The Integration Costs of Wind and Solar Power

An overview of the Debate on the Effects of Adding Wind energy and Solar Photovoltaic into Power Systems

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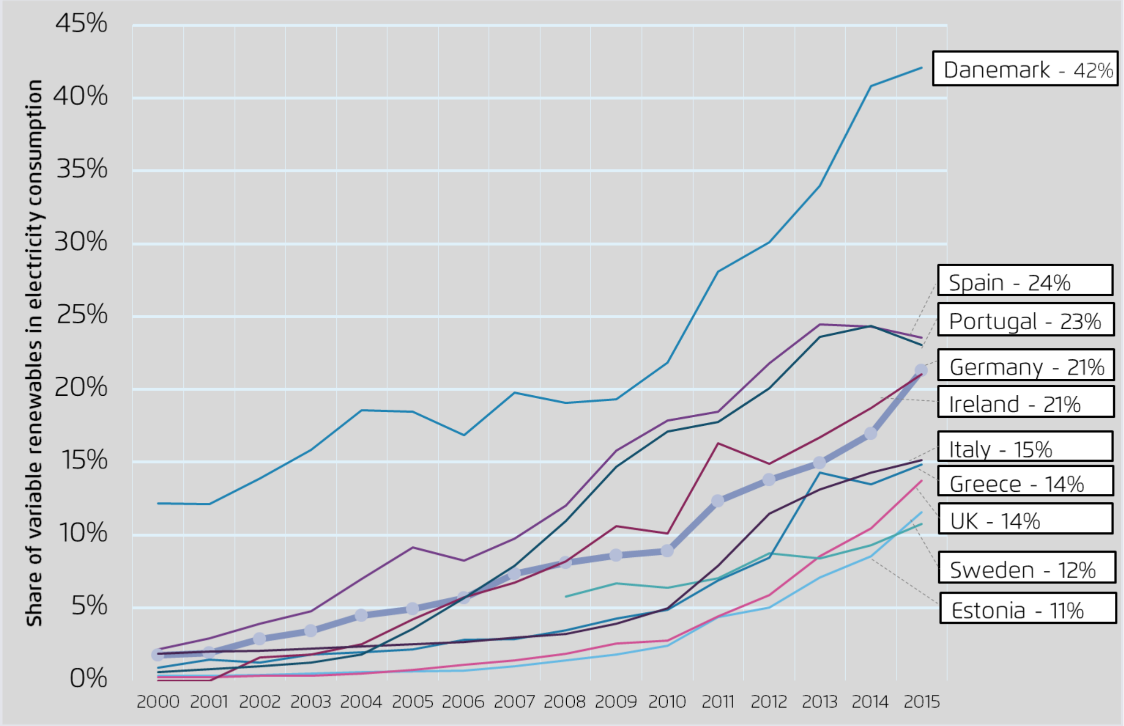
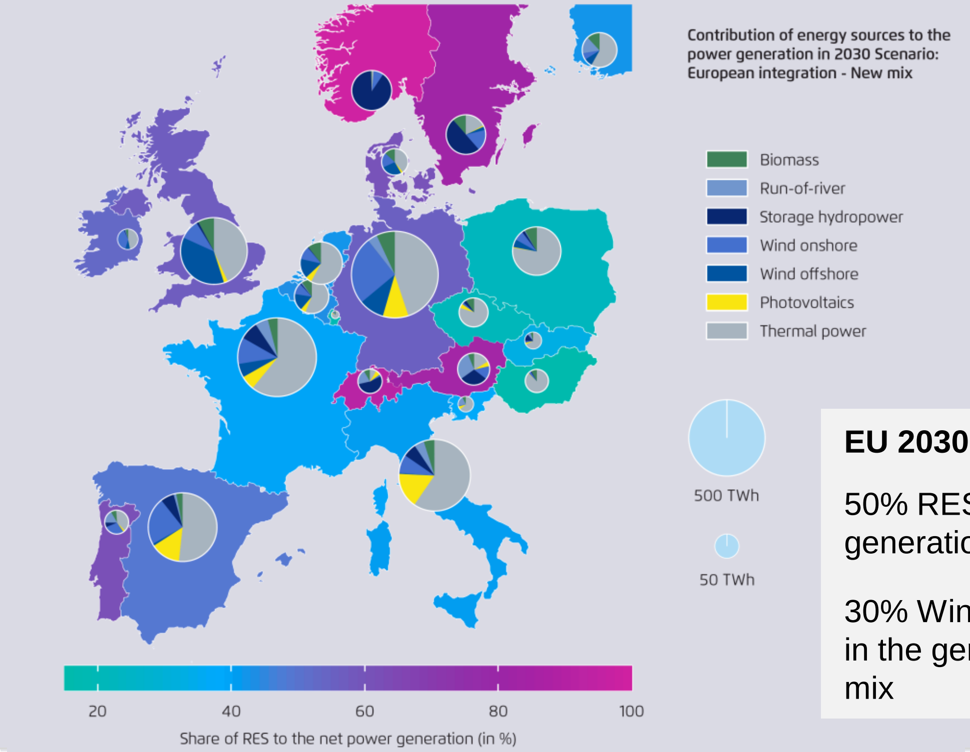
Wind power and solar PV become key pillars of the European power system

Development of variable renewables in the 10 EU countries with shares above 10% in 2015



IEA (2016), adapted from Hirth (2015), data for 2015 runs until 10/2015

RES-E share in the EU generation mix 2030



EU 2030

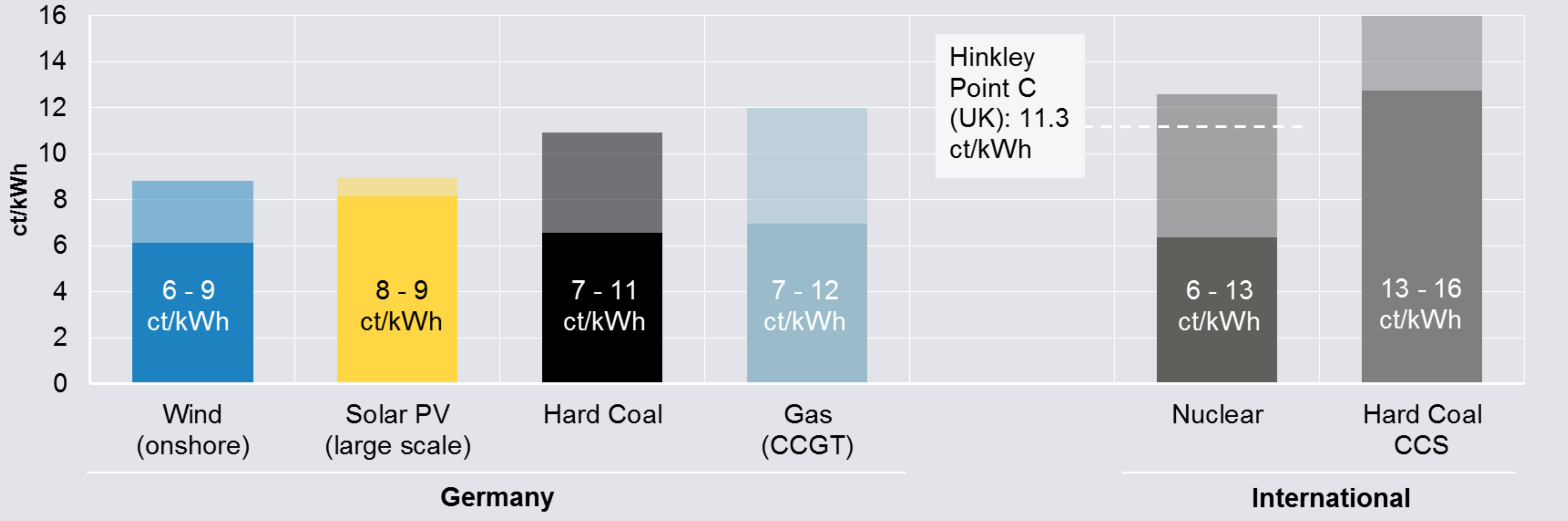
50% RES-E in the generation mix

30% Wind and PV in the generation mix

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

Project scope : generation costs alone (as captured e.g. by the LCOE) is not sufficient. A system perspective must be embraced in order to capture the economic challenges of power sector transformation.

Range* of levelized cost of electricity (LCOE) 2015



Agora Energiewende (2015e)

* based on varying utilization, CO_2-price and investment cost

„Integration costs“ is a concept used to compare the total costs of wind and solar energy with those of other technologies: it is controversial and varies tremendously depending on power systems, perspectives and methodologies.

