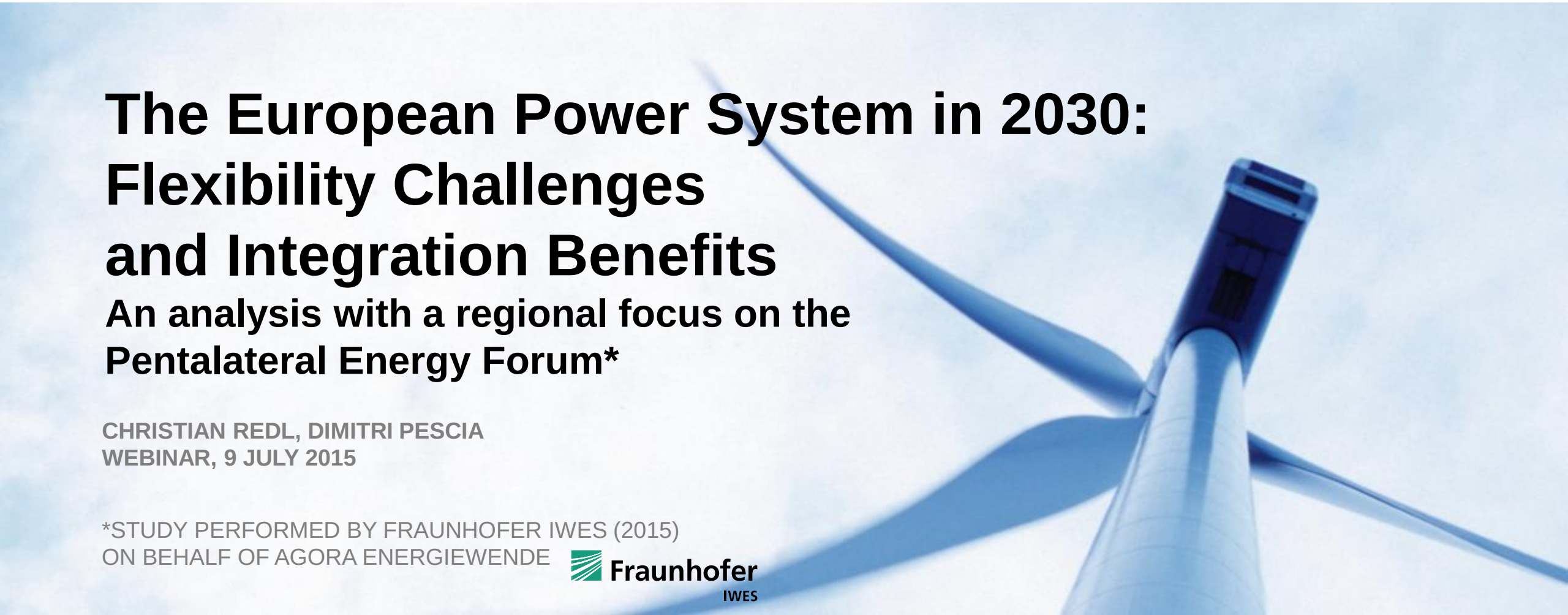
# The European Power System in 2030: Flexibility Challenges and Integration Benefits

## An analysis with a regional focus on the Pentalateral Energy Forum*

CHRISTIAN REDL, DIMITRI PESCIA

WEBINAR, 9 JULY 2015

*STUDY PERFORMED BY FRAUNHOFER IWES (2015)
ON BEHALF OF AGORA ENERGIEWENDE



# Agora Energiewende – who are we?

Independent think tank; 19 energy policy experts

- Project duration 2012-2017
- Financed by the Mercator Foundation and the European Climate Foundation

- Mission: How do we make the *Energiewende* in Germany a success story?

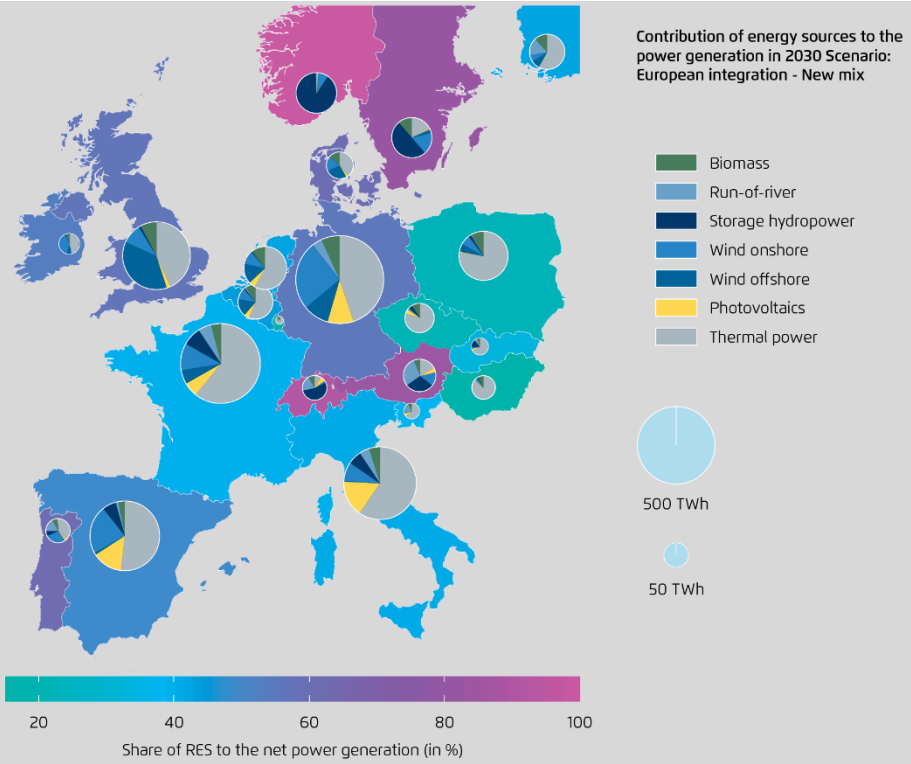
- Scientific assessments
- Dialogue
- Putting forward proposals

# The study

## Scope, input data and modelling approach

# Wind power and solar PV become key pillars of the European power system

RES-E share in the “EU” generation mix 2030




Fraunhofer IWES (2015); Assumptions based on national energy strategies and ENTSO-E scenarios in line with EU 2030 targets

**EU 2030**

- → 50% RES-E in the generation mix
- → 30% Wind and PV in the generation mix

**Region Pentalateral Energy Forum* 2030**

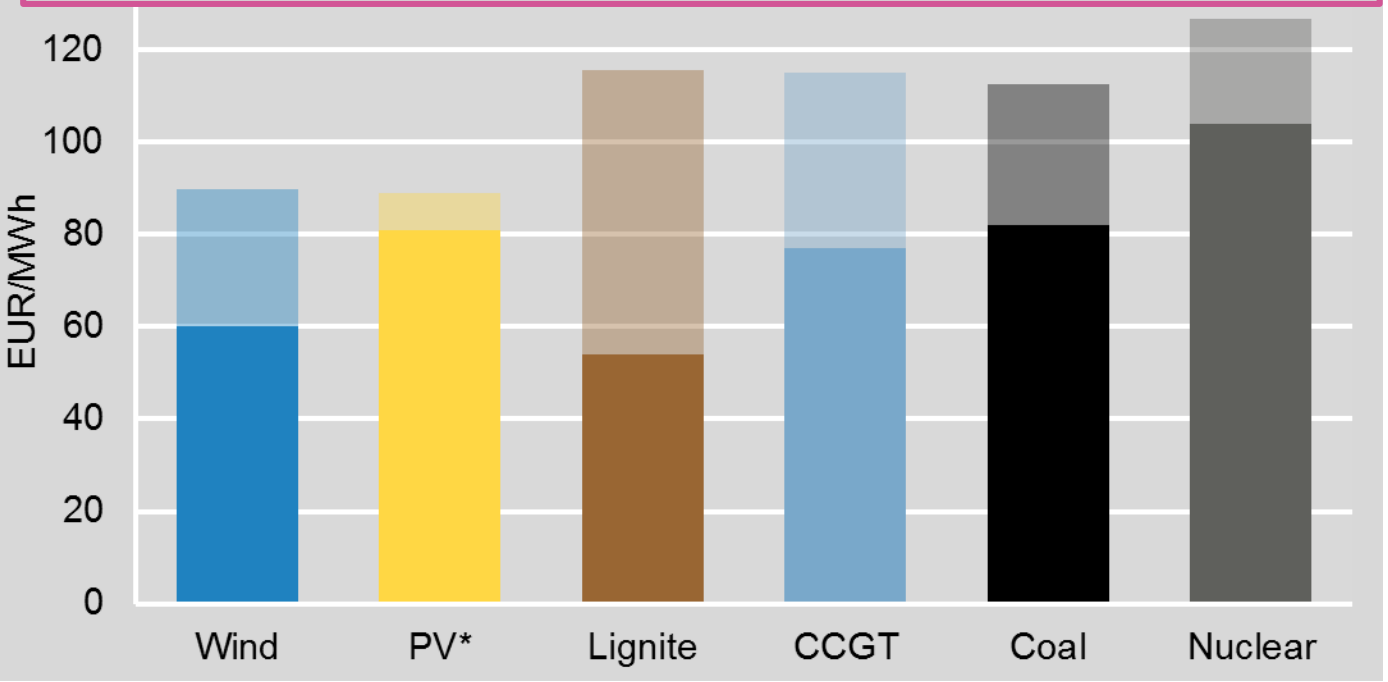
- → 54% RES-E in the generation mix
- → 34% Wind and PV in the generation mix

* AT, BE, CH, DE, FR, LU, NL

# Project scope: Implications of further growth of wind power and solar PV on EU power systems

Range of levelised cost of electricity (LCOE) of new plants in 2015 in EUR/MWh

A mix of wind onshore, PV with gas turbines as backup costs ~70 EUR/MWh

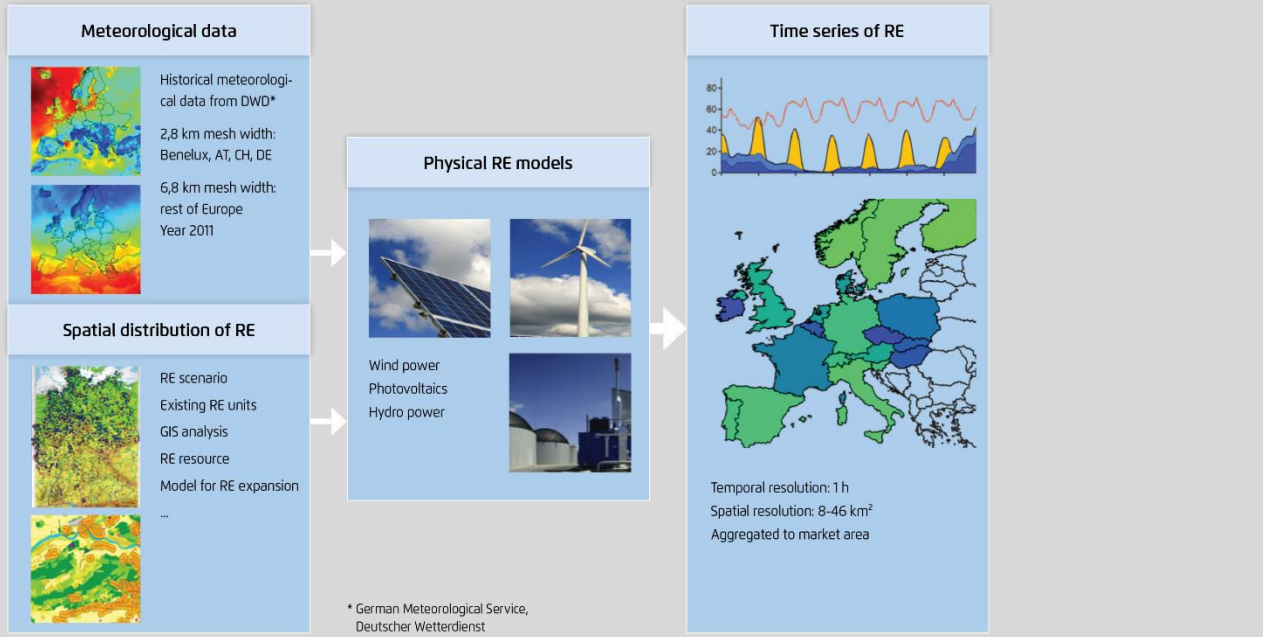



Agora Energiewende (2015) *Ground-mounted PV, irradiation conditions central Europe. Cost for lignite heavily depend on CO2 price: Here 5-40 EUR/t CO2

**The EU power systems in 2030**

- Wind and PV rapidly gain importance due to EU energy policy targets and competitive performance
  - LCOE 6-9ct/kWh (2015) to 4-6ct/kWh for onshore wind and large-scale PV during the next 10-15 years
- Fraunhofer IWES conducted model based analysis of future power system scenarios
  - Quantification of flexibility requirements arising from fluctuating, weather-dependent production of wind and PV
  - How can market integration help mitigating the flexibility challenge?
- Results focus on **Pentalateral Energy Forum (PLEF)** region

