					
Sector coupling					
Demand-side flexibility					

# Period

1

## 2000-2004

Market opening in the power sector provided first incentives for flexible operation and interconnector capacity was fully made available to the market

12-19% of VRE

### In this chapter



Dynamic electricity pricing

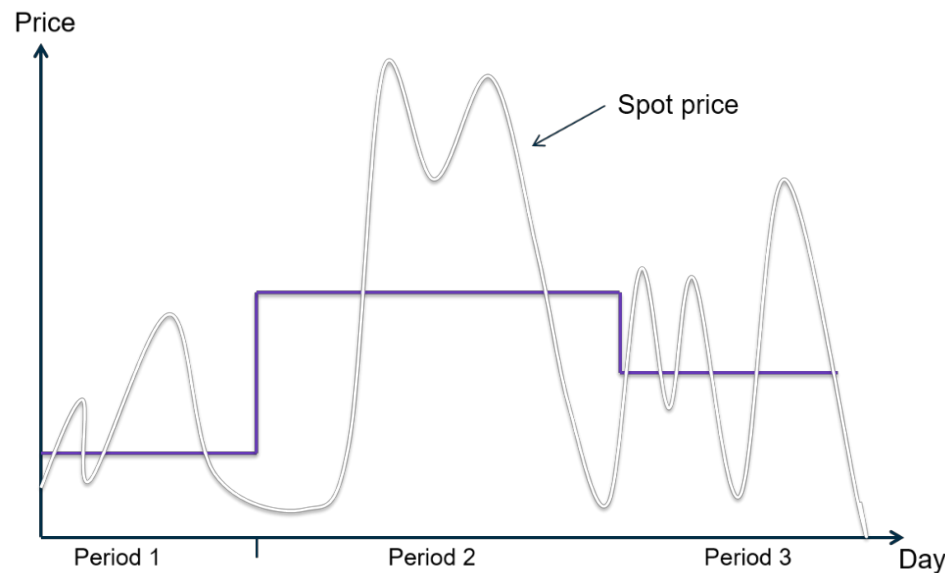


CHP flexibility

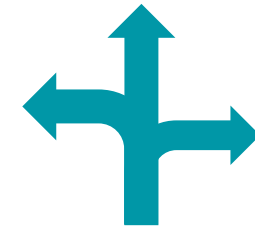


Utilising interconnectors

## Market design – From **fixed tariffs** to **hourly electricity prices**.



*Figure 6: Difference between three-part tariff pricing and spot market price formation*



Dynamic pricing

- Competition between all producers on a daily auction
- hourly electricity price reflect the short-run marginal costs of generating electricity in each bidding zone of that hour
- Fits better the dynamics of fluctuating energy sources
- Denmark joins Nord Pool

## Utilisation of interconnectors

When joining the Nordpool exchange, the entire interconnector capacity is made available for market dispatch