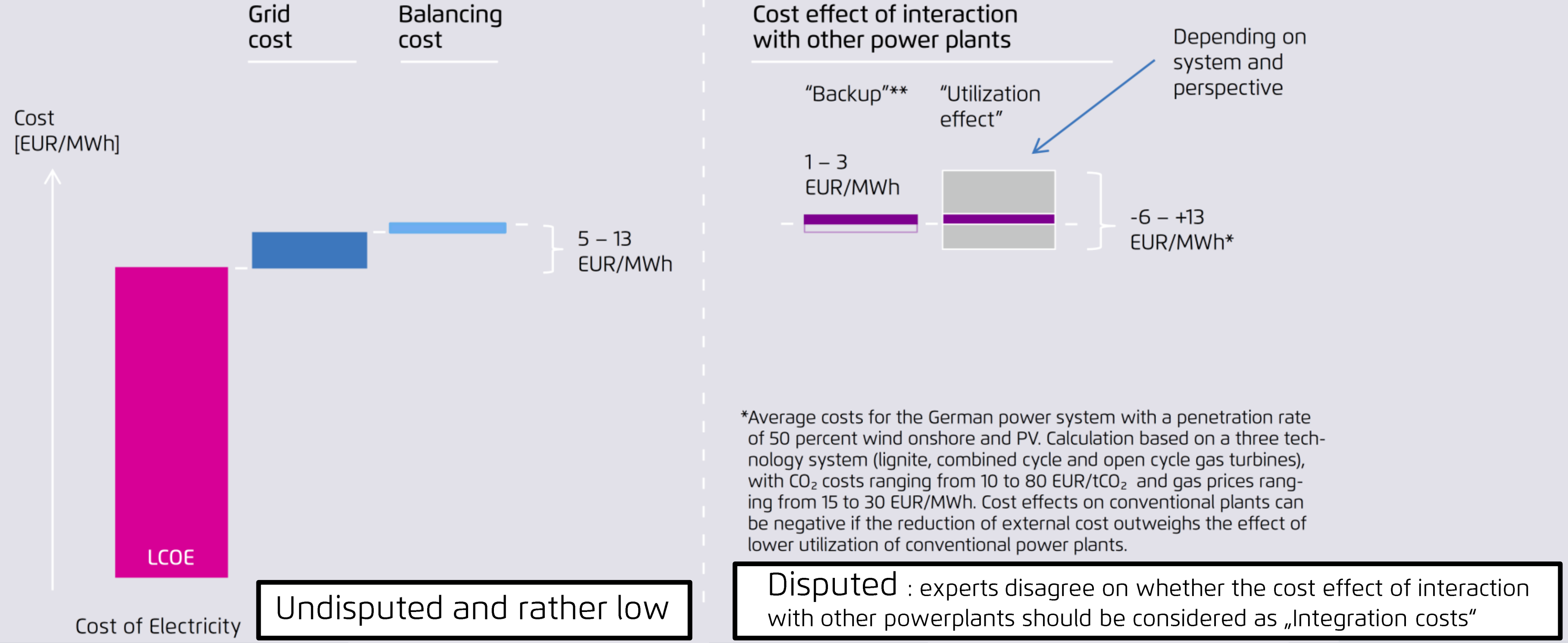
Overview of key discussion points surrounding integration costs

Area of discussion	Key controversy / difference of perspectives		
Calculation of costs	Lost revenues	vs.	Cost to consumers
	Non-optimized approach	vs.	Optimized approach
	Legacy system	vs.	Adapted system
Attribution of costs	Integration costs of new technologies	vs.	Interaction costs between technologies
System boundaries	Low internalization of external costs	vs.	High internalization of external costs
Context of the analysis	Marginal costs (scientific analysis)	vs.	Average costs (political debate)
Focus of the analysis	System in transition	vs.	System after transition

Own illustration

Three components are typically discussed under the term "integration costs": grid costs, balancing costs and the cost effects of vRES on conventional power plants (so-called "utilization effect")

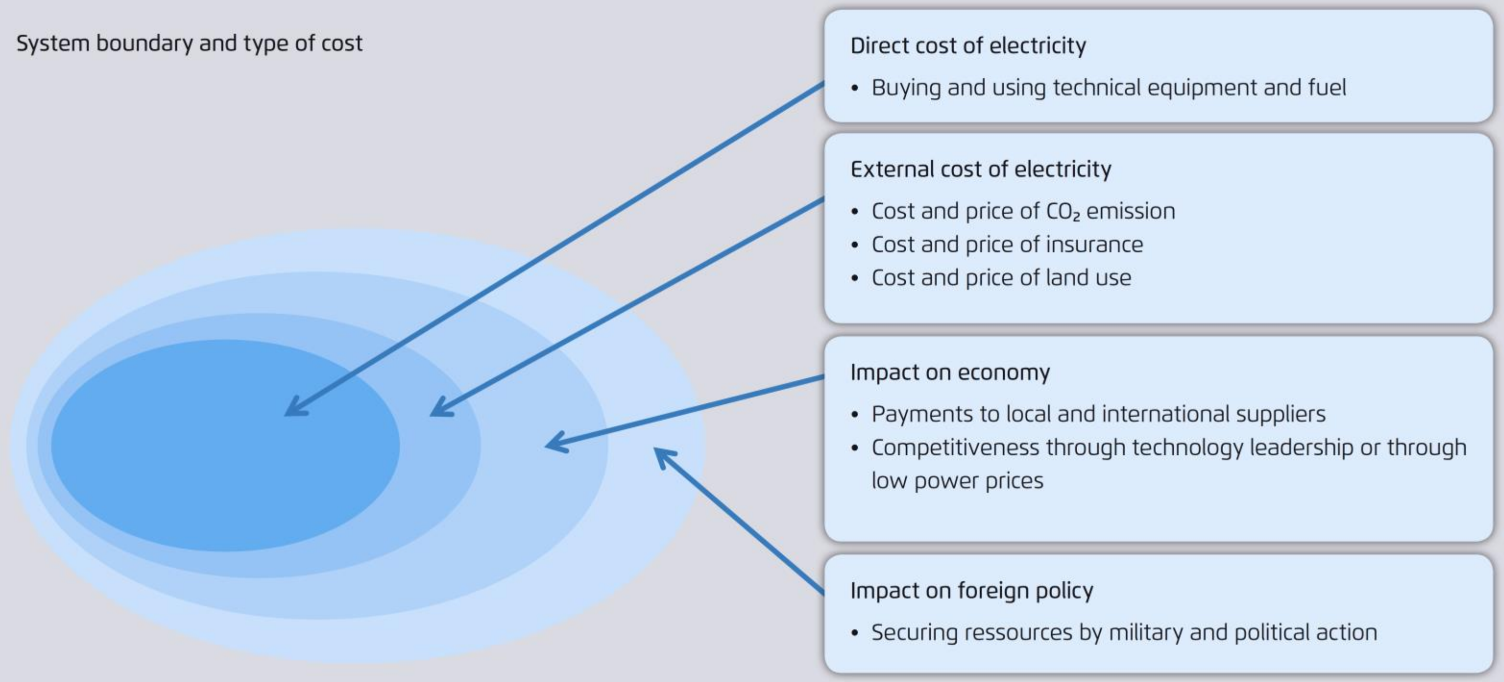
Overview of components discussed under „integration costs“



Agora Energiewende (2015)

While a definition of „integration“ may be challenging, an objective definition of „costs“ is likely to be impossible

Overview of possible system boundaries and types of costs and benefits

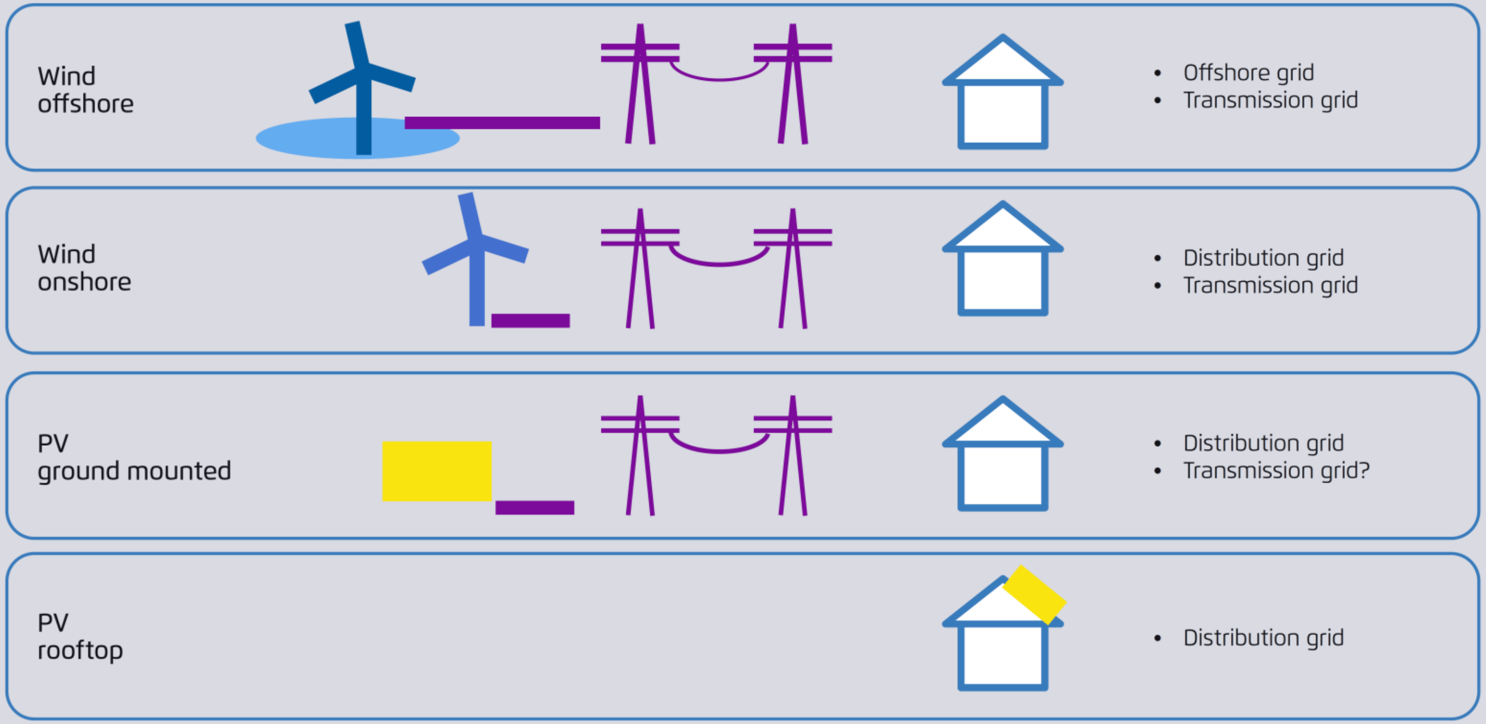


Adapted from NEA (2012)

Grid and balancing costs

Certain costs for building grids and balancing can be attributed without much discussion to the addition of new capacities. Several challenges remain nevertheless in identifying these costs.