# Modelling approach




Fraunhofer IWES

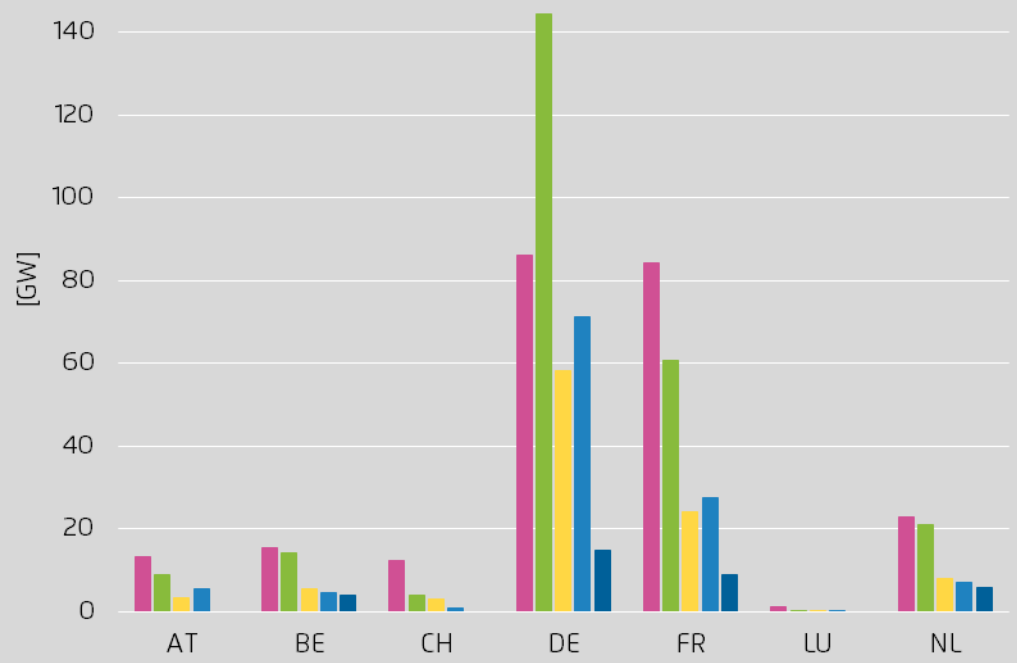
Source: ENTSO-E; Own calculations

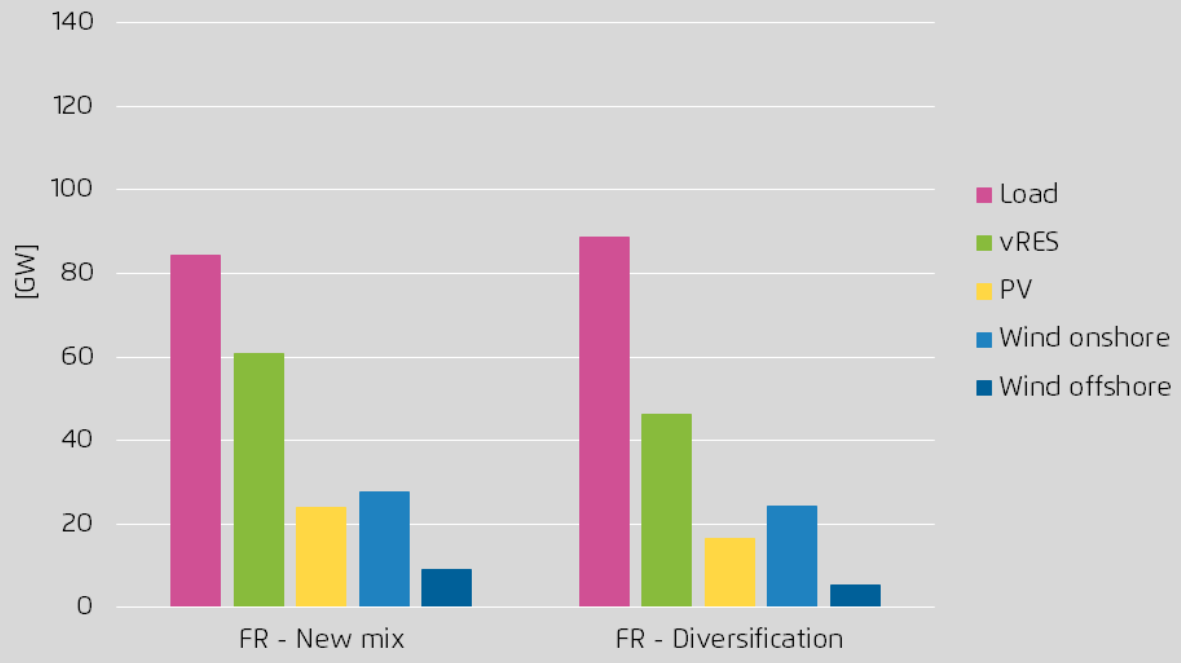
- → Input assumptions: Consumption, peak load, renewable capacities, interconnector capacities

- → Model setup:
- → Modelling of disaggregated renewables time series (weather data for year 2011)
- → Load pattern based on 2011 profile
- → Modelling of EU-wide power plant dispatch based on simplified synthetic power plant park (must-run assumptions per country)
- → Countries modelled as “national copper plates” linked through NTC capacities

# Input data: Consumption, peak load and renewable capacities

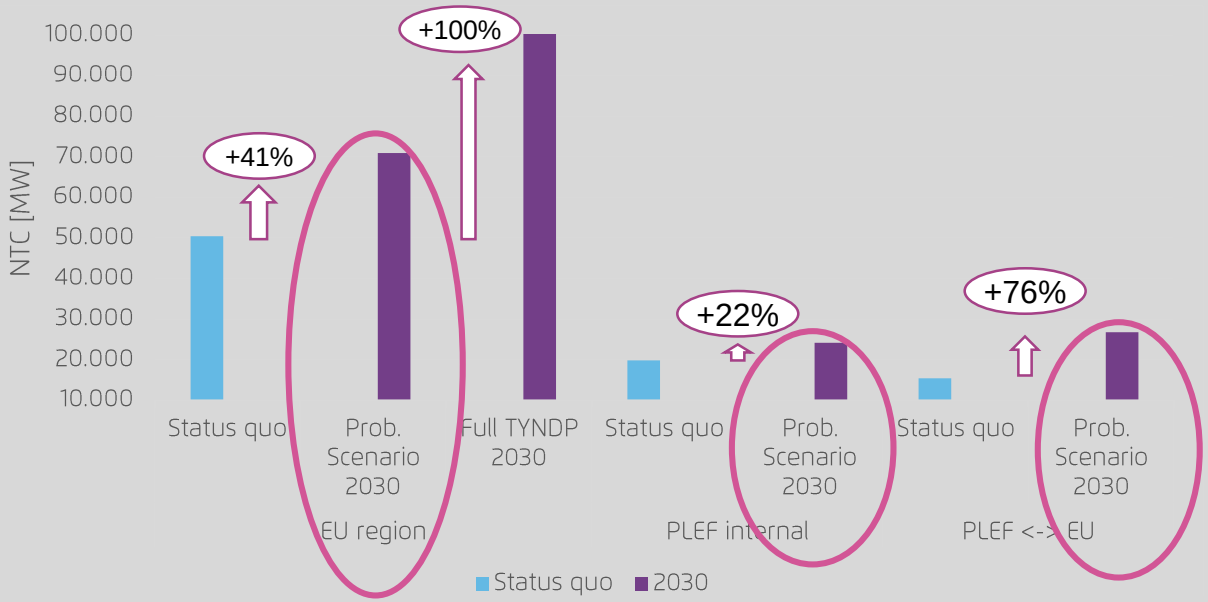
- “Bottom-up” derivation for PLEF, UK, DK (nat. TYNDPs / Energy strategies); Two scenarios for France: “New mix”; “Diversification”
- ENTSO-E SOAF 2014 S3 (Green Transition) scenario for other countries




Source: National energy strategies and TYNDPs, ENTSO-E

# Input data: Interconnector capacities

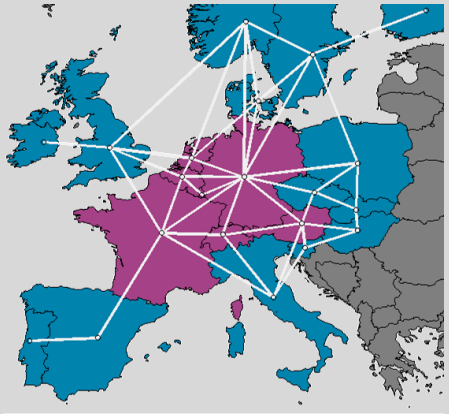



Source: ENTSO-E; Own calculations

- → National power systems modelled as “copper plate” → considered to be free of any domestic grid congestions
- → Countries are coupled with neighbours through interconnectors → Net Transfer Capacity (NTC) values as input
- → TYNDP 2014 (at times of modelling in consultation) as starting point: Would yield doubling of NTCs
- → The chosen “Probable Scenario 2030” assumes lag rate of 50% compared to TYNDP

# Power system modelling approach

NTC assumptions

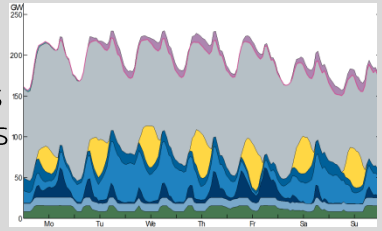


Load curve
- Must-run RES
Residual load time series

**Unit commitment**

- Linear programming
- Target function: cost minimal load coverage
- Accounting for NTC restrictions, storage restrictions, ...

Time series:
- Flexible biomass
- Stored hydro turbines
- Thermal power plants
- Import / export
- Curtailment



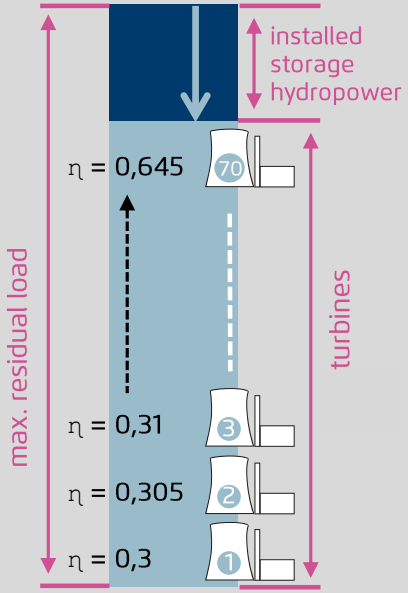
Approach neglects:
- Stored hydro pumps
- Pumped hydro storage

→ Additional flexibility providers not modelled (e.g. DSR, batteries)

!

Hydro power turbines, flex. biomass

Synthetic thermal power plant portfolio (s.t. must-run assumptions per country (e.g. 5 GW DE, 15-20 GW FR)




single gas turbine capacity:

$$P_n = \frac{\max(RL) - hydro\ storage}{70}$$

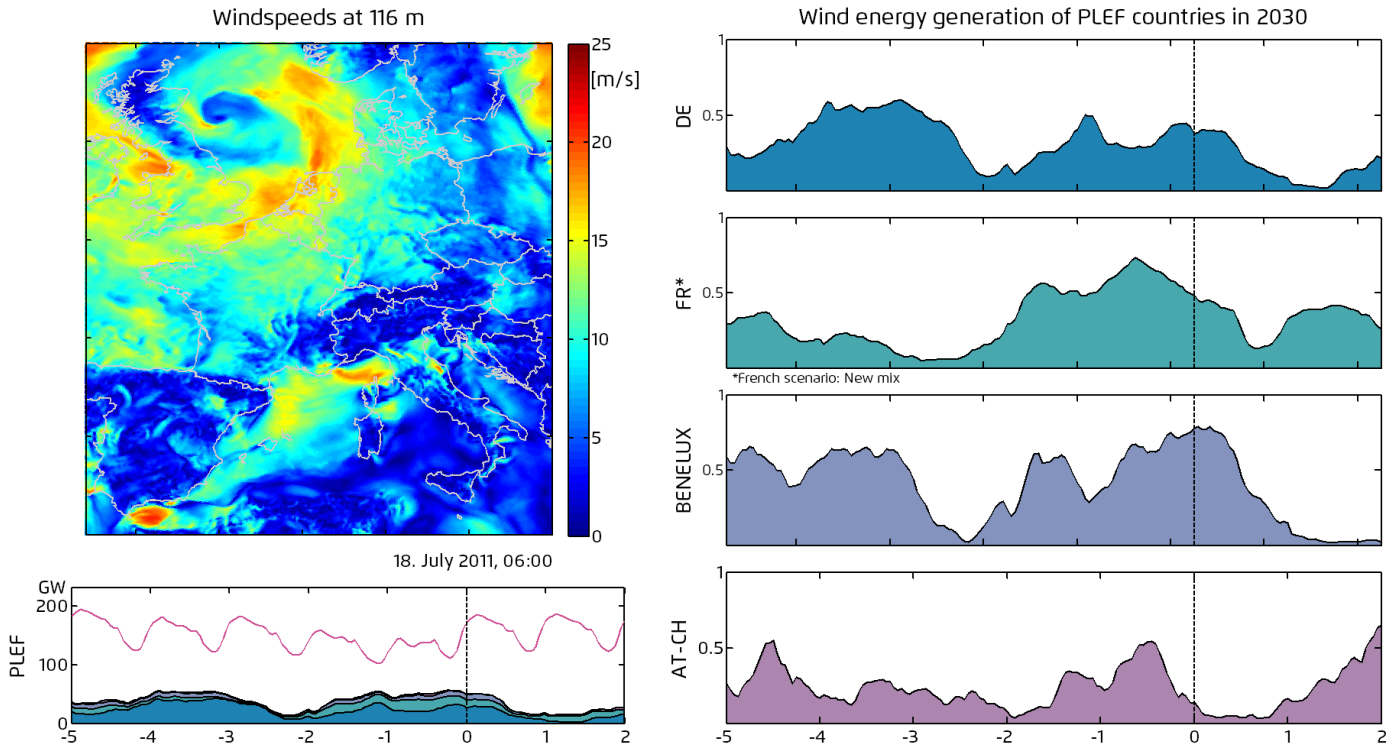
Fraunhofer IWES

Source: Fraunhofer IWES

# A 2030 European power systems outlook

## Renewables deployment and flexibility requirements in the context of market integration and autarchy

# As wind power and solar PV are weather-depend generation is fluctuating and flexibility requirements increase.
# Yet, coupling power systems helps




