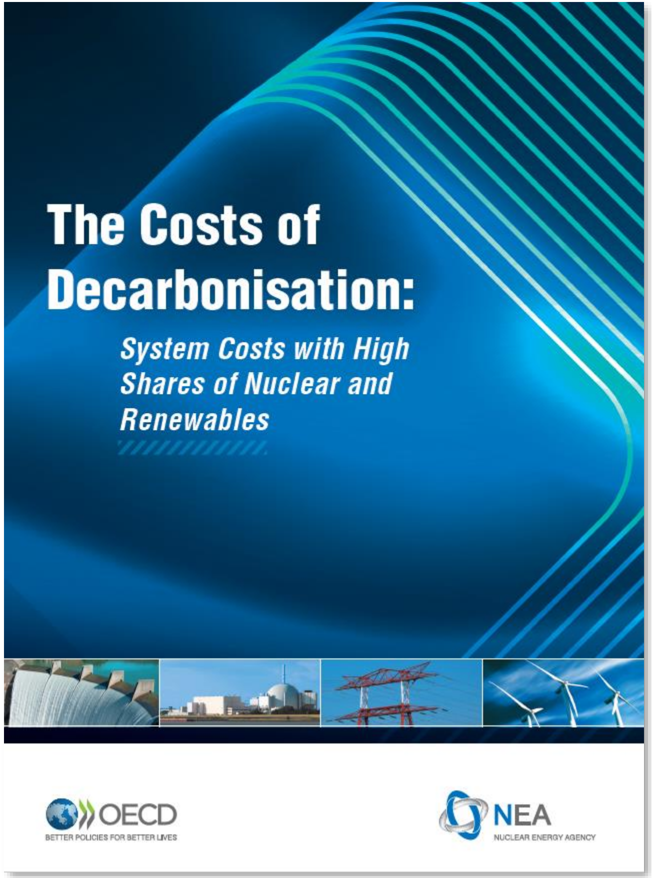

Methodological contributions based on recent work, including *The costs of decarbonization* (NEA, 2019), to the Workshop on Benchmarking Methodologies for the Assessment of System Costs in Integrated Electricity Systems at KU Leuven, Belgium

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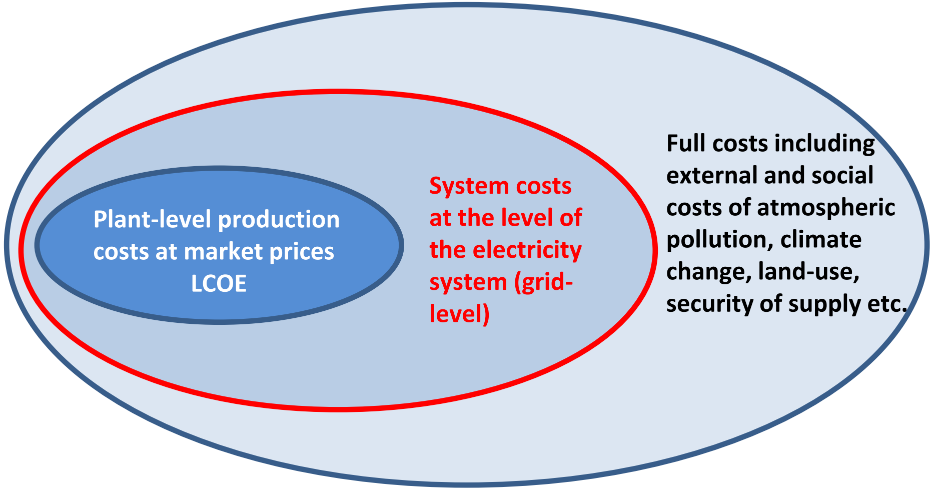
System Costs and other Costs

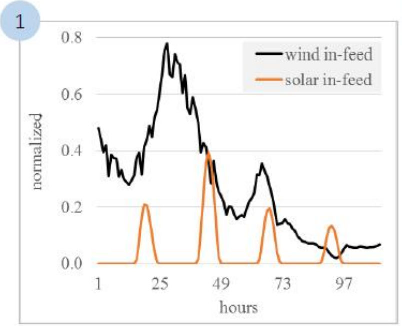


Characteristics of System Costs (Profile Costs)