Overview of grid costs (distribution and transmission grid) for different renewable technologies



Grid costs include distribution and transmission grid costs, depending on technology

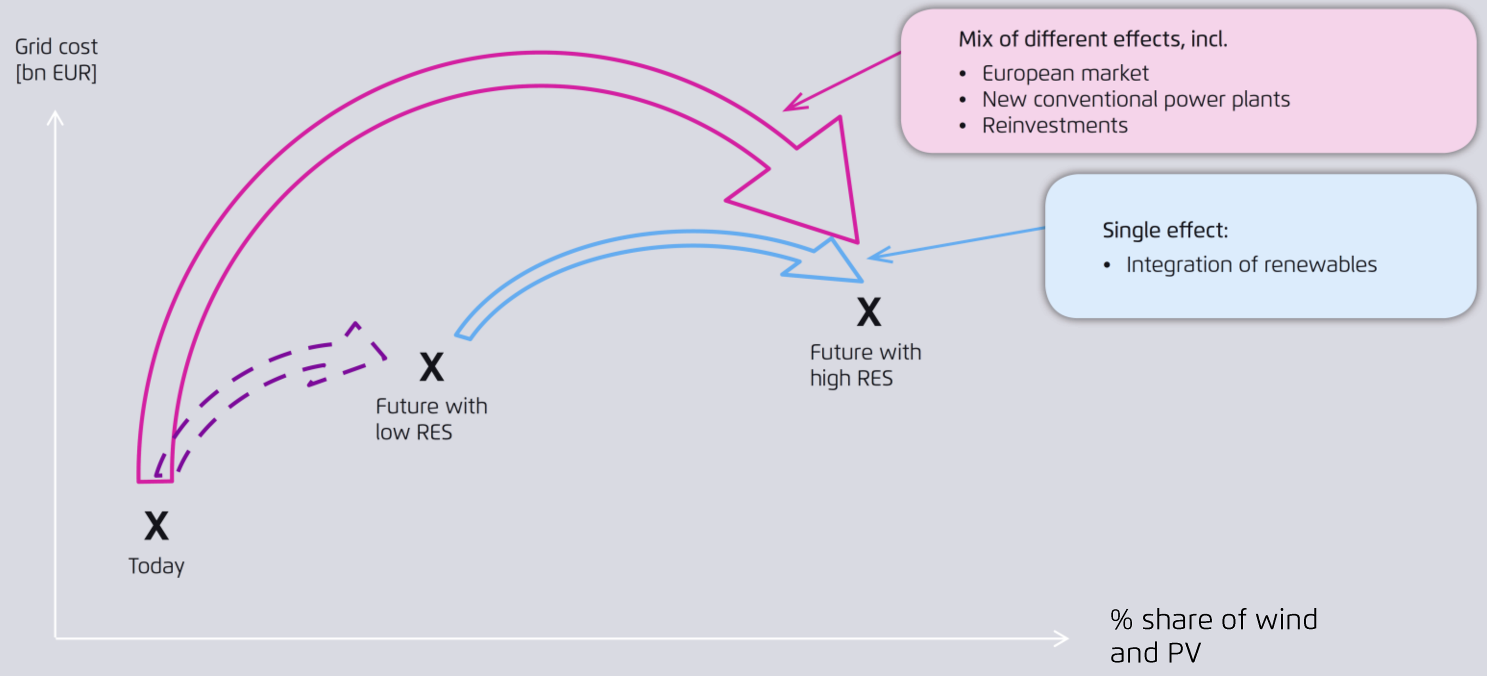
Distinguish **grid costs** from **generation costs** may not be straightforward, as trade offs exist between these two cost components (i.e. locating power plants at the sites with good resources or near customer demand?).

Curtailment of vRES can also reduce significantly grid costs, while increasing slightly generation costs.

Own illustration

Calculating grid costs due to renewable energies must be separated from other grid (re)investments

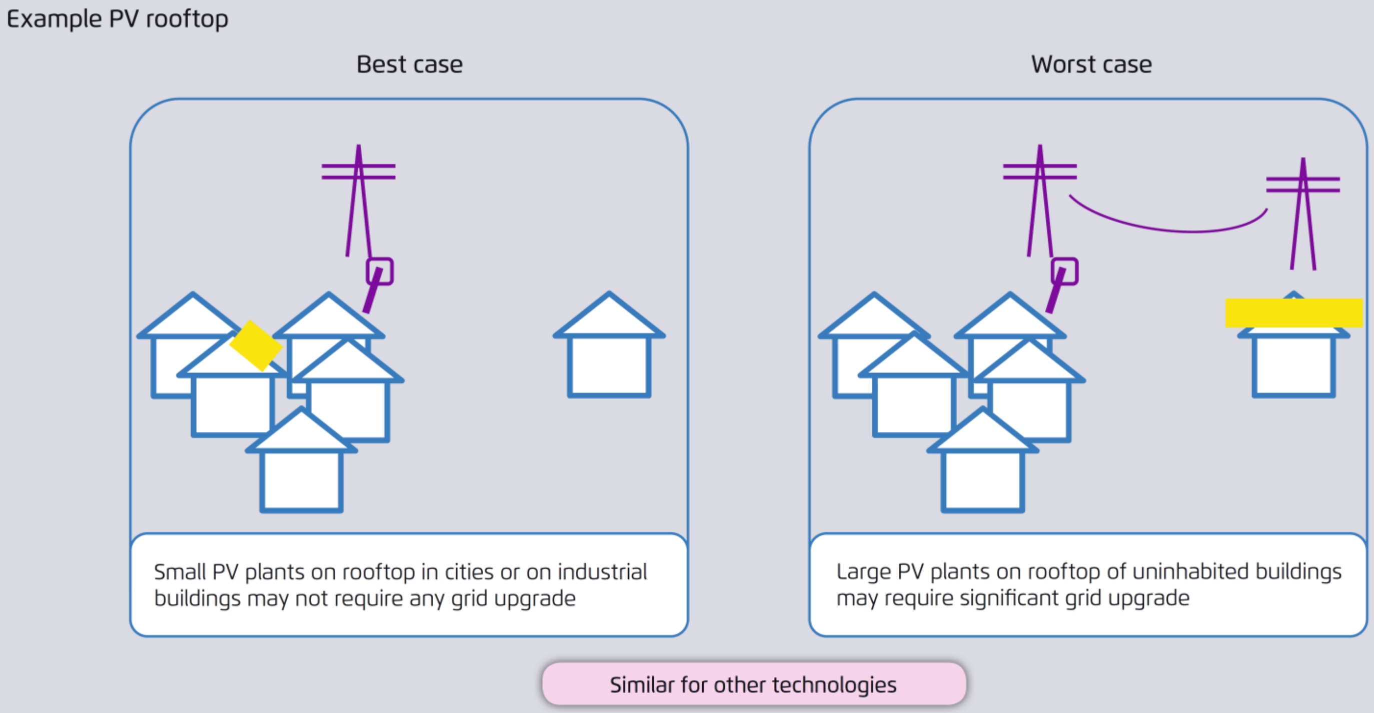
Approaches for calculating grid costs by comparing two different futures (one with low RES and one with high RES)



Own illustration

Grid costs depend strongly on the specific case and variation can be large

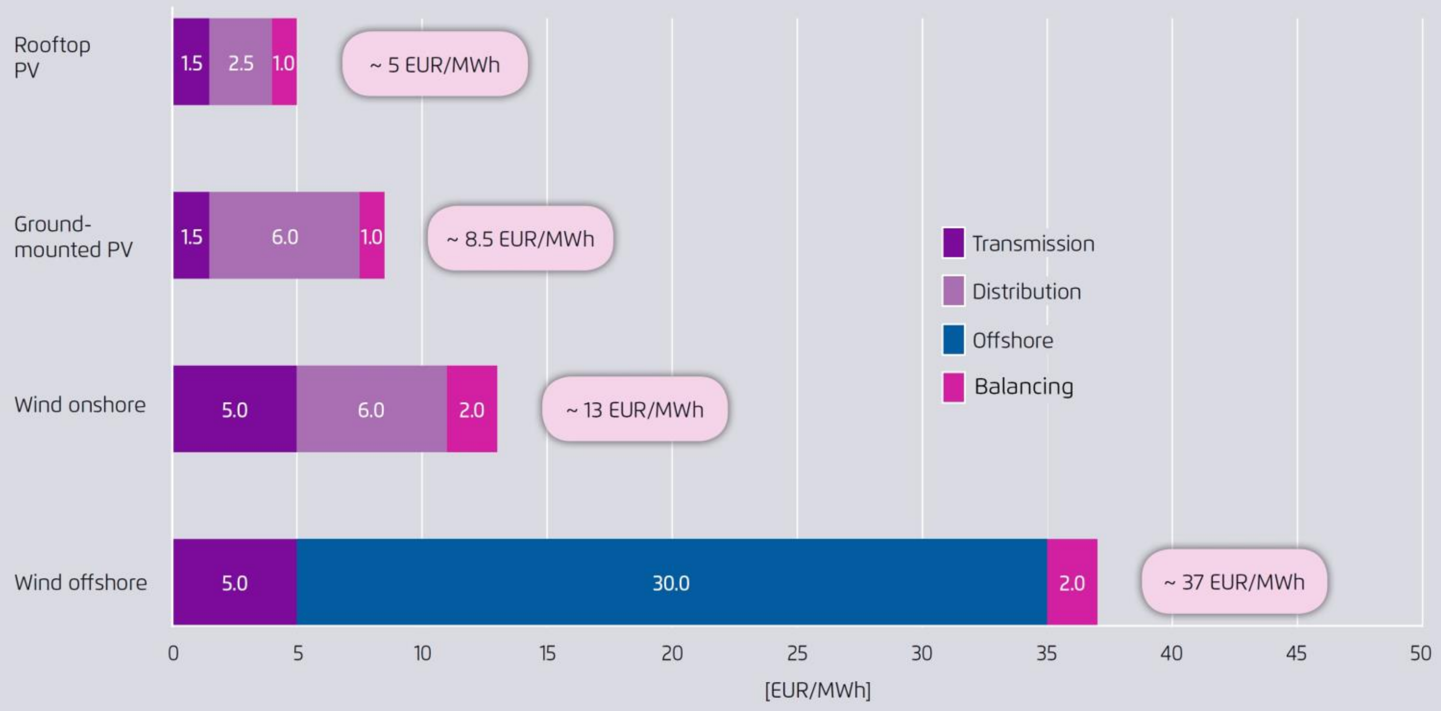
Best-case and worst-case examples of grid costs for rooftop solar PV