Source: Fraunhofer IWES

# Weather patterns are not perfectly correlated across Europe: This yields smoothing effects especially for wind generation (and also load…)

Correlation coefficients (based on Kendall's tau rank) between PLEF countries for wind onshore generation

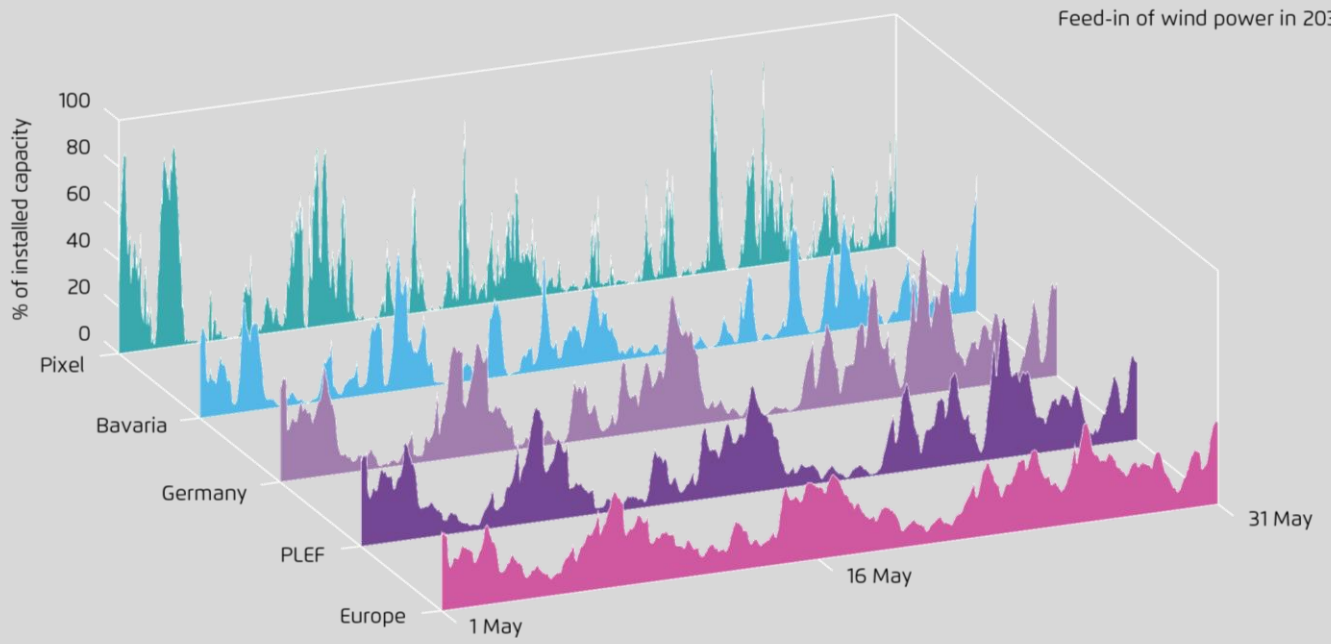
| Wind | AT | BE | CH | DE | FR | LU | NL |
|---|---|---|---|---|---|---|---|
| AT | 100% | 24% | 45% | 35% | 27% | 29% | 22% |
| BE | 24% | 100% | 27% | 49% | 55% | 66% | 60% |
| CH | 45% | 27% | 100% | 28% | 39% | 32% | 22% |
| DE | 35% | 49% | 28% | 100% | 33% | 47% | 58% |
| FR | 27% | 55% | 39% | 33% | 100% | 52% | 34% |
| LU | 29% | 66% | 32% | 47% | 52% | 100% | 44% |
| NL | 22% | 60% | 22% | 58% | 34% | 44% | 100% |

Fraunhofer IWES (2015)

Based on weather year 2011

# Mitigating flexibility needs through market integration: Cross-border electricity flows enable geographical smoothing

Wind onshore generation in May 2030 at different levels of aggregation




Fraunhofer IWES (2015)

* One pixel is equivalent to an area of 2.8 x 2.8 km

**EU-wide aggregation:**

→ Instantaneous total wind power output is much less volatile and lacks extremely high and low values

→ Wind output changes softer and slower. This contributes to lower flexibility requirements

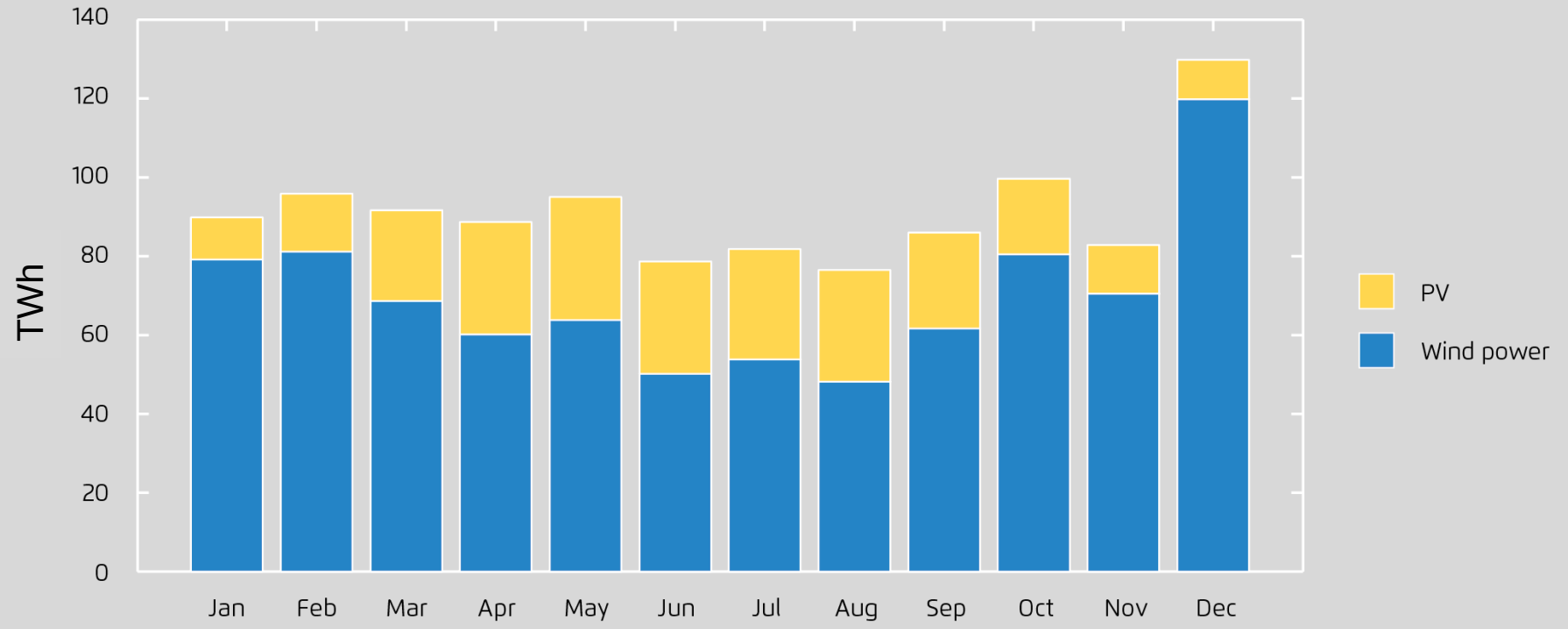
→ Largest EU-wide hourly wind ramp is -10% of installed capacity

→ For comparison, largest hourly wind ramp in France is 21% of installed capacity

→ EU-wide wind ramps larger +-5% in only 23hrs of the year

# Seasonal weather patterns match monthly wind and PV generation yielding a more stable total variable renewables output

Monthly wind power and PV generation in Europe in 2030

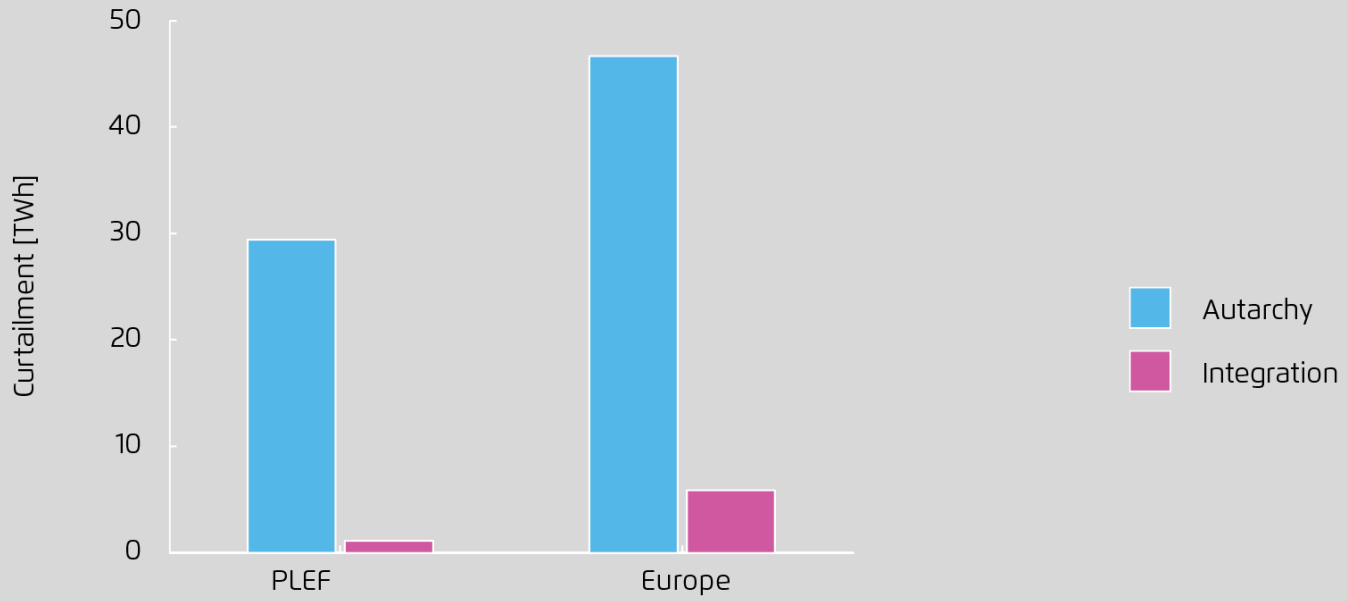



Fraunhofer IWES (2015)

Weather year 2011

# Through market integration, less wind and PV electricity must be curtailed (or stored) at times with high feed-in, increasing its value

Curtailment of vRES within PLEF and Europe in autarchy and integration scenarios

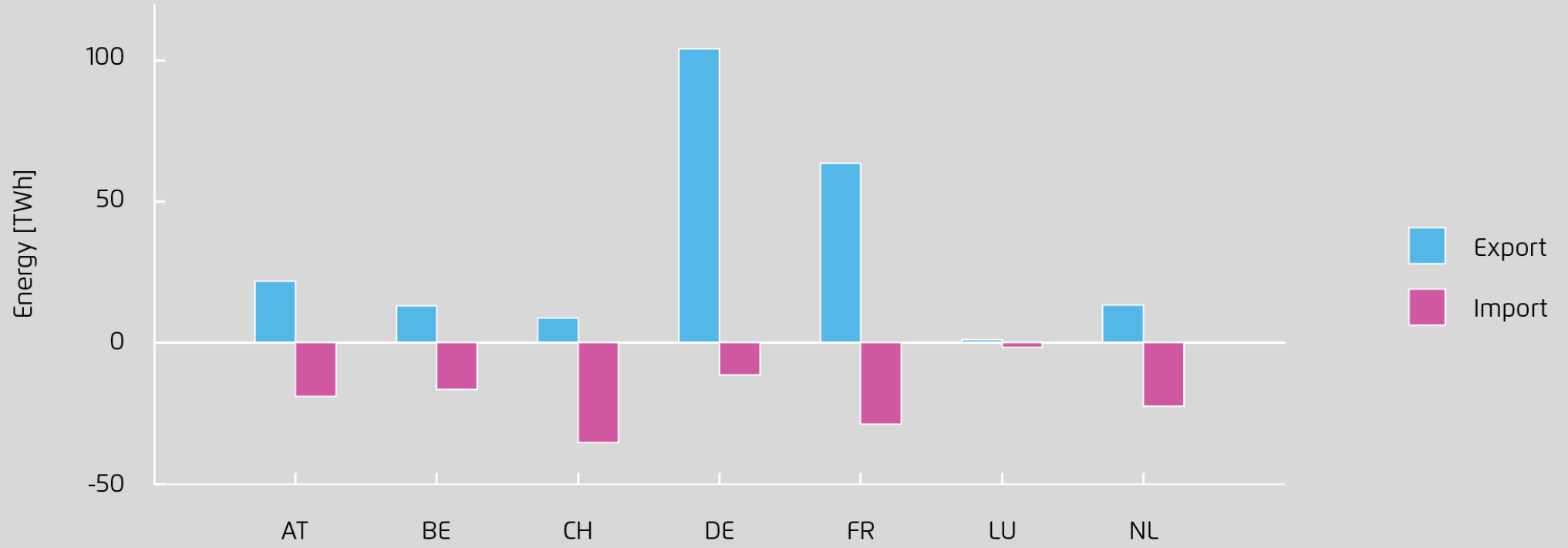



Fraunhofer IWES (2015)