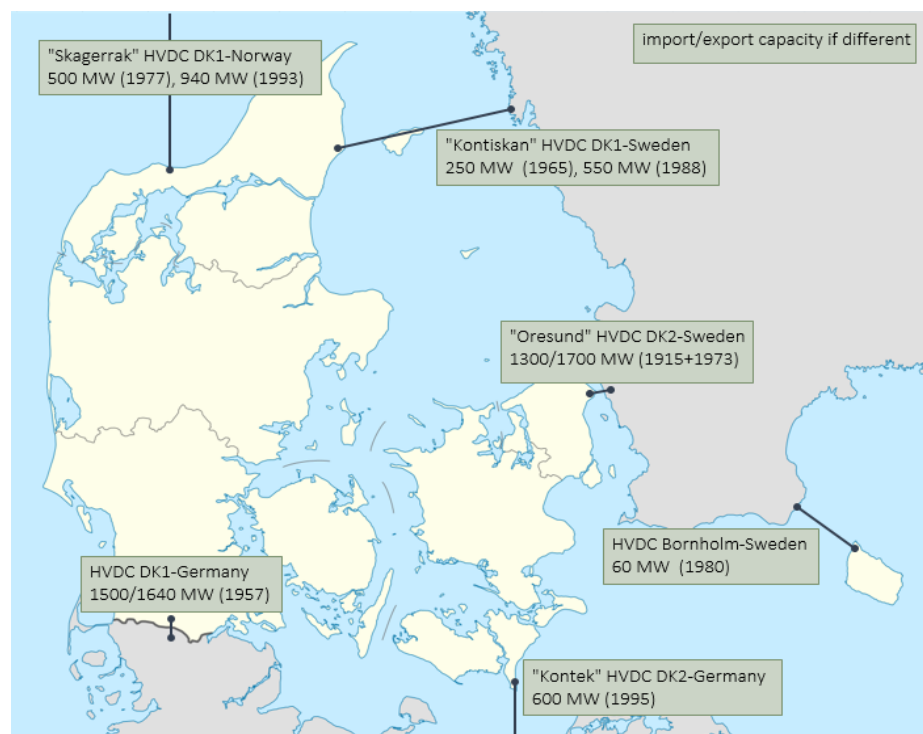


Figure 8: Map of interconnectors as of 2004

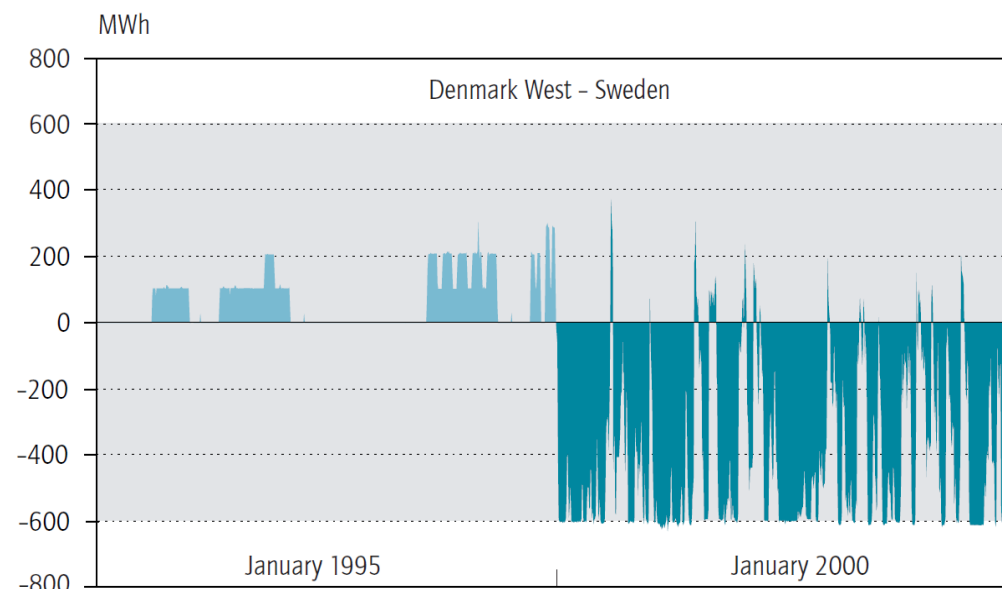


Figure 7: Flow over the interconnector between Western Denmark and Sweden in January of 1995 and 2000. Positive numbers illustrate import and negative numbers illustrate export, and the shaded area marks the rated capacity of the interconnector

# Period

2

## 2005-2009

CHP plants changing roles from baseload to a key source of flexibility and regulation passes negative spot prices