Own illustration

In economic studies, grid and balancing costs for PV and wind onshore are often estimated at +5 to +13 EUR/MWh, even with high shares of renewables. Grid costs for wind offshore are higher.

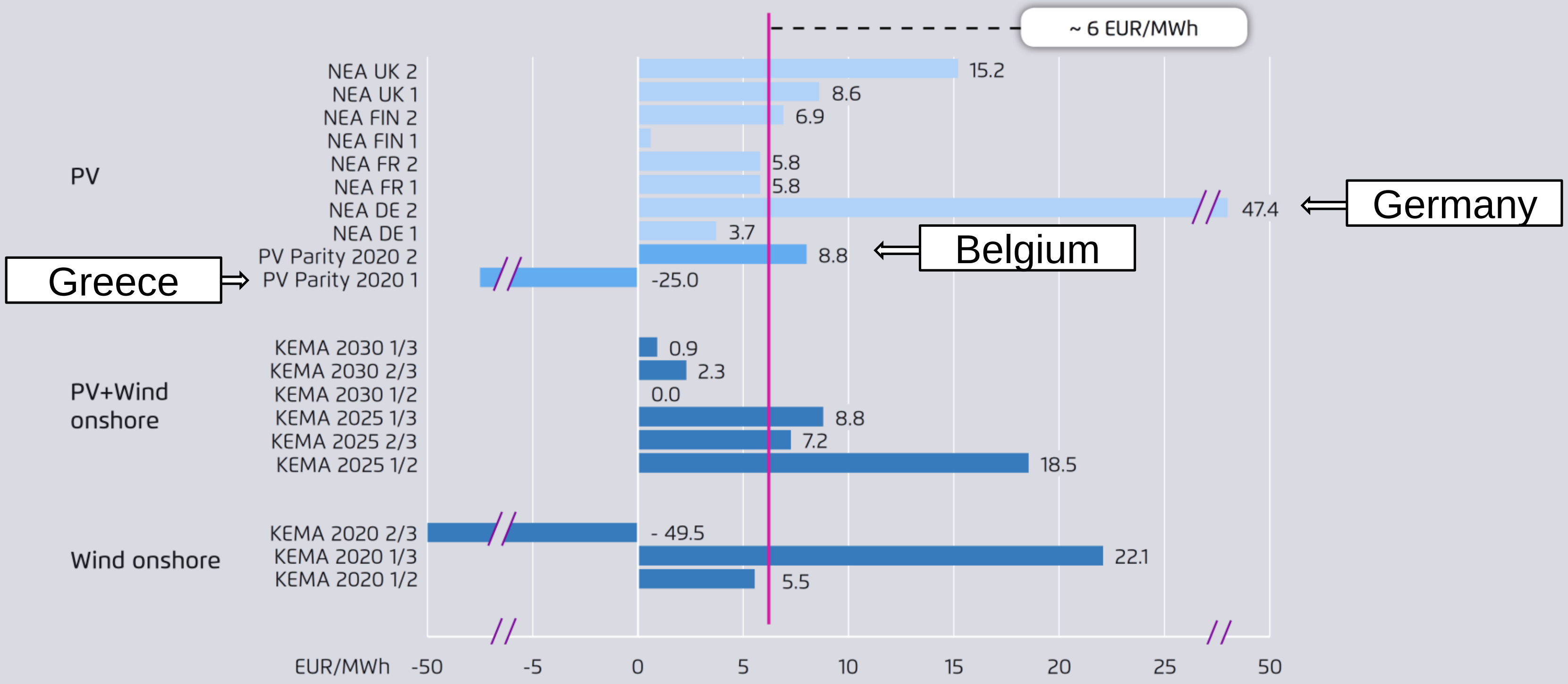
Representative grid and balancing costs for wind and solar power



Agora Energiewende (2015), based on NEP, IAEW, Consentec, IC London, KEMA, NEA

The results for distribution grid costs from different EU studies are characterized by high variations, reflecting system specificities, different assumptions and calculation methods

Quantification of distribution grid costs in Europe

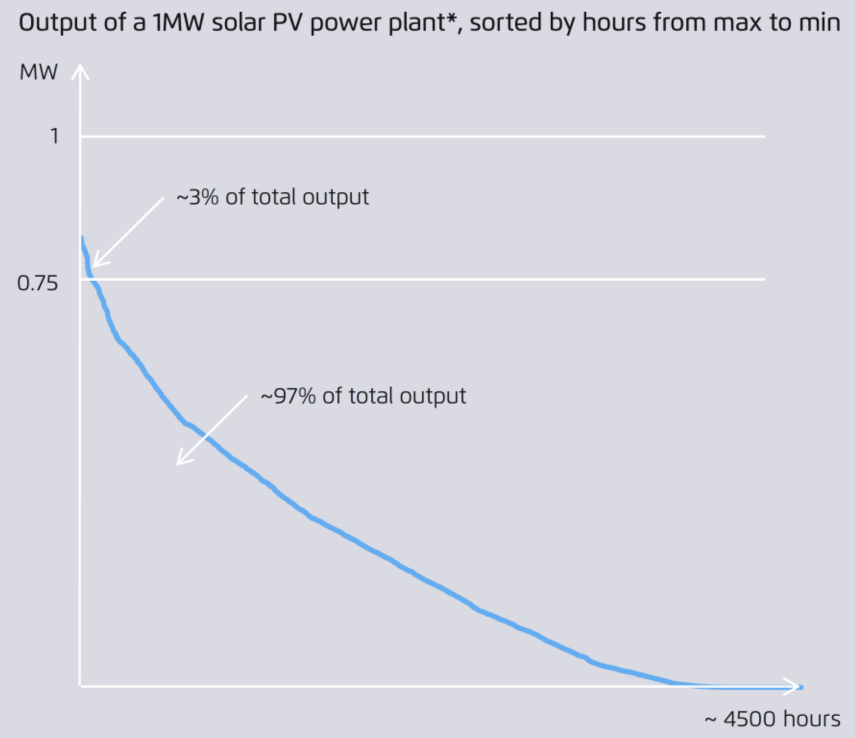


Agora Energiewende (2015), based on IC London, KEMA, NEA

“State-of-the-art” grid planning, allowing for some punctual curtailment, can reduce grid cost very significantly

Cost effects of curtailing maximum feed-in of solar power

Illustrative



Grid connection requirements

~1 MW Grid needed to transport 100% of 1MW Solar PV power

~0,75 MW Grid needed to transport 97% of 1MW Solar PV power

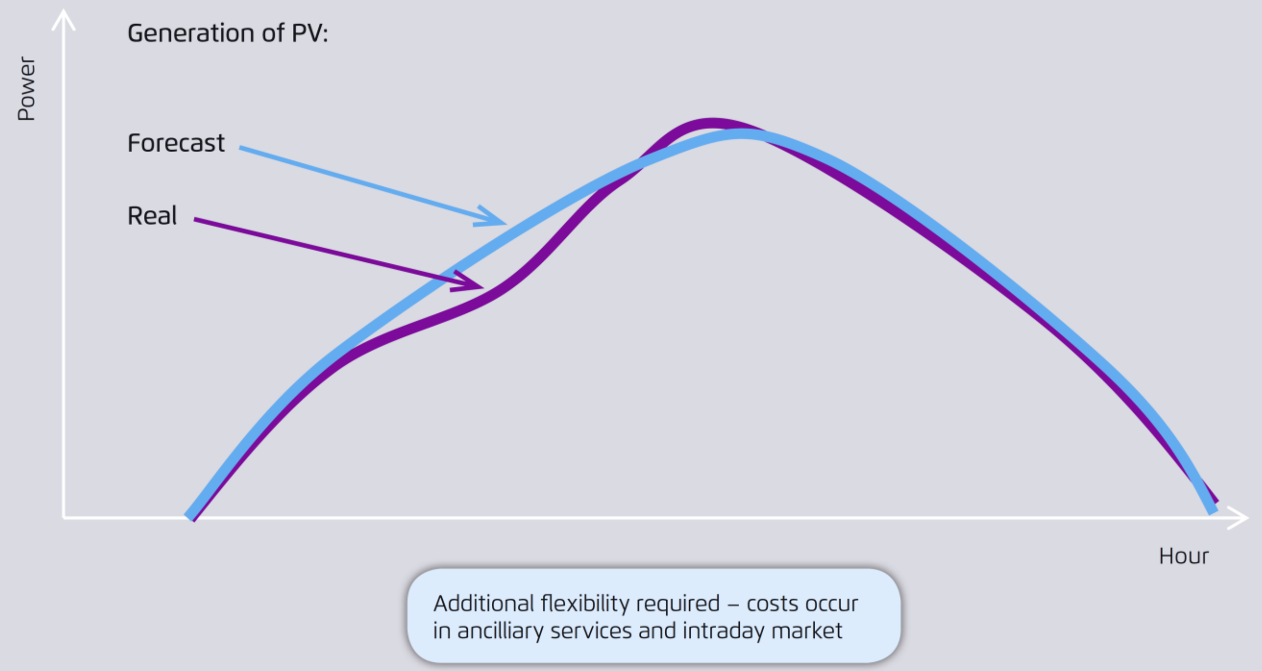
Effect on cost

+ Savings: 25% lower grid connection cost
- Cost: ~3% higher LCOE of PV

* Based on data of a solar power plant located in southern Germany, provided by EEG TU Wien