- System costs are real economic costs in EUR or USD, not un-priced social costs or externalities;
- In competitive EO-markets with free entry and exit **and no out-of-market arrangements (FITs, CFDs etc.), system costs are even fully internalised and constitute no sub-optimality;**
- However such markets are rare; if VRE receive out-of-market support (and supposing the remainder of the market is competitive) then they force a suboptimal generation mix with overall higher economic costs **even if their LCOE are lower than those of dispatchable generators.**

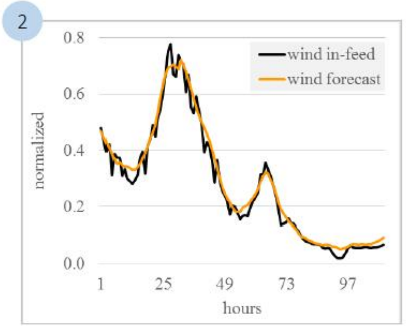
Assessing the total costs of electricity systems

- Total system costs are the sum of plant-level generation costs and grid-level system costs
- System costs are mainly due to profile costs of variable generation.



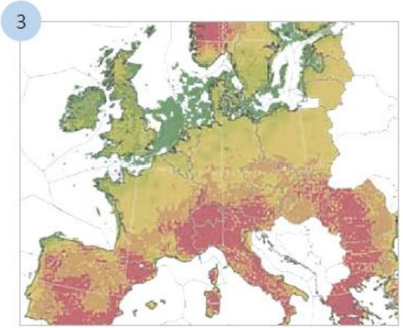
Wind does not always blow

Profile costs (Varying load)



Difficult to predict

Balancing costs (Uncertainty)



Good sites are distant from load centers

Transmission and distribution costs

Source: L. Hirth

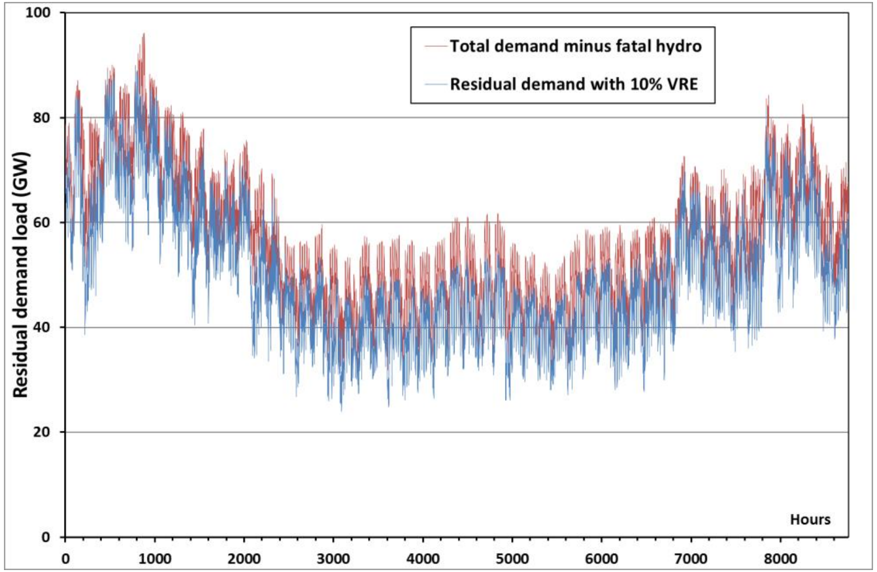
System costs depend on:

- Country characteristics and the existing mix;
- VRE penetration and load profiles;
- Flexibility resources (hydro, storage, interconnections).