- Curtailment is greatly reduced by market integration
  - Curtailment in autarchy case is ten times higher due to lack of exchange options with other regions
  - Additional flexibility options (not modelled) such as new storage, demand response would allow remaining surplus power to be utilised
- Avoiding curtailment altogether would be difficult to achieve just by increasing transfer capacities, as highly correlated feed-in situations can occur
- Not only cross-border grids are important, but also enough transfer capacities within countries must be available

# Market integration enables to deal with domestic deficits and surpluses: Each country is sometimes importing, sometimes exporting

Exports and imports of the PLEF countries in 2030

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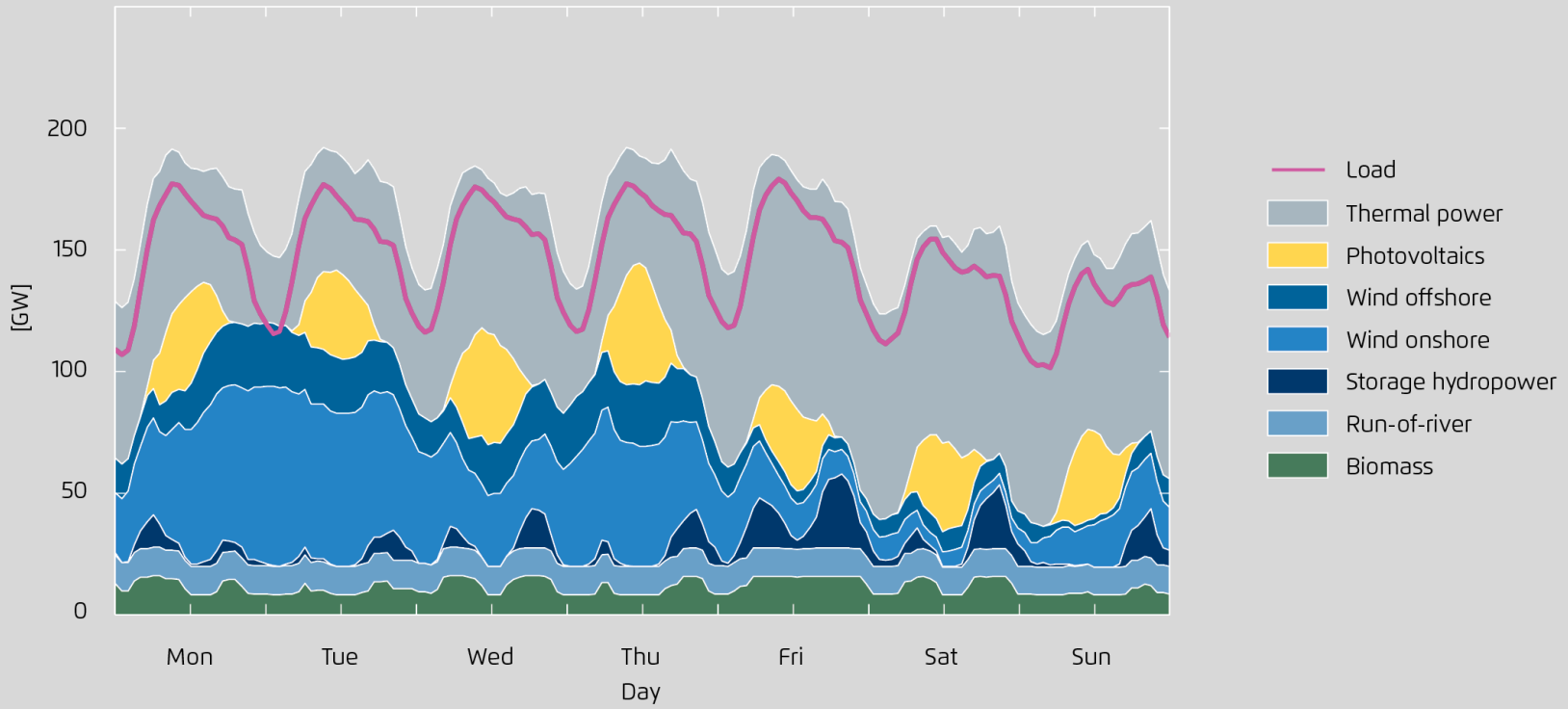
# Summary: Market integration effects

- → Market integration reduces flexibility requirements through geographical smoothing
  - → Reduction of hourly wind onshore ramps ~50% compared to national case
- → Market integration minimises curtailment of fluctuating renewables
  - → Reduction of 90% compared to national autarchy
- → Market integration is beneficial for all, as countries are sometimes exporters, sometimes importers
  - → (Over the year, of course, they are either net exporters or net importers)

# The “remaining” flexibility challenge
## (after market integration)

# We need a flexible power system to manage remaining ramps from variable renewable energies

Electricity production and consumption in CWE / Pentalateral Energy Forum* region, calendar week 32 - 2030

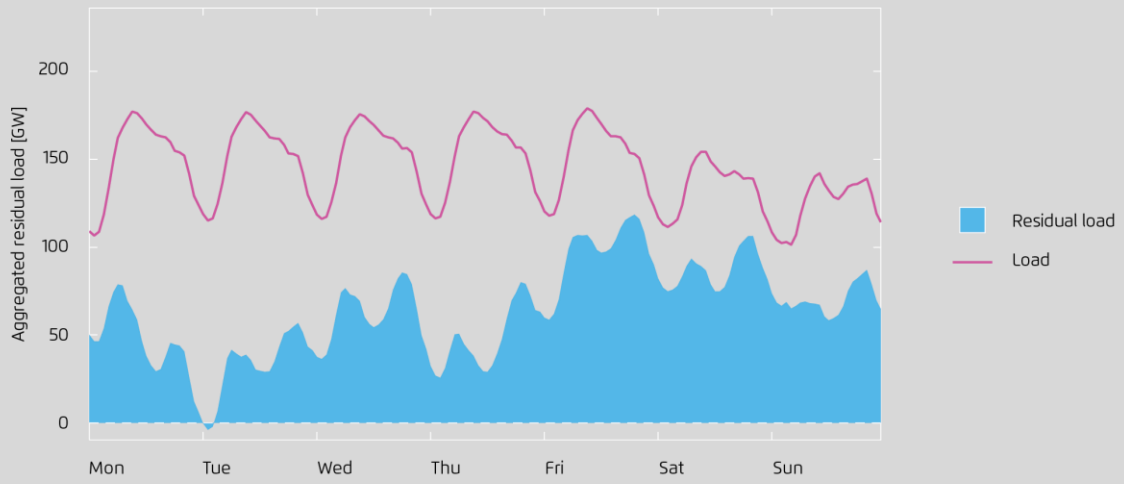



Fraunhofer IWES (2015)

*AT, BE, CH, DE, FR, LU, NL

# Residual load* will show steeper ramps, baseload needs reduce; Market price signals need to incentivise flexibility options

(Residual) load in PLEF/CWE region (calendar week 32 - 2030)

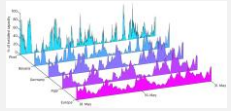



Fraunhofer IWES (2015)

*Load minus non-dispatchable renewables

**Important flexibility options**

Grids (domestic & cross-border)
➔ enabling smoothing effect



Partial curtailment of wind and solar power

Flexible fossil and biomass plants (incl. CHP with heat storage & Power-to-Heat)

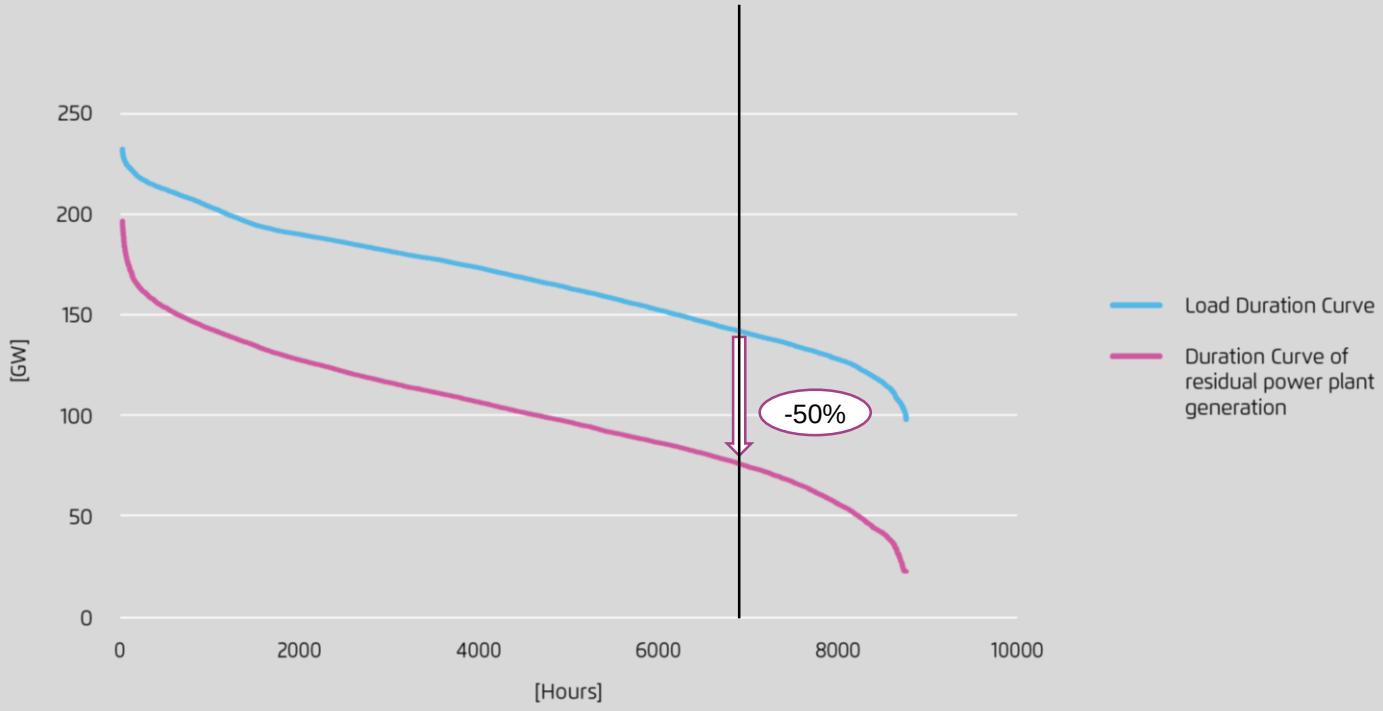
Focus in the following

Demand Side Management

Storage (Hydro; Batteries, Power-to-X)

# The need for baseload power plants is significantly reduced in 2030

Load duration curve, duration curve of generation of residual power plant park for PLEF* 2030




Agora Energiewende based on Fraunhofer IWES (2015)

*AT, BE, CH, DE, FR, LU, NL; Weather year 2011

→ 30% wind and PV (~2030) reduce capacity needs for power plants running more than 7000hrs per year by 50%;

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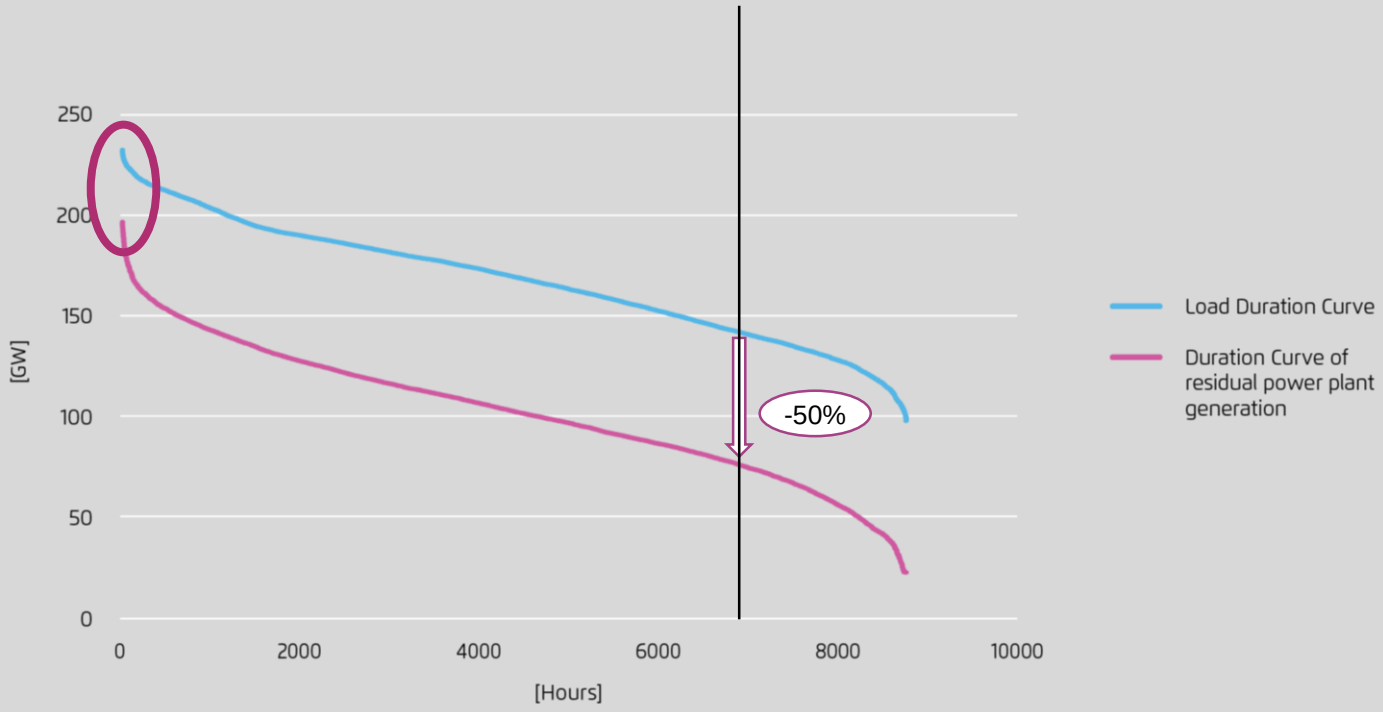