Balancing costs are driven by imperfect forecast on power production of intermittent renewables

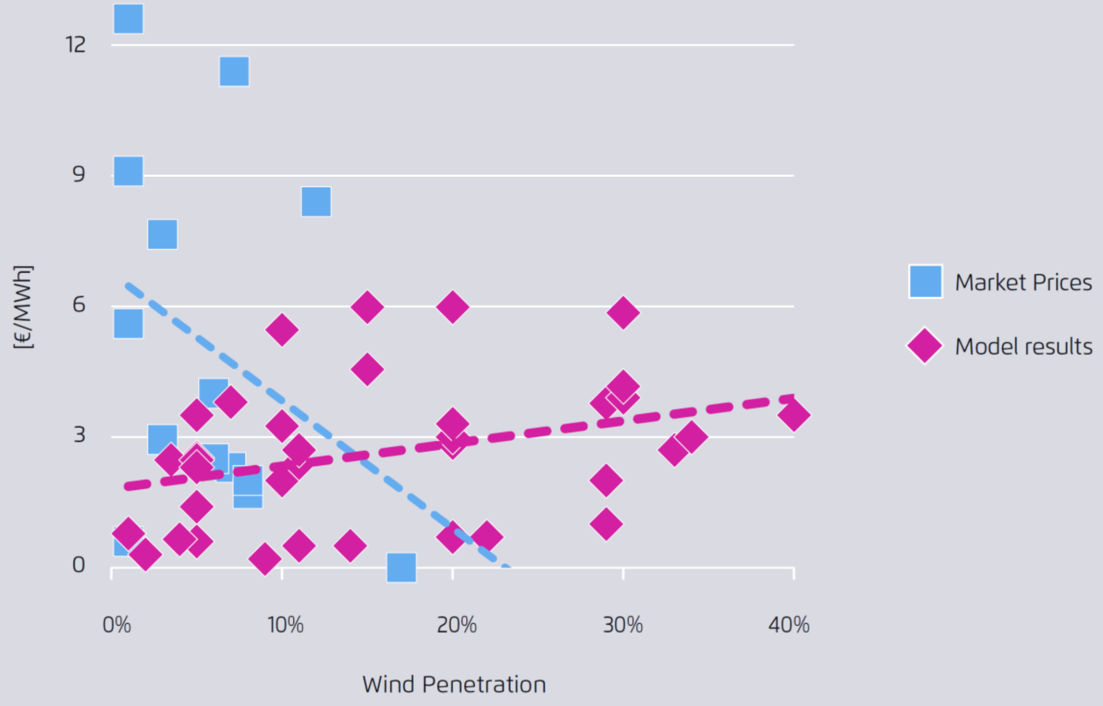
Forecasted and real power production by solar PV



Own illustration

In economic literature, balancing costs for wind onshore are typically about 2-3 EUR/MWh. Studies on PV are much less common, with estimation around 1 EUR/MWh.

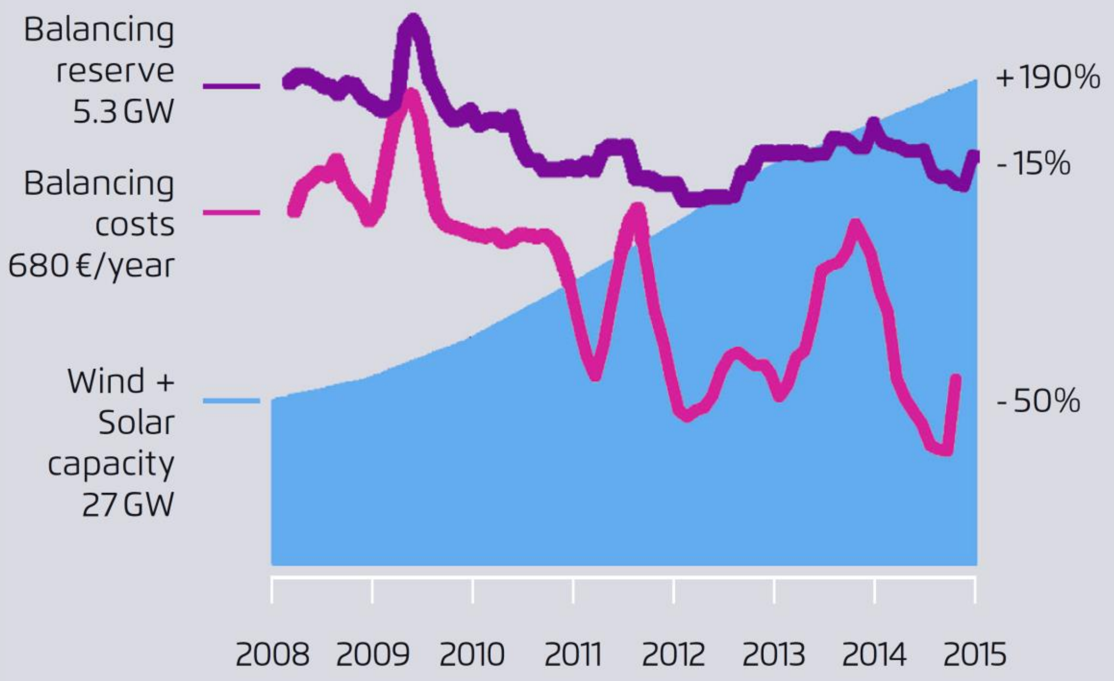
Balancing cost for wind estimates from the academic literature



Adapted from Hirth et al. (2015)

In Germany, balancing costs have declined over the last seven years: improvements on the balancing market have outweighed the impact of increasing renewables

Balancing reserve and cost development in Germany since 2008



Adapted from Hirth et al. (2015)

Since 2008, vRES capacity has been multiplied by three in Germany, while balancing costs have decreased by 50% over the same period.

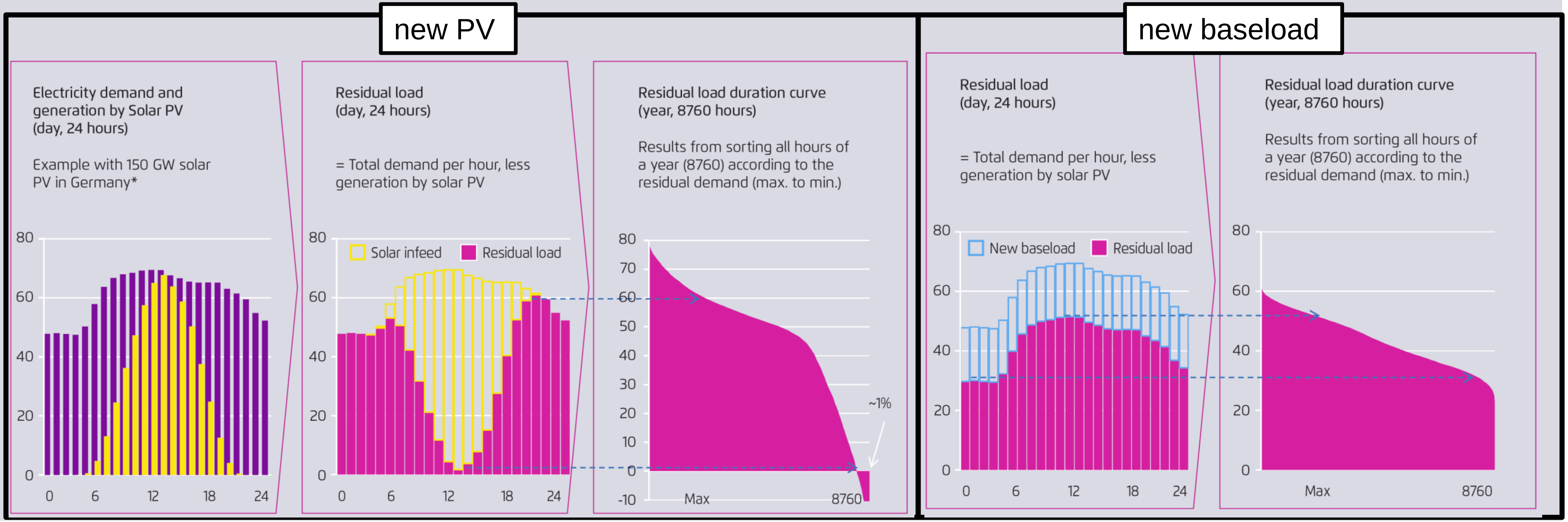
Other factor have overcompensated the VRE expansion (depressing the requirement for balancing reserve requirement) :