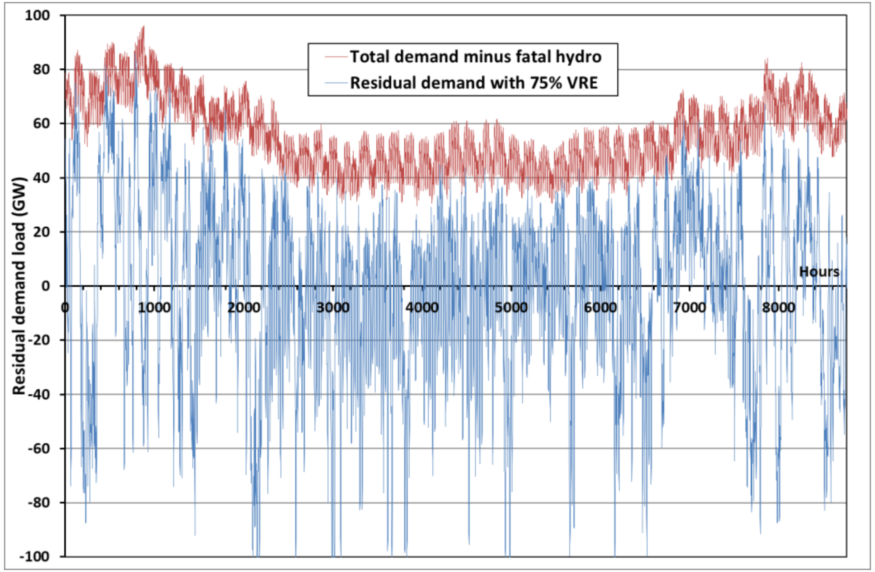
Additional impacts on load factors of dispatchable generators and prices.

Concentrating on profile costs

10% Variable Renewables



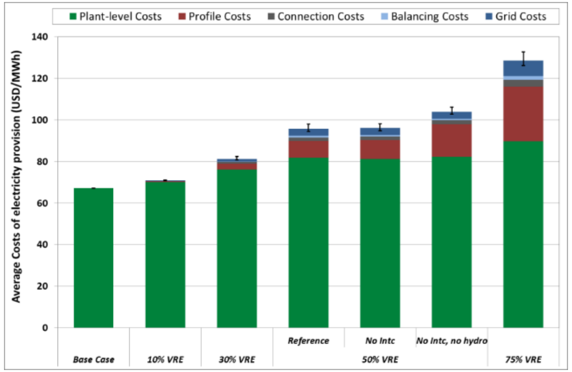
75% Variable Renewables



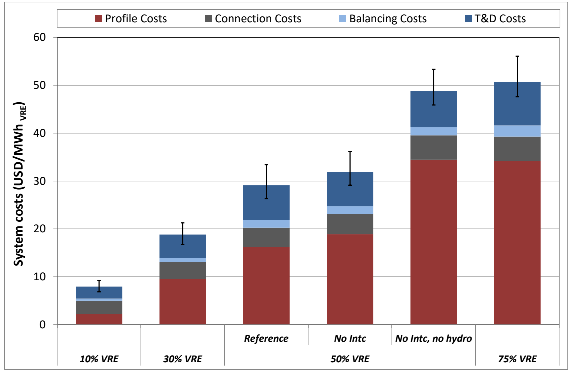
- High VRE shares result in challenges for system management.

Profile costs of VRE *employed above their economically optimal level* will increase the overall costs of the electricity system, keeping constant the overall load, carbon constraint and the level of security of supply.