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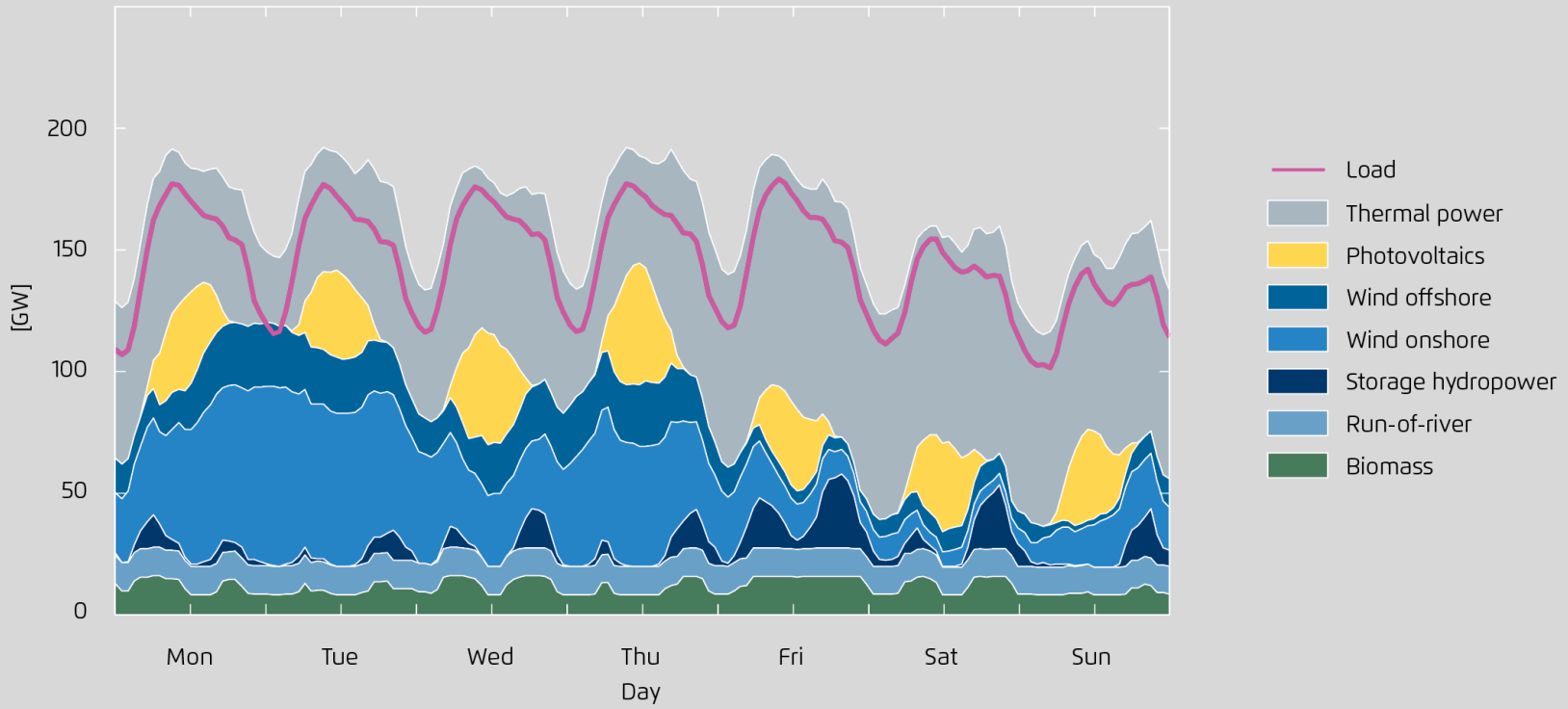
→ 30% wind and PV (~2030) reduce capacity needs for power plants running more than 7000hrs per year by 50%;

→ Peak load needs are reduced less strongly

# Residual power plant park to react w.r.t. both to short term output fluctuations…

Power generation in the PLEF* region with high vRES (calendar week 32)

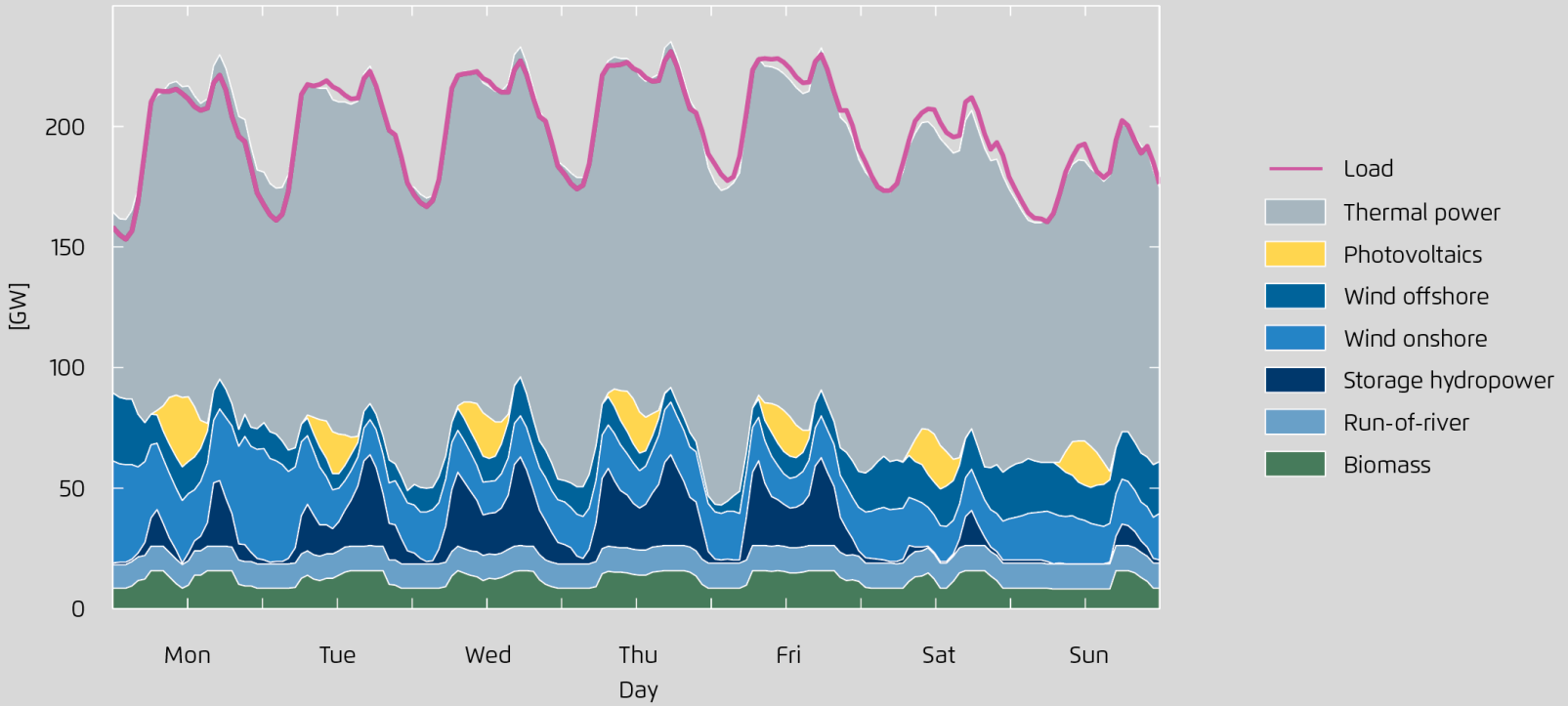



Fraunhofer IWES (2015)

*AT, BE, CH, DE, FR, LU, NL

# Residual power plant park to react w.r.t. both to short term output fluctuations and longer-term backup

Power generation in the PLEF* region with little vRES (calendar week 3)




Fraunhofer IWES (2015)

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# Selected country-specific results

## Germany
## France
## BENELUX
## Alpine countries Austria & Switzerland

# Germany's residual power plant park is most affected in the PLEF region: Increased ramping requirements, partial load operation and more short-term starts and stops

1h and 20 h ramps of the German residual power plant park vs. prevailing generation level for 2013 and 2030 for integration scenario


Agora Energiewende based on Fraunhofer IWES (2015)

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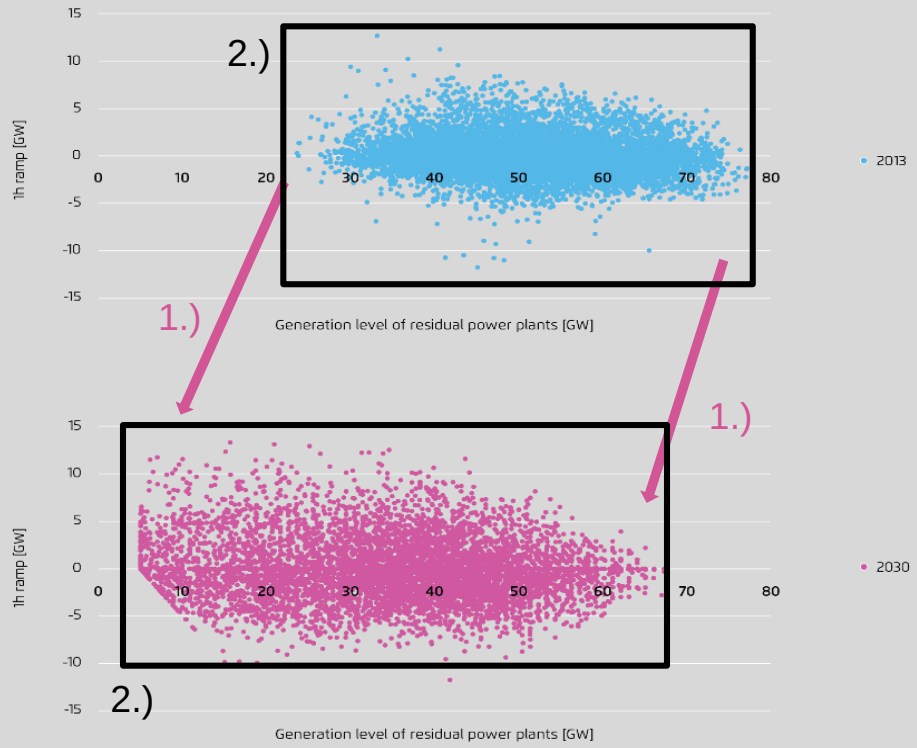


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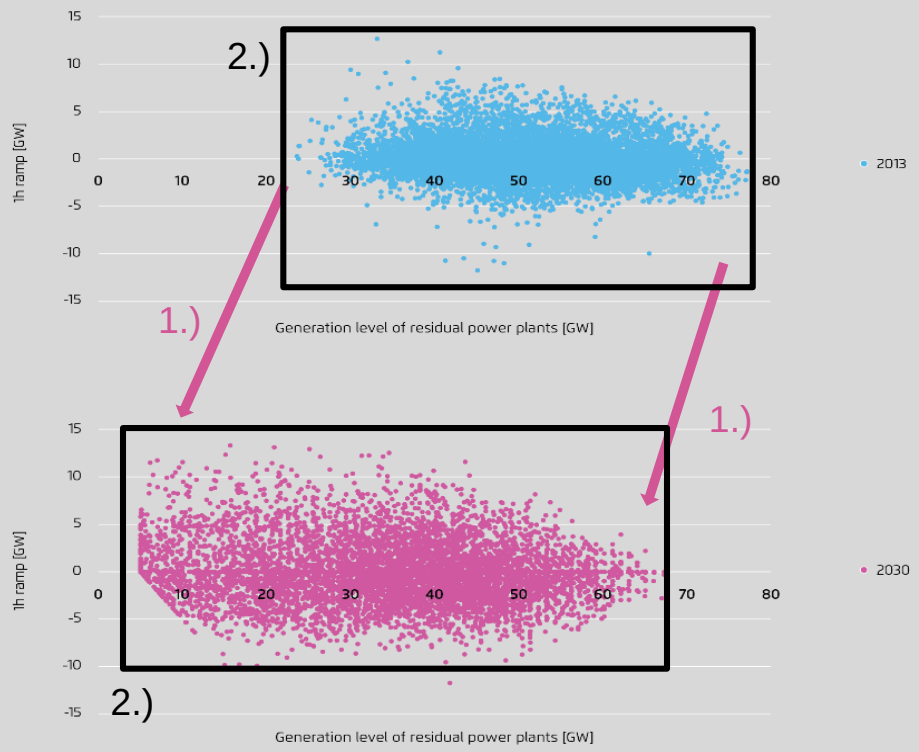