- TSO cooperation
- More competitive balancing power markets
- Improvement of forecasts
- More liquid spot markets
- Economic recession (increase balancing power supply)

“Reduced utilization effect” – the cost of “interaction” between vRES and other power plants

Adding new wind and PV or new baseload to a power system has a different impact on the residual generation, and its costs

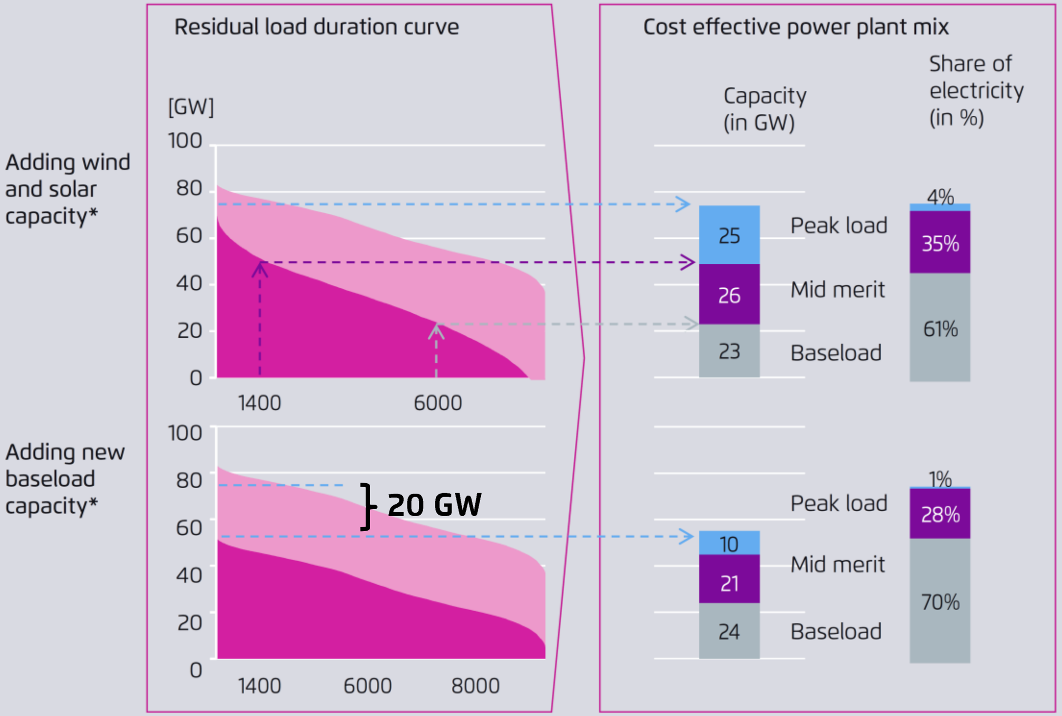
Explaining the residual load duration curve : adding significant solar PV (150 GW ~ 25% of electricity demand) or baseload



Example Germany with (left) 150 GW solar PV, assuming non-optimized solar PV plant design based on real infeed data 2014 (~25% of electricity demand) or with (right) 18 GW new baseload power plants (~25% of electricity demand)

Wind and solar energy shift the residual demand towards more mid-merit and peaker power plants, without reducing the maximal residual demand.

Different cost-effective power plant mix in case of adding 50% wind and solar vs 50% new baseload capacity



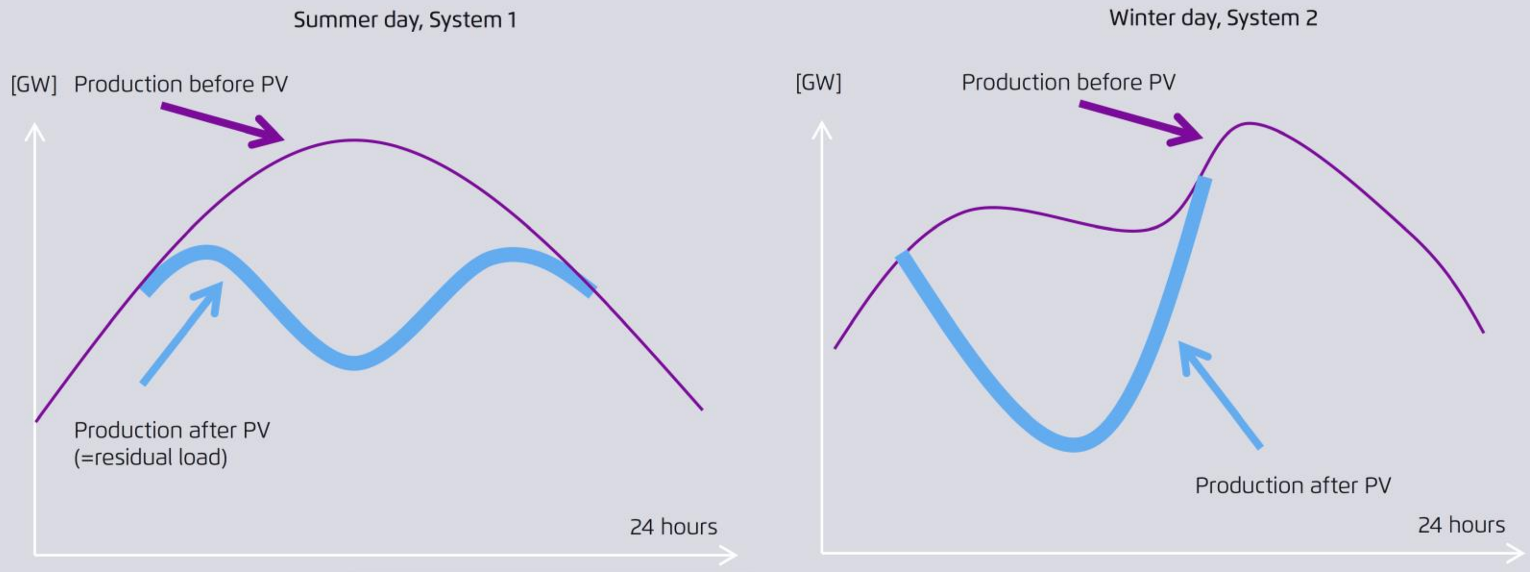
Adding 50% vRES in the power system leads – in most cases - to higher specific generation costs of the conventional power (lower utilization of installed capacity and higher use of mid- and peak-merit)

The quantification of this „utilization effect“ depends on :
- the structure of the conventional power plant mix : it is driven by the capital costs and the fuel costs
- the pricing of externalities : if externalities are valued at very high costs, the “utilization effect” effect can become negative (–> integration benefits)

Own illustration and calculation

The cost of “reduced utilization” is very system specific

Schematic representation of power production by thermal power plants, before and after adding solar PV



“Lost revenues”:
Fossil fuel generators loose sales revenues in times of highest prices

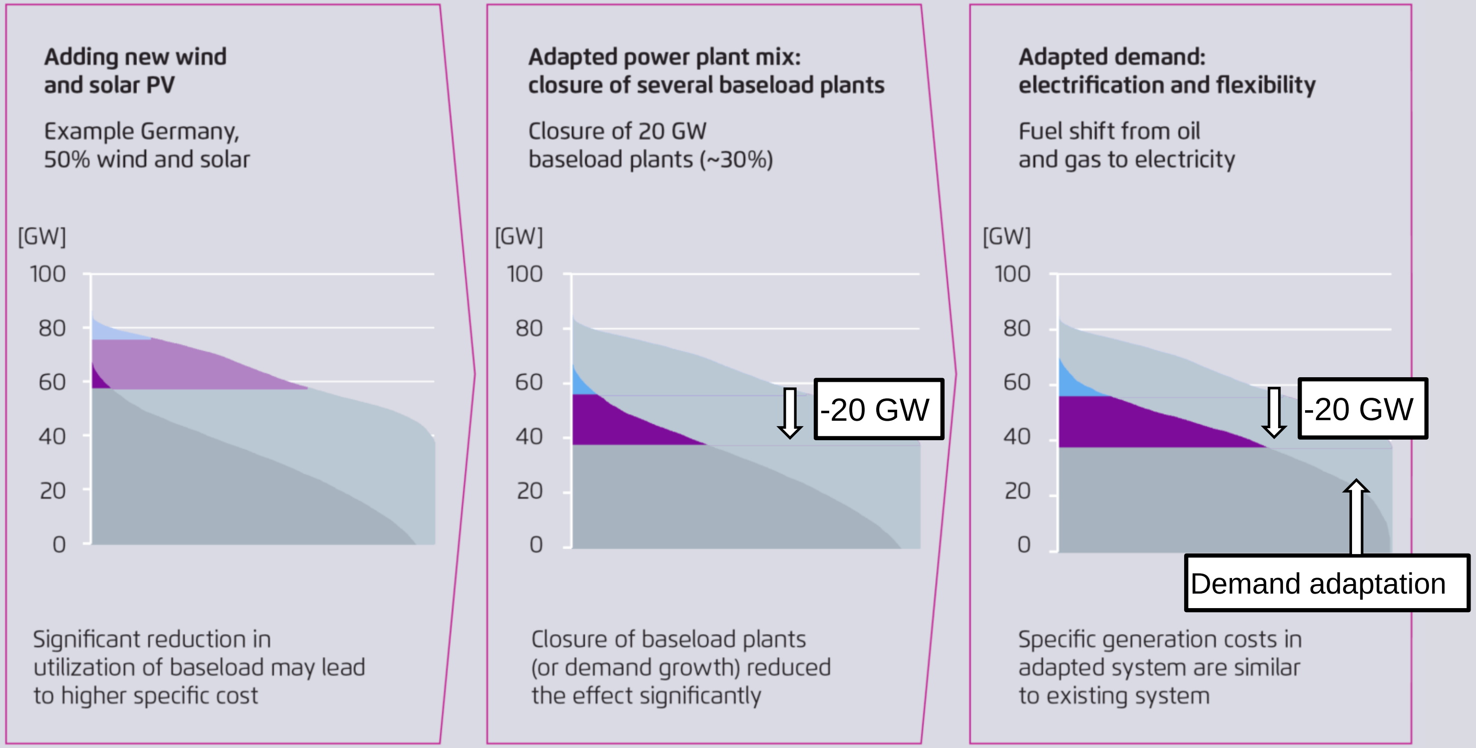
Less backup cost:
Less power plants are needed in systems with high demand by air conditioner

Higher cost to serve load:
Same amount of peak capacity needed, even at very high shares of solar power

Own illustration

System adaptation, flexibility and further electrification allows higher utilization rates of residual power plants, reducing considerably the integration costs.