Total Costs



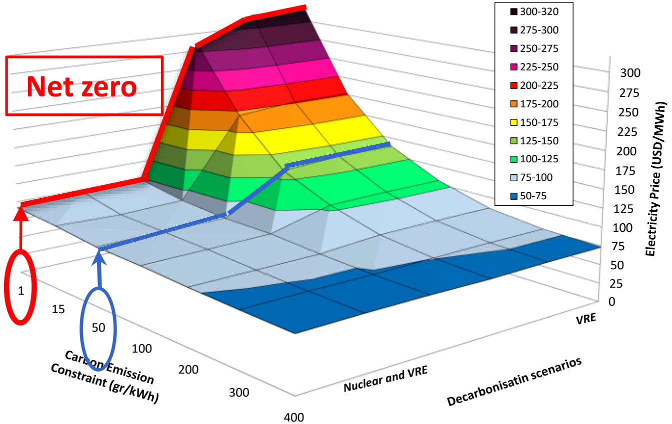
Breakdown of System Costs

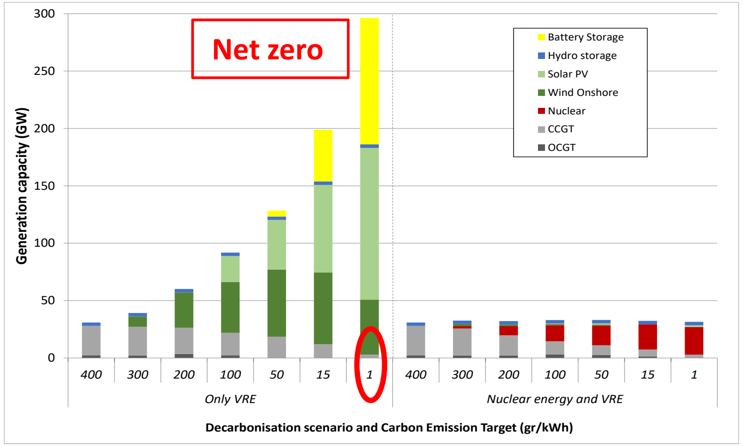


Profile costs are primarily a function of three factors:

- The correlation between the load profiles of non-dispatchable resources and demand (system load)
- The share of VRE in the total generation mix and the cost of curtailment.
- The availability, cost and technical characteristics of flexibility resources such as (1) dispatchable electricity generation, (2) demand response, (3) storage and (4) interconnections

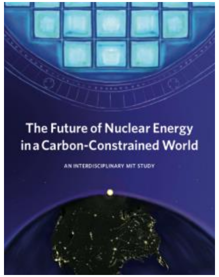
System Costs Are a Function of (1) Carbon Targets and (2) VRE Targets





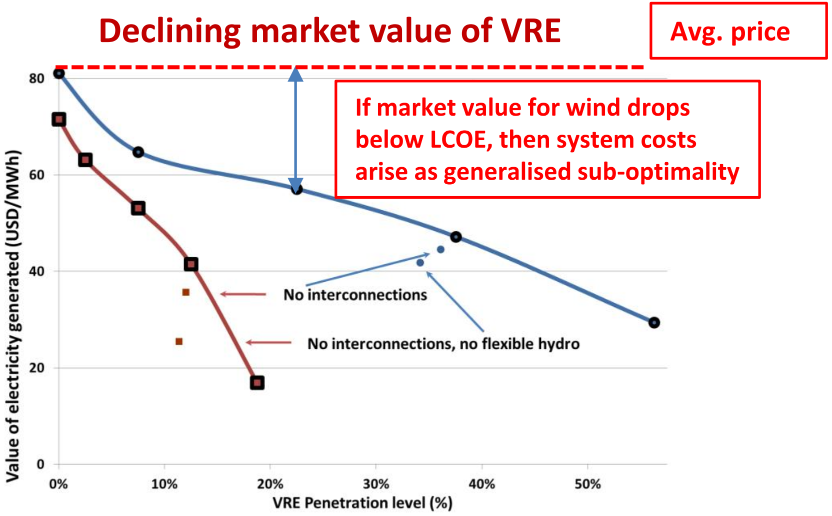
Source: N. Sepulveda, MIT

- The average cost of electricity increases with the stringency of the carbon constraint. The increase is much more significant in scenarios where only VRE are deployed.
- The structure of the optimal generation mix changes drastically as the decarbonisation target becomes more binding.

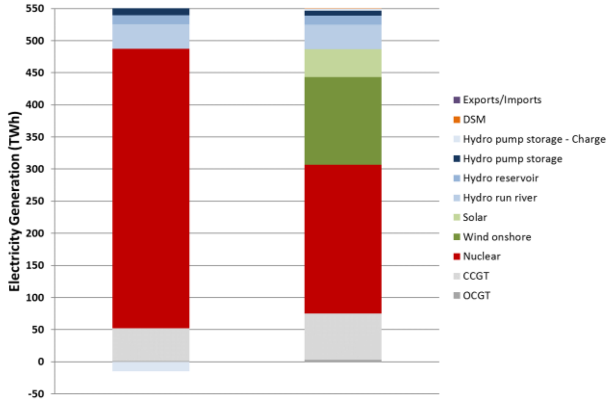


In competitive electricity markets, system costs are internalised through the declining value factor of VRE (left-hand graph). True competition will, as always, ensure optimality. If LCOE of VRE are lower than those of other low carbon producers, the will enter on their own merits. However entry will cease at the point where revenues no longer cover costs. At this point other low carbon producers, e.g., nuclear will enter (right-hand graph).