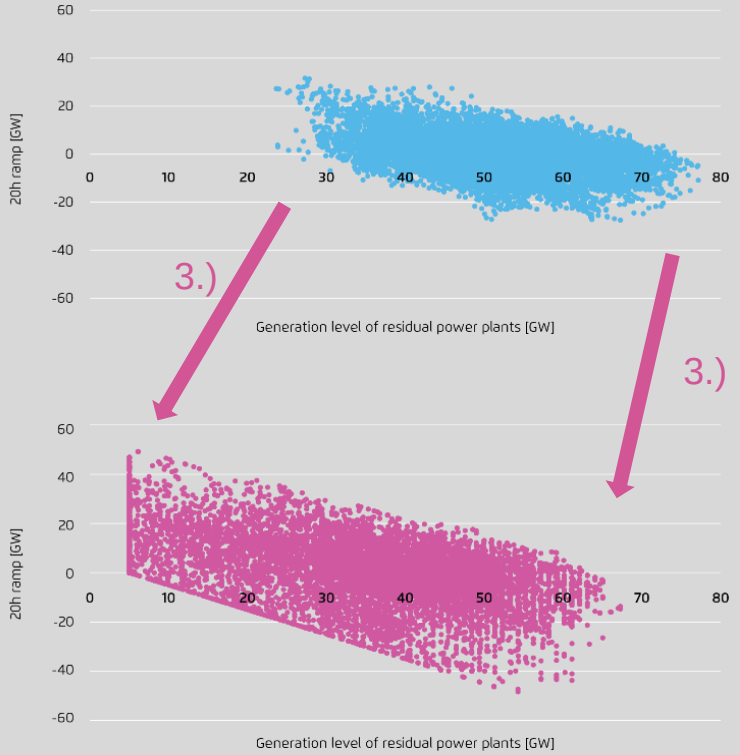


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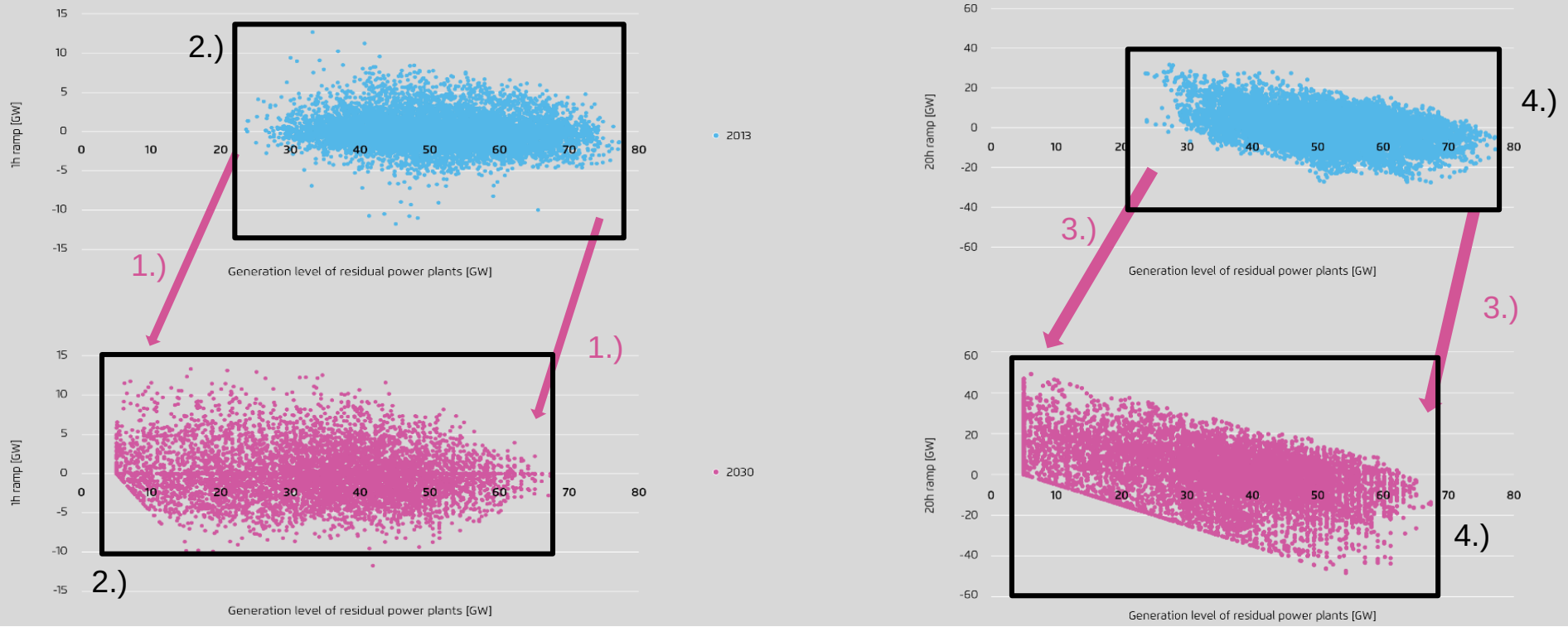
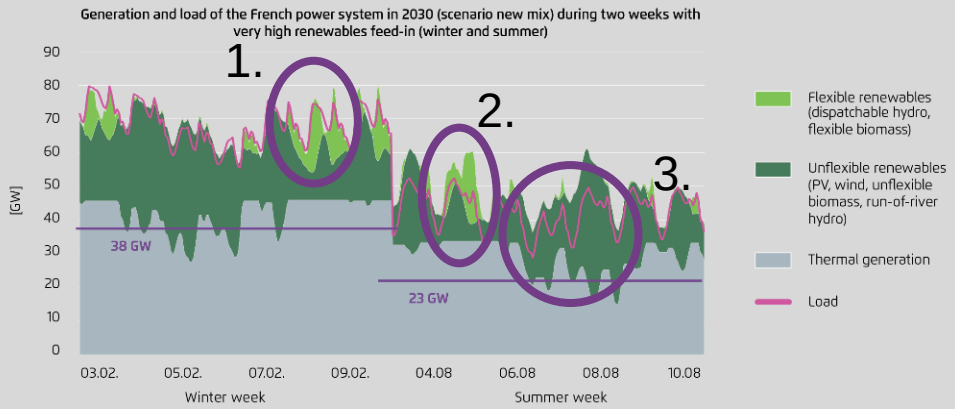
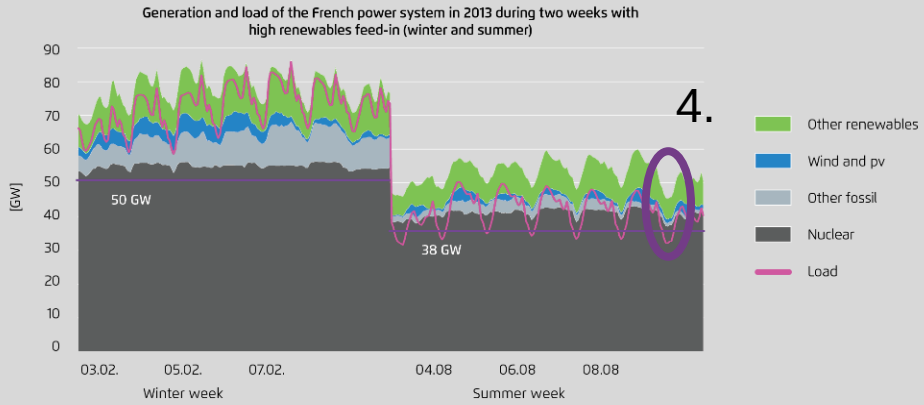



Agora Energiewende based on Fraunhofer IWES (2015)

# The diversification strategy for the French power mix : a balance of variable renewables, hydropower and nuclear

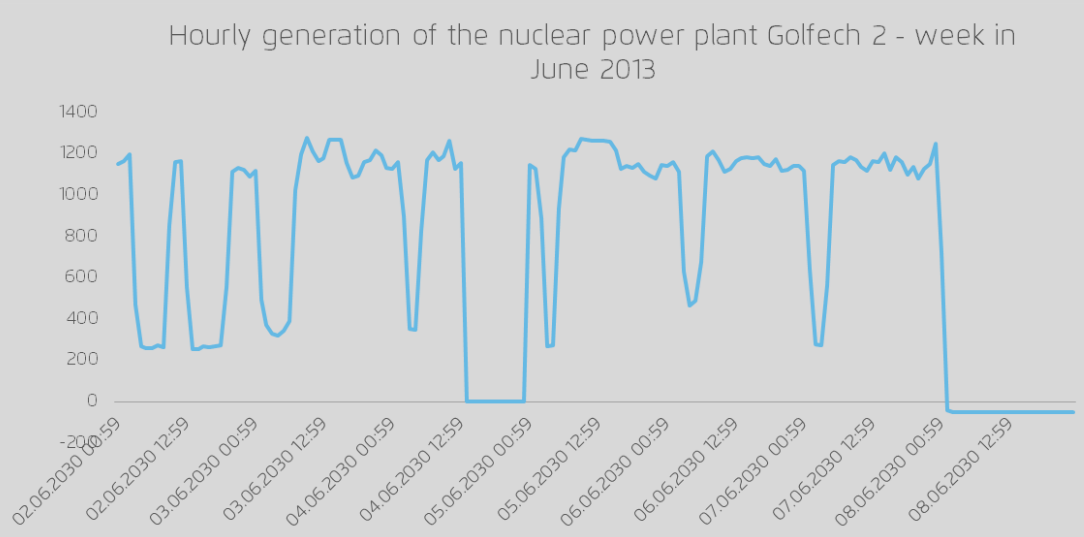



- 1. Hydropower is the flexibility asset of the French power system. It can play a significant role for balancing the v-RES in France
- 2. Large exports will continue to happen in days with high share of renewables
- 3. With 25% v-RES in the French mix, a specific flexibility challenge will occur during some specific days, especially in summer
- 4. With its load following capabilities, the nuclear fleet can respond in part to increasing flexibility needs

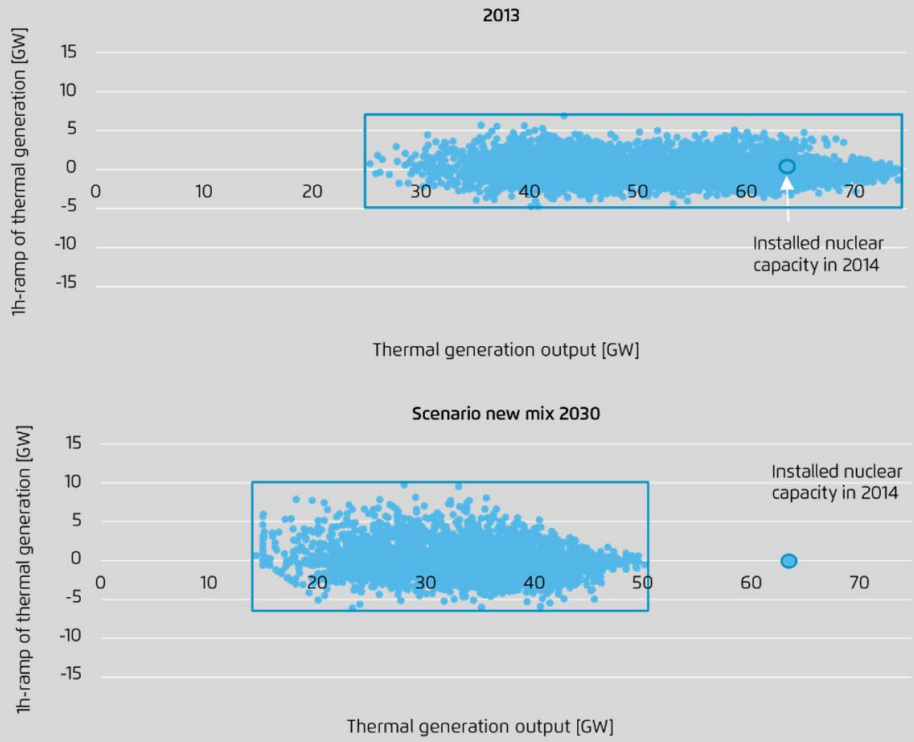
# The nuclear fleet can respond in part to increasing flexibility needs. Incorporating 40% RES requires nevertheless some resizing of the park and (moderate) changes in its short-term operation.

Hourly generation of the nuclear power plant Golfech 2 (week in June 2013)




Agora Energiewende based on Fraunhofer IWES (2015)

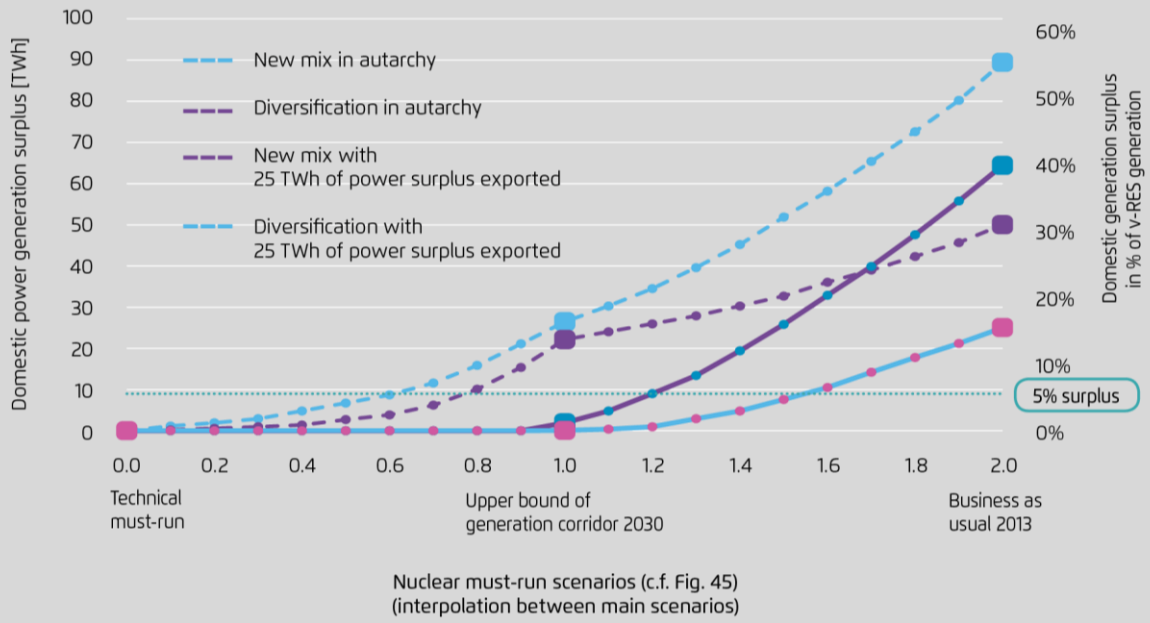
Thermal generation ramping (1-hour ramps) as a function of generation output