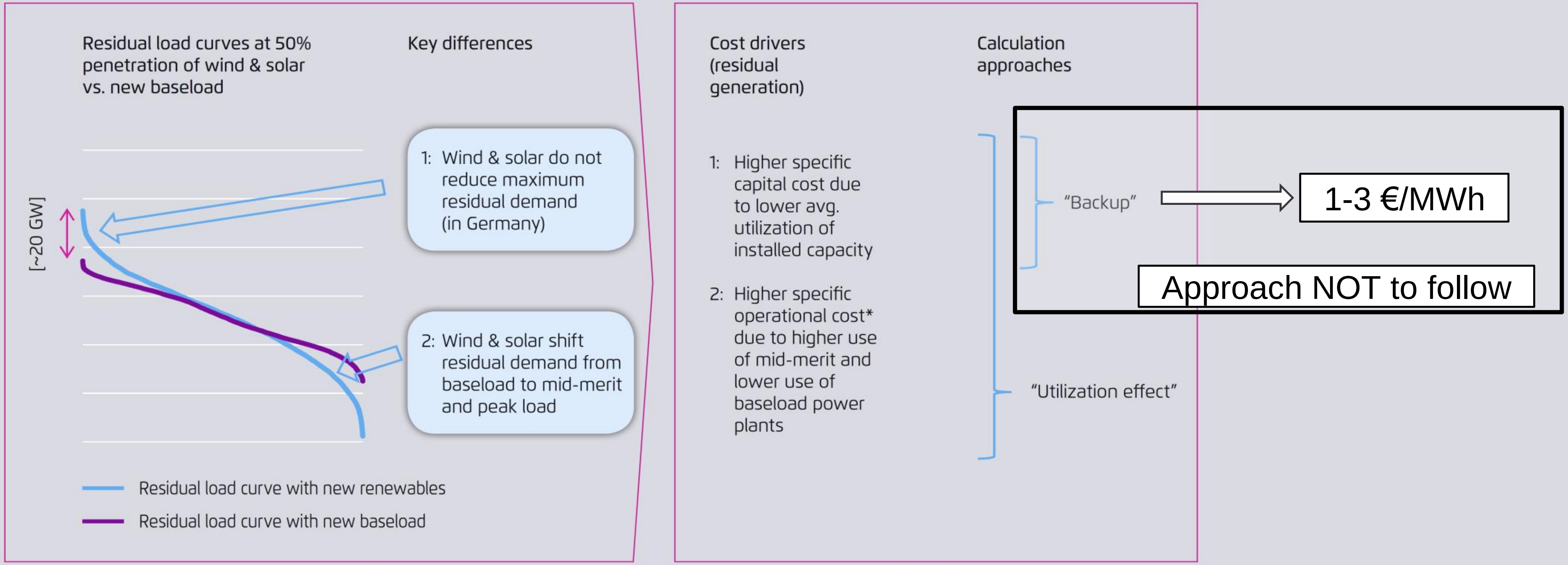
Residual load after adding wind and solar power in non-adapted (right) and adapted (middle and left) systems



Own illustration

Adding new baseload or new wind and PV to a power system have a different impact on the residual generation, and its cost

Key differences, cost drivers and calculation approaches for analyzing cost effects on residual power generation

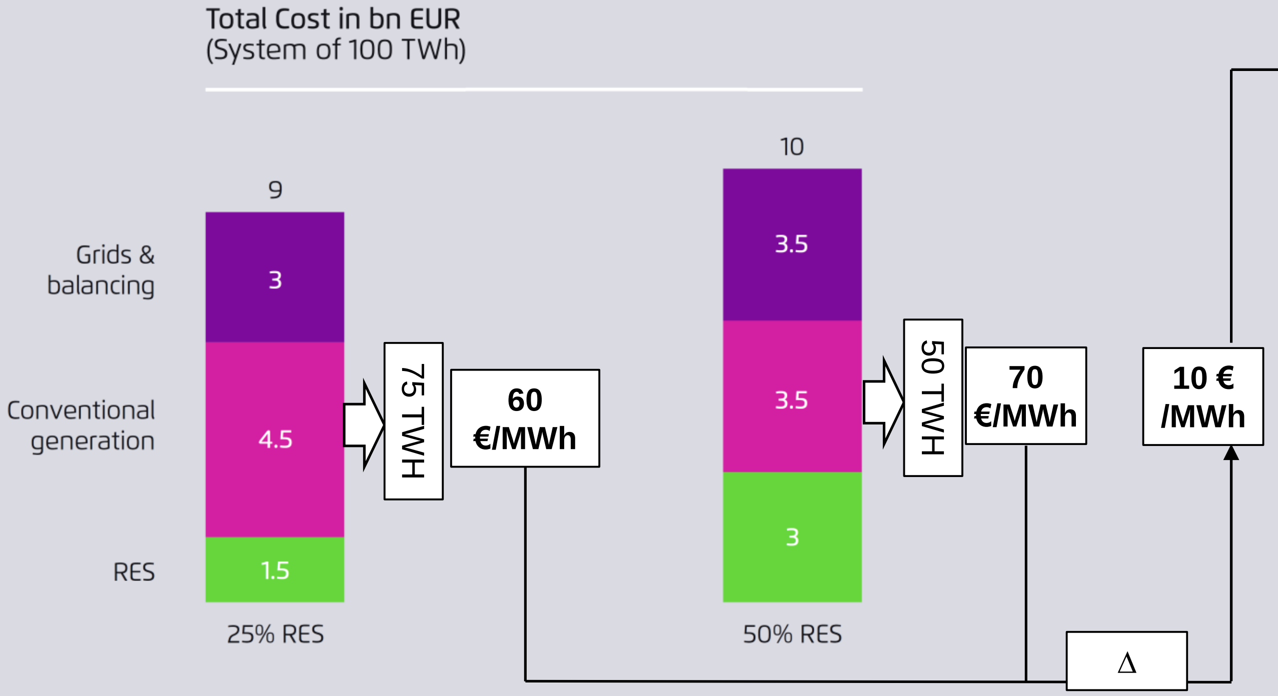


Own illustration

*Assuming investment costs of 20 GW "back-up" at a cost of 20 EUR/kW/year (old depreciated CCGT) or 30-50 EUR/kW/year (new OCGT) when 300 TWh variable renewables are added

An approach for quantifying the „utilization effect“ is described in our report. This approach has nevertheless led to controversial debates.

An example of integration costs calculated from additional costs and **less than proportional** decreased costs.



Total integration cost („utilization effect“) is **500 M€**

Specific integration costs is

… per MWh renewables (50 TWh) : **10 €/MWh**

… per MWh added renewables (25 TWh) : **20 €/MWh**

… per MWh total power (100 TWh) : **5 €/MWh**

Own illustration

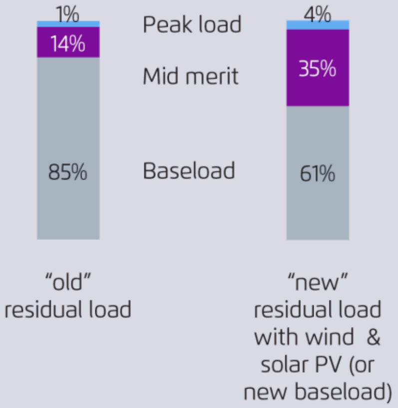
*example here: fully considering higher specific generation cost as integration cost, assuming that specific cost of conventional generation increase from 60 to 70 EUR/MWh, multiplied by 50 TWh (alternative calculation: 3,5 bn EUR – 4,5 bn EUR/ 75 TWh*50 TWh

Based on this method, calculations of the „utilization effect“ of 50% wind and PV in Germany could range between -6 and +13 EUR/MWh, depending on gas costs and CO2 cost (and the way it is internalized)

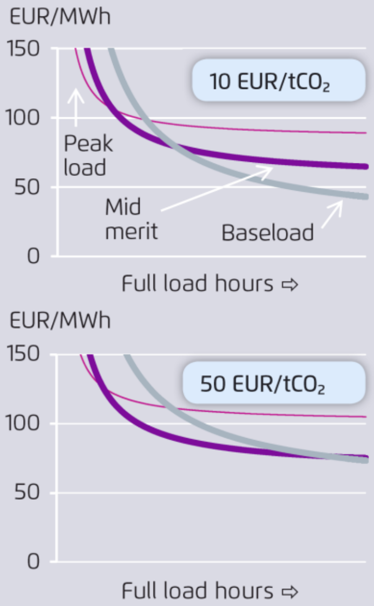
High CO2 and natural gas assumptions drive down the cost of „reduced utilization“

Lower share of baseload generation

Contribution in % of electricity (Example Germany, 50% penetra-tion***)



Generation cost of different technologies (assumptions*)



Cost for “reduced utilization”

Cost increase in specific generation cost:

- @10 EUR/tCO$_2$, gas 30 EUR/MWh +24% (from 54 to 67 EUR/MWh) ⟹ + 13 EUR/MWh
- @50 EUR/tCO$_2$, gas 20 EUR/MWh +2% (from 90 to 92 EUR/MWh) ⟹ + 2 EUR/MWh
- @80 EUR/tCO$_2$, gas 15 EUR/MWh -5% (from 118 to 111 EUR/MWh)** ⟹ - 6 EUR/MWh

Cost per wind and solar PV added depends on CO$_2$ prices and gas costs. In these three examples, the cost for reduced utilization would be -6, +2 or +13 EUR/MWh.