Declining market value of VRE



Optimised system with VRE *and* nuclear



$LCOE_N < LCOE_{VRE}$ $LCOE_{VRE} < LCOE_N$

- **VRE earn *less than average market* prices due to auto-correlation during generation hours. This effect increases with their share. Low cost flexibility resources such as storage or DR limit this effect.**

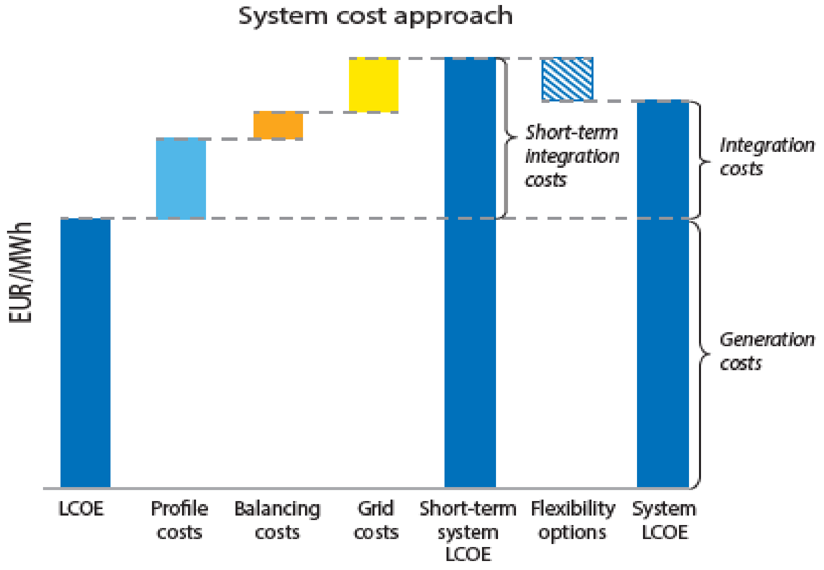
Some considerations on methodology adopted in NEA studies

System effects and costs can be understood and quantified only by comparing two different systems

Objective of the NEA study was to quantify the additional costs induced by the variability, unpredictability and grid requirements of VRE **in comparison to a dispatchable baseload technology.**

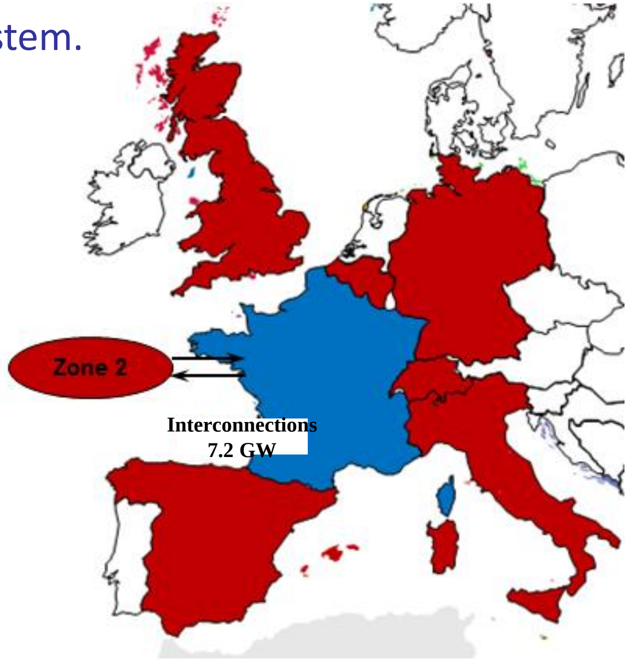
Context: to complement the LCOE methodology which compares the costs of baseload technologies.

- Attempt to look at the system costs of a system in **long-term** equilibrium.
- Analysis is limited to the power system alone, without coupling with broad energy system.