VRE share between 18-20%

### In this chapter



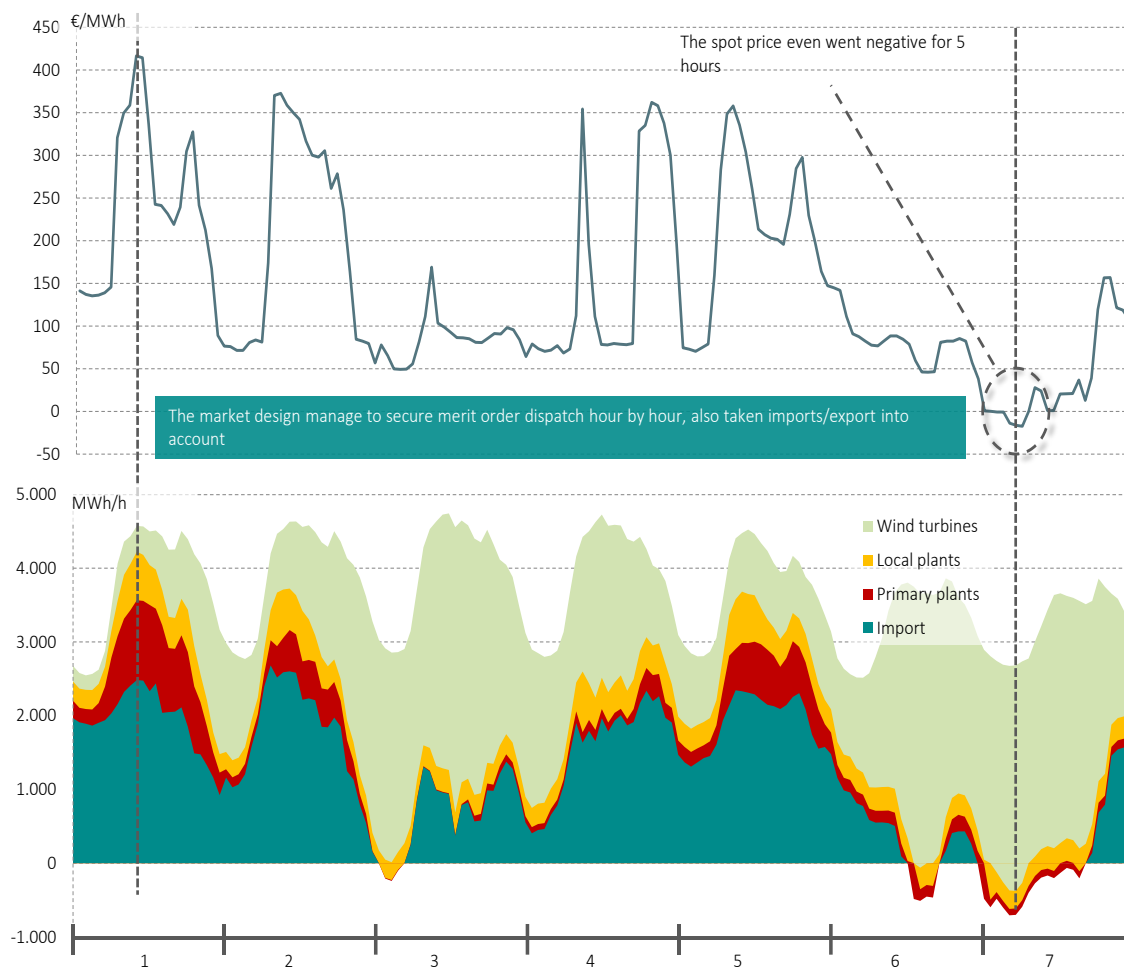
Improved operation of generators



Economic incentives for flexibility



Negative pricing



## Negative prices allowed

Negative prices led to more dynamic operation of traditional generation through the use of electric boilers

*Figure 13: Example of how negative spot prices incentivise power plants to consume electricity*

# Period

3

## 2010-2015

Increased use of CHP plants as a flexibility source and large investments in interconnectors accompanied by an integrated day-ahead market across Europe

first power system to reach 22-44% VRE share

### In this chapter



Thermal plants delivering flexibility – decoupling electricity and heat



Utilisation and flexibility of interconnectors

## VRE shares incentive thermal power plants to further implement flexibility

- VRE-share continually increasing – demanding innovations and retrofiting
- Various CHP unit solutions contribute to higher flexibility
- Higher VRE shares brought longer periods with electricity prices lower than the marginal cost of running CHP