(Cost of ”reduced utilization can be negative if the reduction of external costs outweighs the cost effect of lower utilization of conventional power plants.)

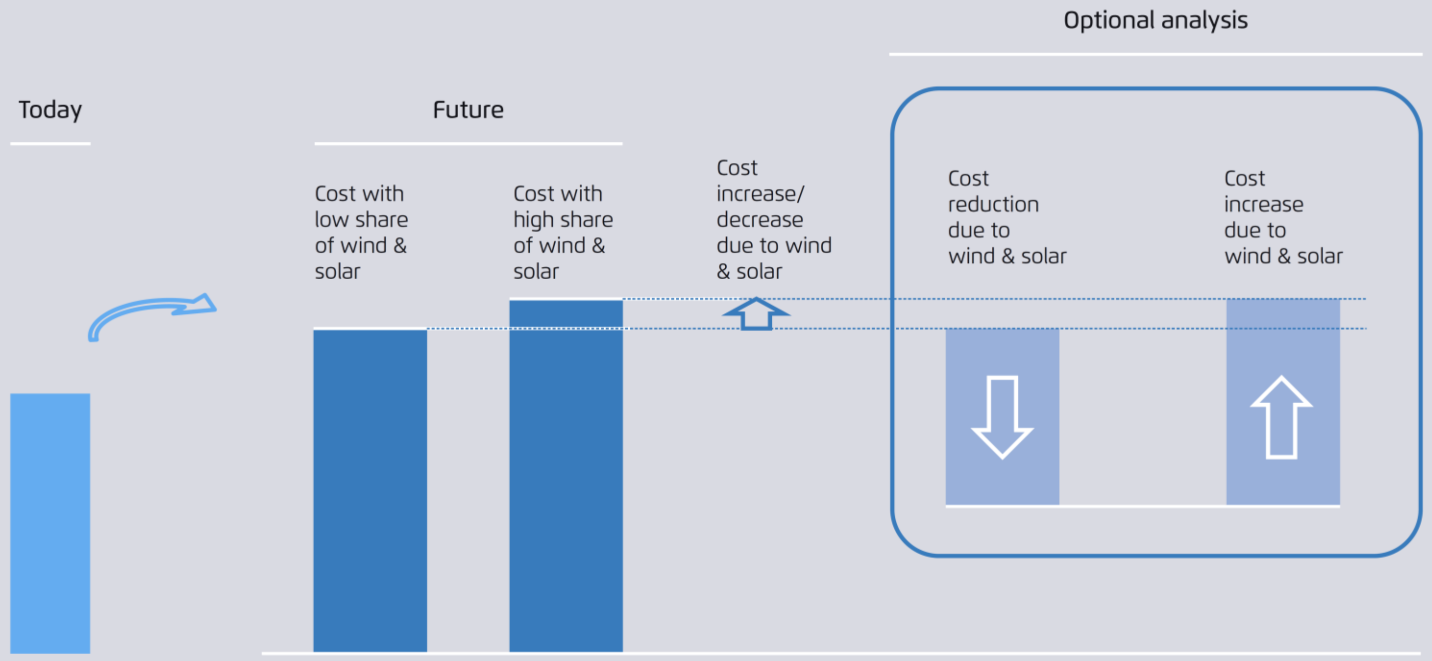
Own calculation

*Assuming lignite, CCGT and OCGT as base/mid-merit and peak technologies, natural gas price of 30 EUR/MWhth
**Illustrative calculation, assuming the same generation mix as above (ie cost for CO$_2$ are not internalized and have no impact on power plant dispatch)
***optimized technology mix @ 30 EUR/tCO$_2$, gas 30 EUR/MWh

Total system costs

A total system costs approach of different scenarios would be a more appropriate approach, avoiding the controversial attribution of system effects to specific technologies

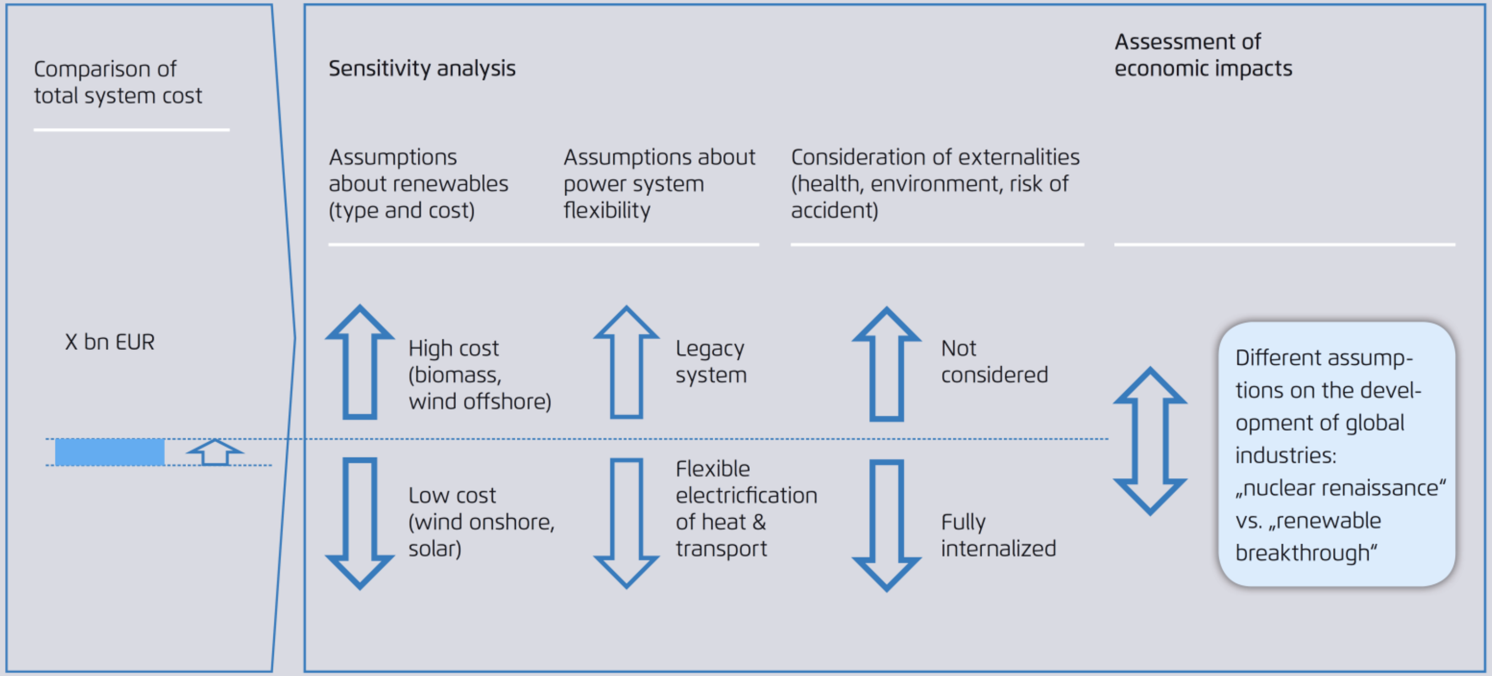
Total system cost approach for comparing different renewable energy penetration scenarios.



Own illustration

The total system cost approach must be subject to an intensive and transparent sensitivity analysis

Overview of key sensitivity analysis and impact assessments to accompany total system cost comparison



Own illustration

Key insights of the study “The Integration Costs of Wind and Solar Power”

Key insights of the study

1. **Three components are typically discussed under the term “integration costs” of wind and solar energy: grid costs, balancing costs and the cost effects on conventional power plants (so-called “utilization effect”).** The calculation of these costs varies tremendously depending on the specific power system and methodologies applied. Moreover, opinions diverge concerning how to attribute certain costs and benefits, not only to wind and solar energy but to the system as a whole.

2. **Integration costs for grids and balancing are well defined and rather low.** Certain costs for building electricity grids and balancing can be clearly classified without much discussion as costs that arise from the addition of new renewable energy. In the literature, these costs are often estimated at +5 to +13 EUR/MWh, even with high shares of renewables.

3. **Experts disagree on whether the “utilization effect” can (and should) be considered as integration costs, as it is difficult to quantify and new plants always modify the utilization rate of existing plants.** When new solar and wind plants are added to a power system, they reduce the utilization of the existing power plants, and thus their revenues. Thus, in most cases, the cost for “backup” power increases. Calculations of these effects range between -6 and +13 EUR/MWh in the case of Germany at a penetration of 50 percent wind and PV, depending especially on the CO_2 cost.

4. **Comparing the total system costs of different scenarios would be a more appropriate approach.** A total system cost approach can assess the cost of different wind and solar scenarios while avoiding the controversial attribution of system effects to specific technologies.

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