Agora Energiewende based on Fraunhofer IWES (2015)

# Cross-border exchanges and other flexibility options can significantly ease the integration of vRES in the French power mix

Level of domestic generation surplus in 2030 under different must-run scenarios



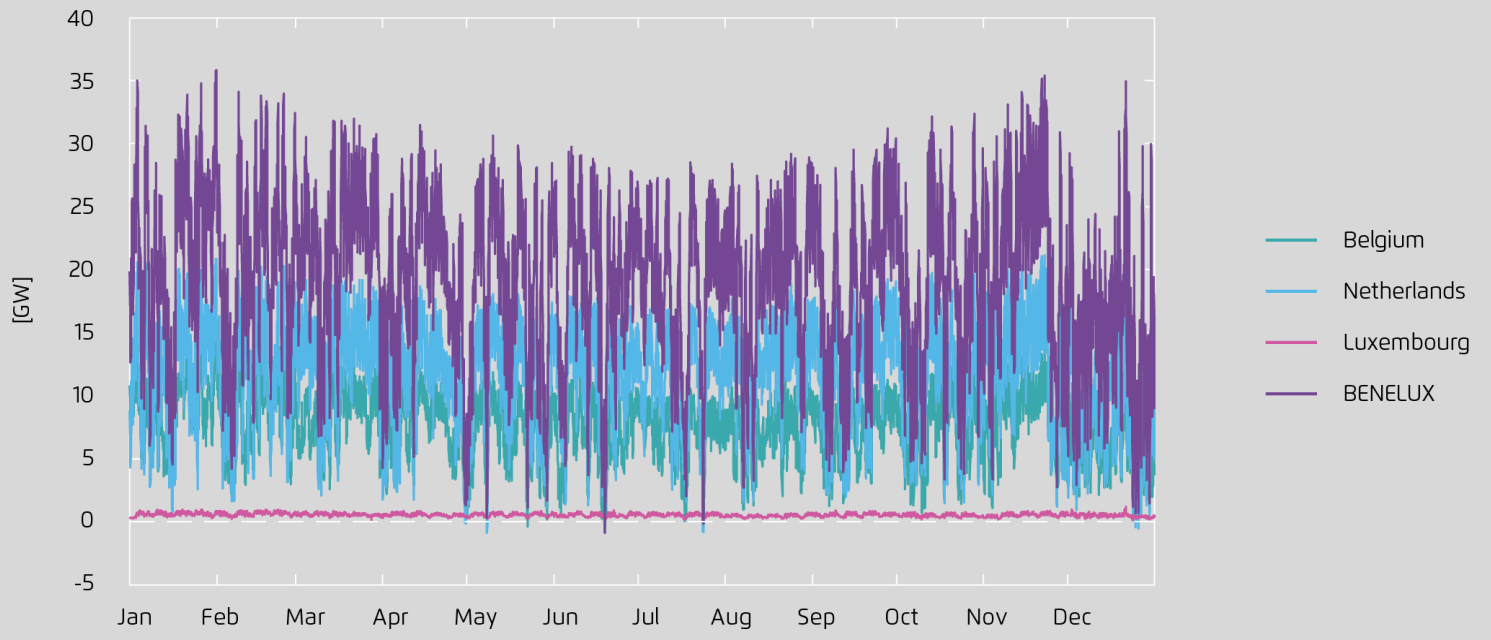

Agora Energiewende based on Fraunhofer IWES (2015)

→ Keeping higher nuclear must-run (for economic or technical reasons) would exponentially increase the power generation surplus

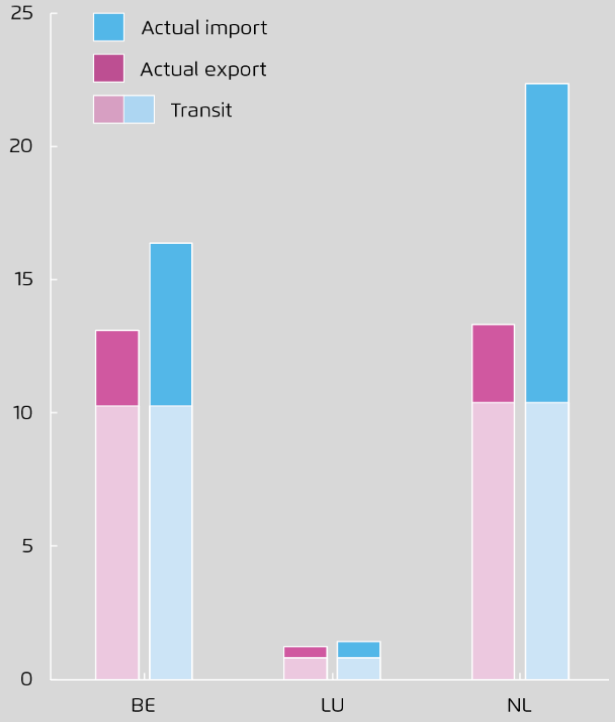
→ Other national flexibility options (DSM, PtH, Punctual curtailment, storage) reduce the conflict between integrating renewables and keeping a higher share of nuclear base-load.

# The BENELUX “power hub”: Variability of residual load in the BENELUX countries is managed through imports and exports. BENELUX as a transit region enables flexibility for other countries in Europe

Time series of the residual load in the BENELUX



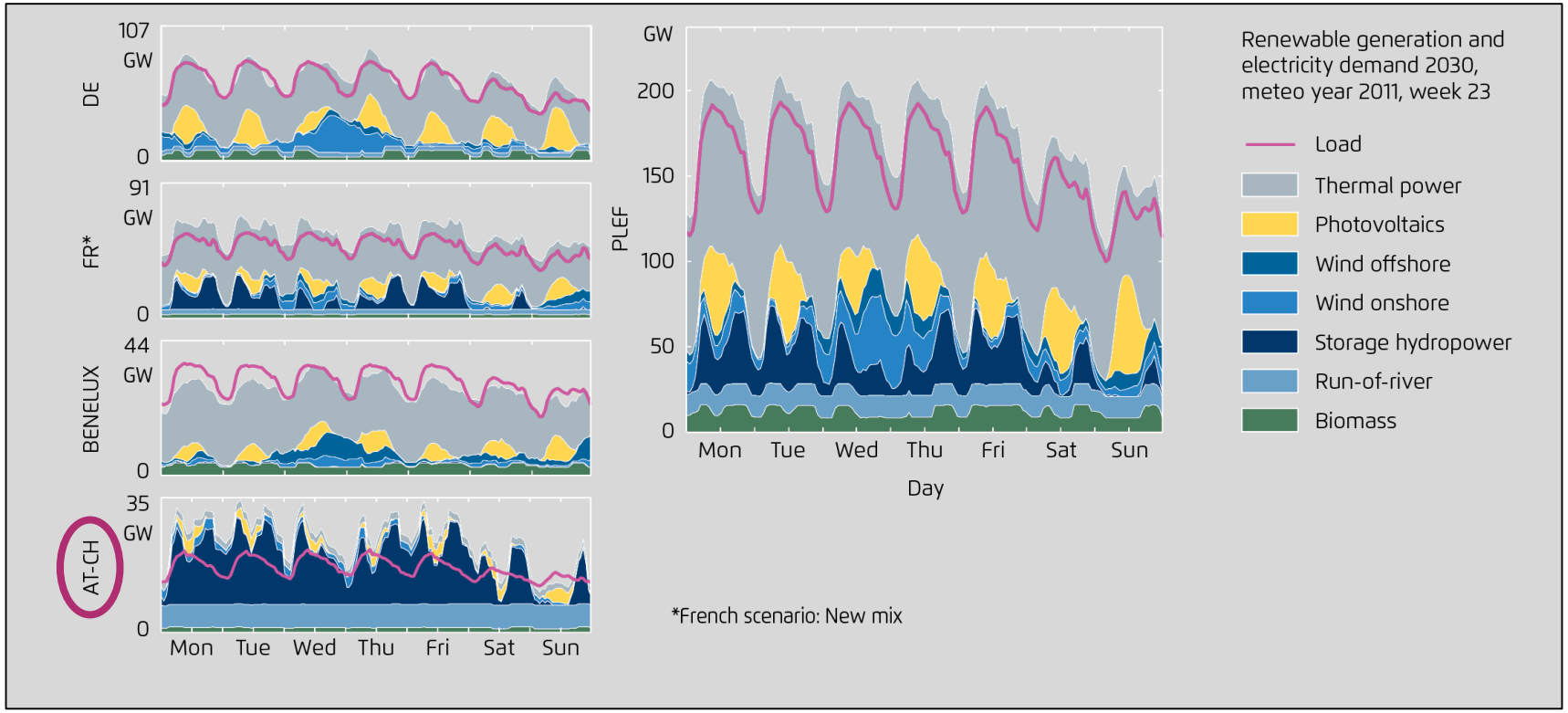

Annual imports and exports in the BENELUX




Fraunhofer IWES (2015

# One regional market, high PV and low wind generation, high wind and low PV, low PV and low wind… …and two constants: The role of Austrian and Swiss hydro storage for the PLEF region

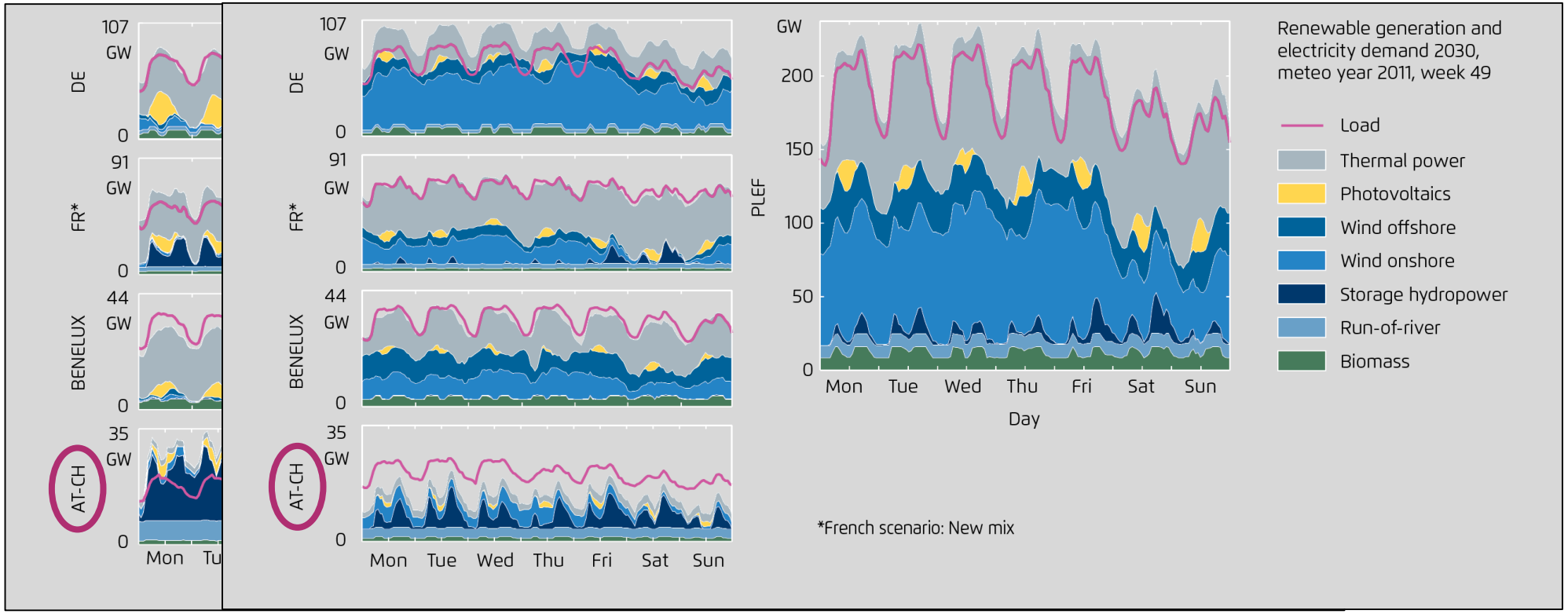
Generation and demand in 2030 in CWE / Region Pentalateral Energy Forum




Source: Fraunhofer IWES (2015)

# One regional market, high PV and low wind generation, high wind and low PV, low PV and low wind… …and two constants: The role of Austrian and Swiss hydro storage for the PLEF region

Generation and demand in 2030 in CWE / Region Pentalateral Energy Forum




Source: Fraunhofer IWES (2015)