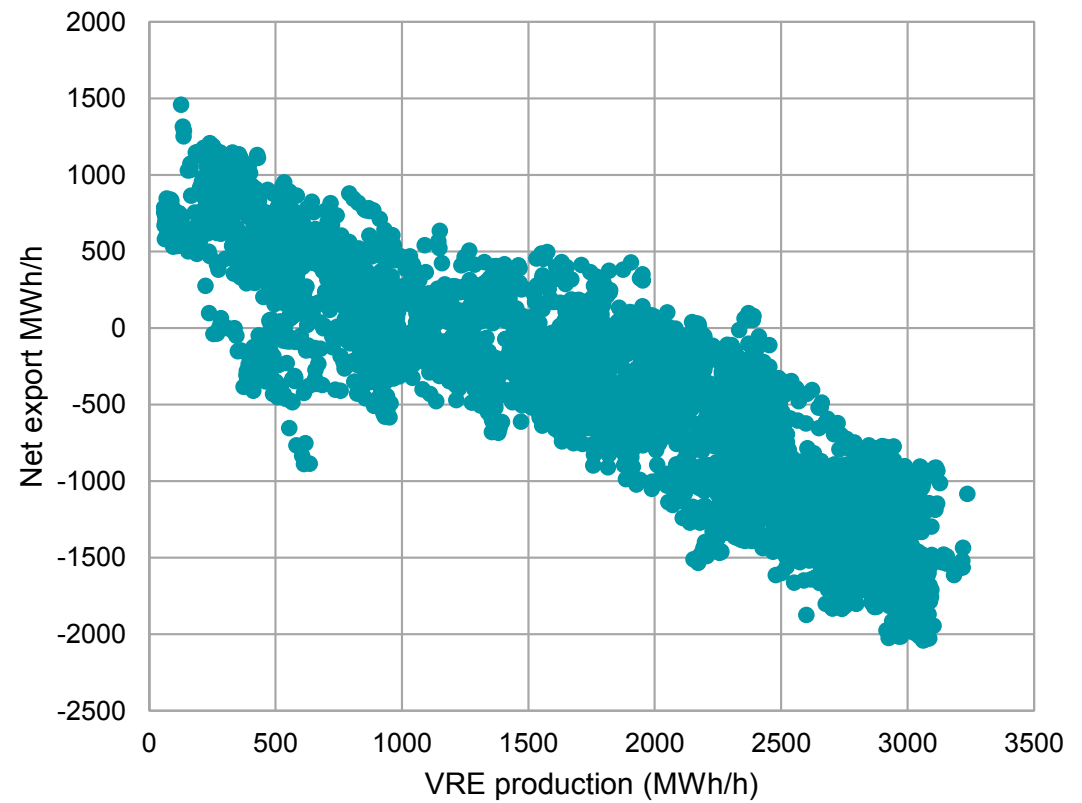
General operational improvements	CHP unit solutions
Enhance the operational limit values	Lower minimum load
	Overload ability
	Turbine bypass
Decoupling of heat and electricity or heat: variable heat-to-power ratio	Electric boilers and heat pumps
Decoupling of heat and electricity: Temporal displacement of thermal load	Heat storage
Short reaction time to market signals	Faster ramp rates and output regulation
	Faster start up and shut down

*Figure 15: Implemented flexibility improvements in thermal power plants*



## Utilisation of interconnectors

Increasingly used to balance wind power production



# Period

4

## 2016-2020

New flexibility measures focus on consumer participation in electricity markets, improved forecasting that allows for proactive balancing, and that wind turbines may provide balancing services