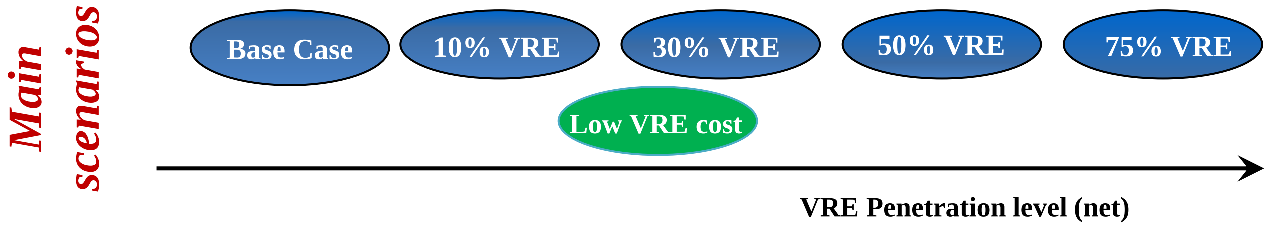
No model can fully represent the operations of the power system

- Study the costs of electricity systems with identical total demand and **carbon emission target (50 g/kWh)** in scenarios with **different shares of VRE and nuclear**.
- Provide a **realistic** representation of a **large interconnected** power system.
  - It represent a large (continental scale) interconnected system, with abundant hydro (reservoir and pumped) and different regimes of VRE generation.
  - Use of actual data from 2015 (demand, realised production from hydro resources and real water inflows, VRE load factors).
  - Two zone system: main node (France) and second node (neighbouring countries) with same electrical demand.



- Economic assumptions derived from the **IEA/NEA 2015** study on electricity generation costs, with conservative assumptions on storage costs and DSM.
- Model cannot assess the **T&D costs** nor **connection costs**

Balancing, T&D and connections have been added afterwards



Six Main scenarios with different shares of VRE imposed exogenously into the system.

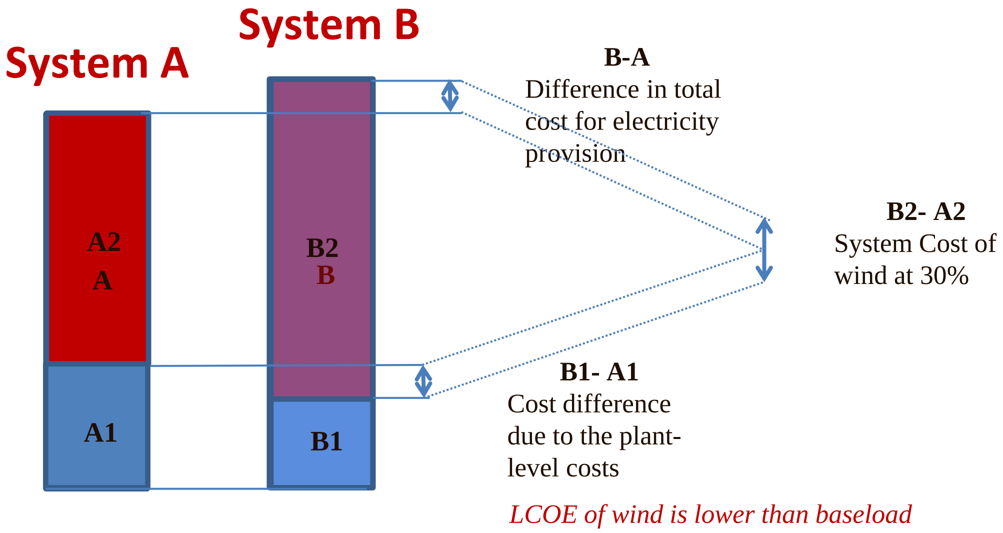
- All scenarios have the **same assumptions** in term of power demand, technologies availability and costs, carbon and other constraints, etc.
- Base case has only dispatchable technologies (baseline for comparison).
- All scenarios represent an **optimum** (least cost optimisation)
- Green-field approach taking a **long-term perspective**

➡ **The objective of the analysis is to "extract" system costs from these results.**