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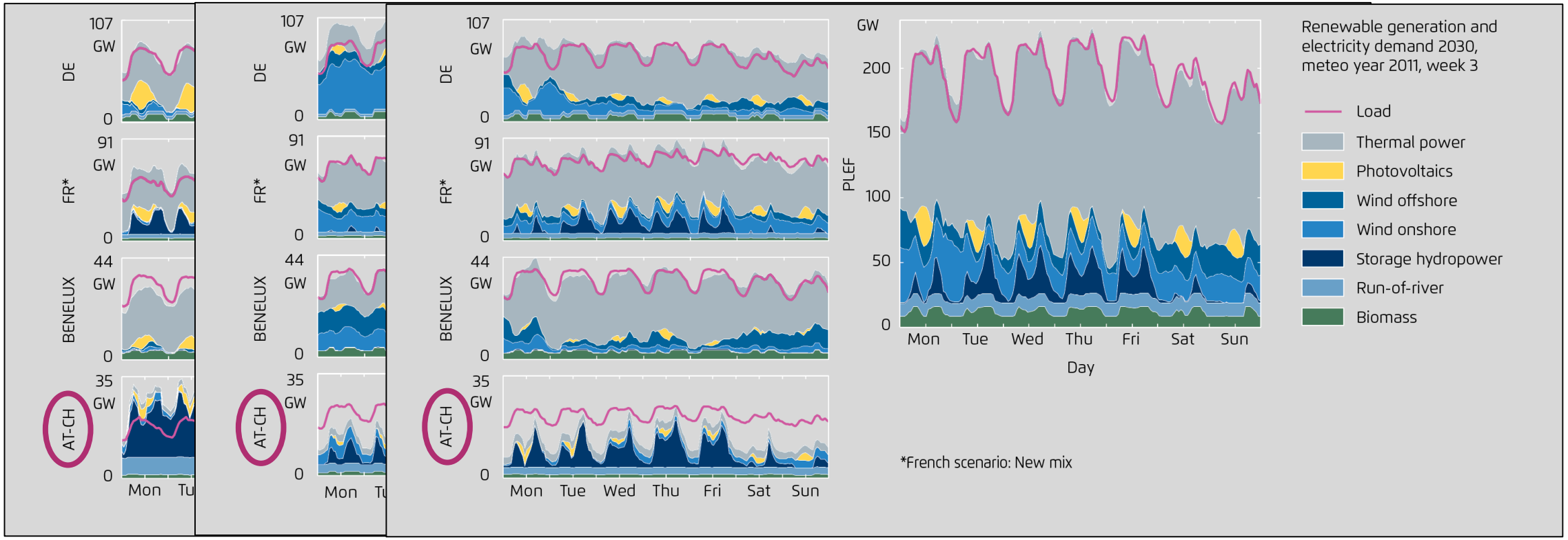



Source: Fraunhofer IWES (2015)

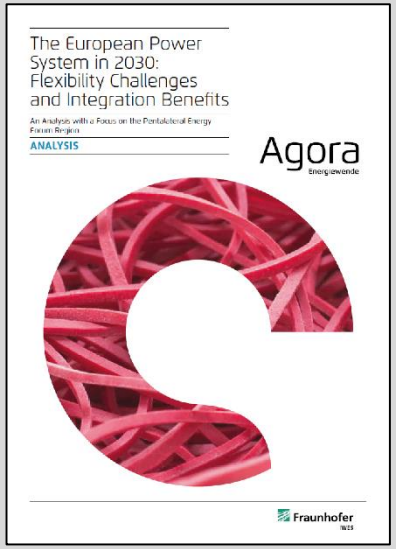
# Flexibility Challenges and Integration Benefits: Main takeaways

- As wind and PV will shape EU power systems (2030 share ~30%), increasing ***system flexibility*** is ***crucial***

- ***Power system integration*** mitigates flexibility needs due to smoothing effects. Hourly wind ***ramps decrease by ~50%*** comparing the national and European scale
  - Integration yields ***reduced gradients of residual load***, ***reduced balancing requirements***
  - Integration ***minimises renewables curtailment by 90%***

- Still, a ***more flexible power system is required***
  - The structure of the conventional power plant park and the way power plants operate will need to change: ***Less baseload, relatively more mid-merit and peak-load plants***
  - Both an ***active demand side*** and an ***adjusted power plant park*** will help manage flexibility challenges

- Flexibility potential is large, its development requires proactive policies
- A ***refined market design*** that stresses increased system flexibility is essential



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# Thanks very much!
# Any questions or comments?

Questions or Comments? Feel free to contact me:
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Agora Energiewende is a joint initiative
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# A note on market design: An Energy-Only Market 2.0 which eliminates flexibility barriers, incentivises flexibility & enables RES-E market integration as no-regret option

- Strong price signals are required to manage the complexity efficiently

- **Faster** day-ahead, intraday and balancing energy markets: From hourly to quarterly
- **Larger** short-term markets: Integrate across balancing areas
- **Link** spot market, balancing market and imbalance price signals
- **Minimise** fossil must-run:
  - Smart balancing energy products (and procurement)
  - RES-E, DSR as new balancing service providers

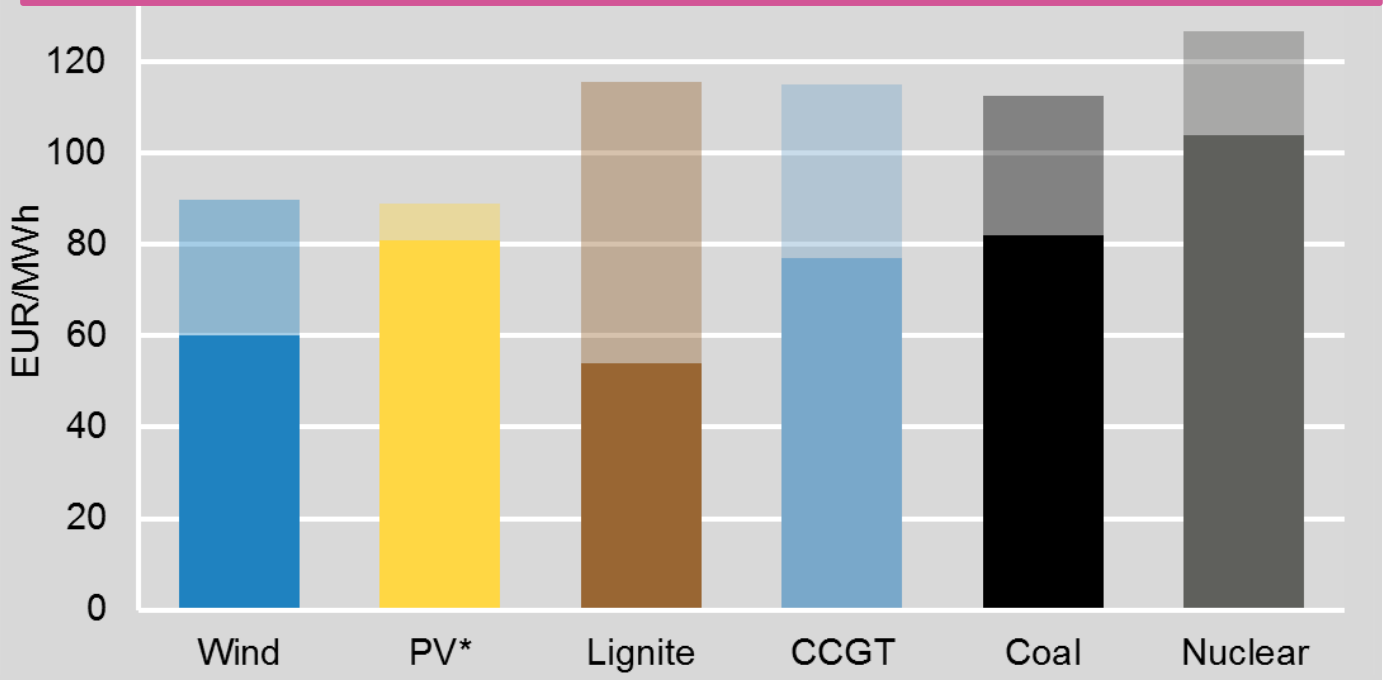
- Spot price as undistorted dispatch signal for all market parties


Source: RAP (2014)

# Onshore wind power and large-scale solar PV are cost competitive compared to other new conventional generation technologies

Range of levelised cost of electricity (LCOE) of new plants in 2015 in EUR/MWh

A mix of wind onshore, PV with gas turbines as backup costs ~70 EUR/MWh



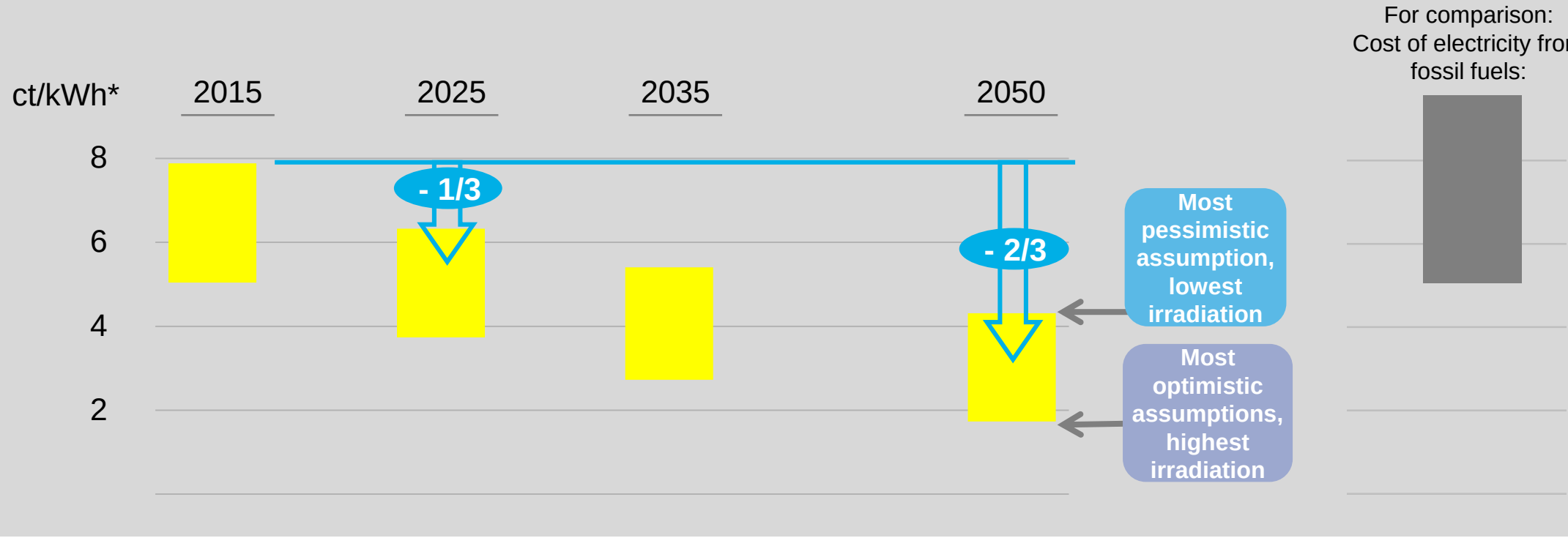

Agora Energiewende (2015)

*Ground-mounted PV, irradiation conditions central Europe. Cost for lignite heavily depend on CO2 price: Here 5-40 EUR/t CO2

- → Generation cost decrease from current 6-9ct/kWh for wind onshore and 8-9ct/kWh for large PV to 4-6ct/kWh for wind and PV during the next 10-15 years
- → Also considering integration costs, RES are cost competitive with new conventional plants
- → In countries with good wind and solar conditions, wind and PV will be cheaper than other generation options
- → Power system transformation towards high RES shares will occur

# Solar PV will soon be the cheapest electricity generation technology in many regions of the world

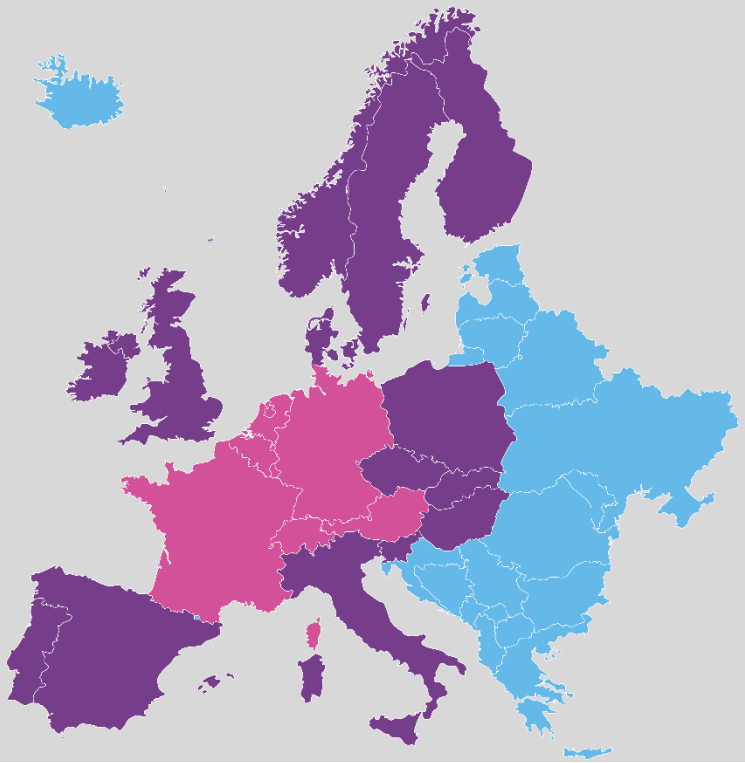
LCOE of new ground-mounted solar PV plants in Southern and Central Europe




*Real values in EUR 2014; bandwidth represent different scenarios of market, technology and cost development, as well as power plant location between south of Germany (1190 kWh/kWp/y) and south of Spain (1680 kWh/kWp/y). Source: Fraunhofer ISE (2015)

# Project scope: Implications of further growth of wind power and solar PV on power system

Power system model: PLEF countries* (pink) and other European countries (violet)



Fraunhofer IWES (2015)

* AT, BE, CH, DE, FR, LU, NL

**The EU power systems in 2030**

- What are implications of further growth of wind power and solar PV on power system?
  - Quantification of flexibility requirements arising from fluctuating, weather-dependent production of wind and PV
  - How can market integration help mitigating the flexibility challenge?
- Fraunhofer IWES conducted in-depth, model based analysis of future power system scenarios
- Results focus on **Pentalateral Energy Forum (PLEF)** region