50% of VRE reached

### In this chapter



Demand-side management



Datahub

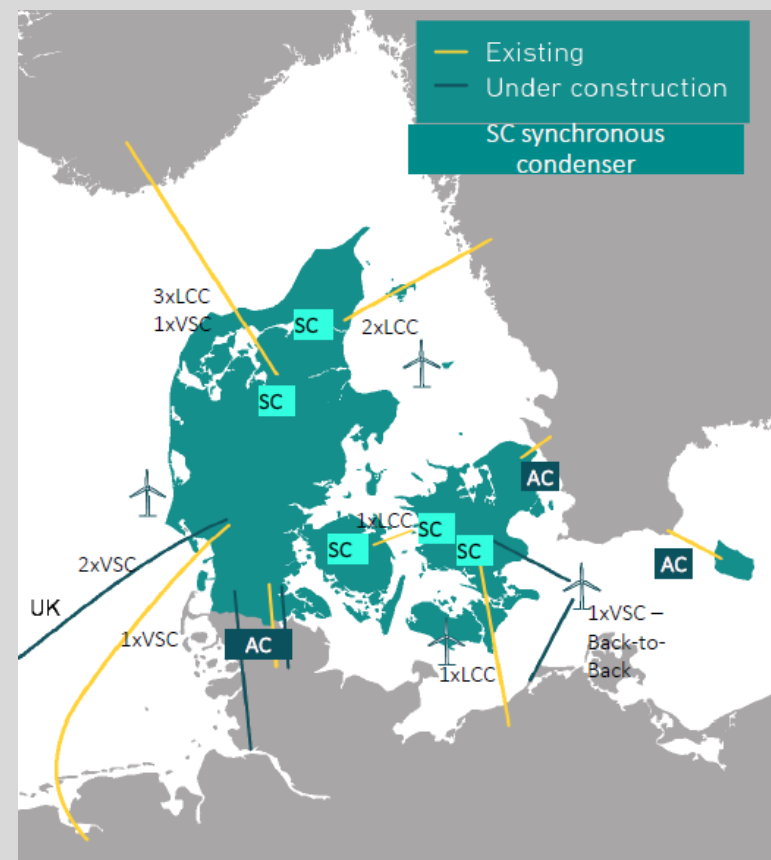
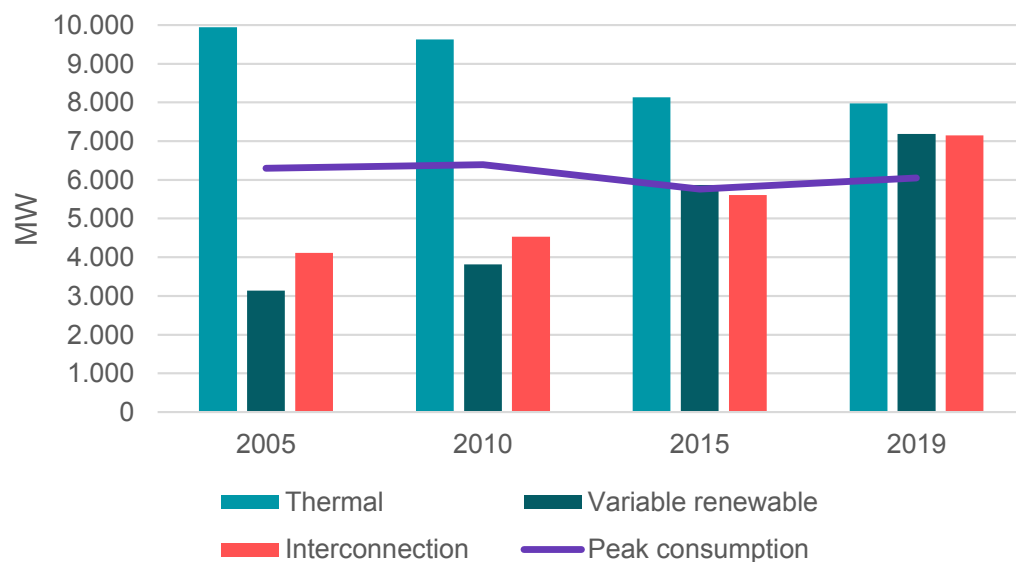


New concepts in the European power market

# Operating the power system

## *Without thermal power plants*

- Interconnectors + European market
- Wind delivers ancillary services
- Synchronous condensers



# Beyond 2020: Future of a 100% RE Danish power grid