Example: Profile costs of wind at 30% share – no curtailment

In all calculations, all economical and technical hypothesis should be the same

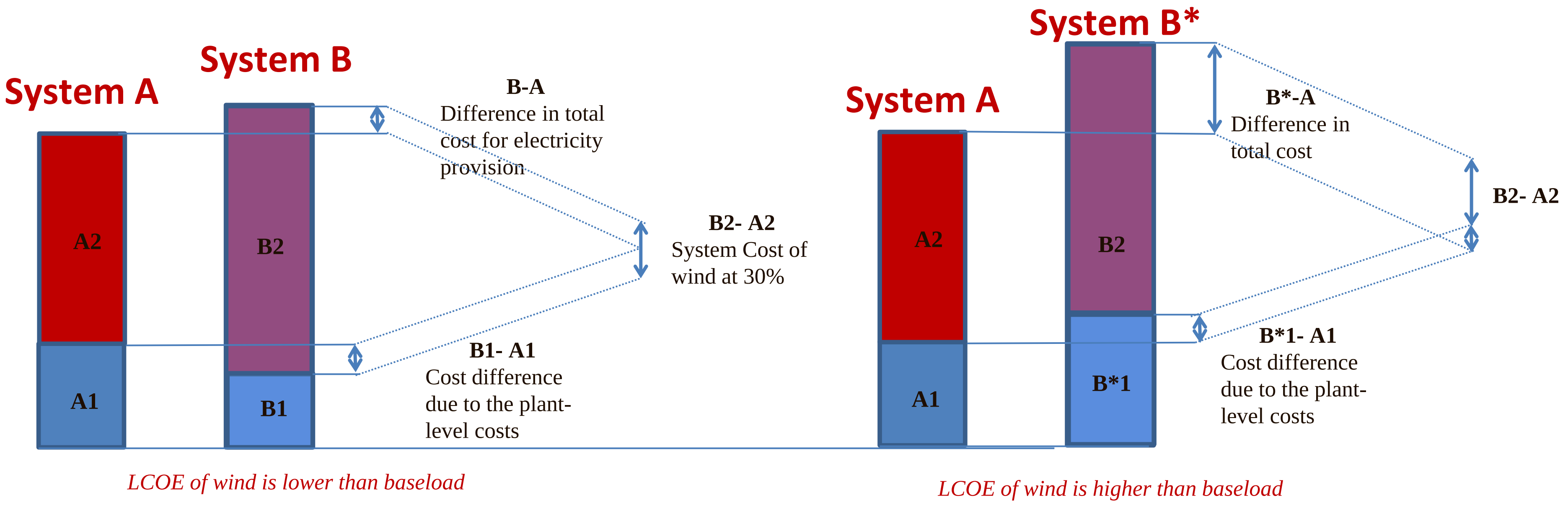
1) Optimise a system with only dispatchable technologies (System A).
2) Optimise a second system with wind producing 30% of generation (System B).
3) Calculate the breakdown of costs for system B:
   B1 = Cost of wind generation
   B2 = Cost of rest of the system.
4) Calculate the breakdown of costs for system A:
   A1 = Cost of baseload technology providing 30% of the generation
   A2 = Cost of rest of the system.



With this methodology B-A represents the **average** (and **not the marginal**) profile cost of wind at 30%.

System costs are always calculated as the difference between 2 optimised systems

What happens to profile costs of wind if its LCOE increases?



➢ The profile cost of wind **does not depend** on its LCOE but only on its generation share and on the other characteristics of the system.

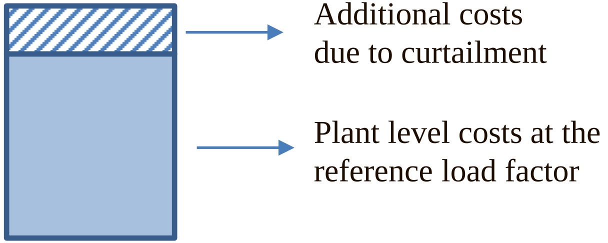
How to treat curtailment

Curtailment of VRE occurs when their generation share exceeds a certain value and it increases with higher generation share.

Curtailment during hours of excess VRE generation is the least-cost flexibility option and contribute to system optimisation.

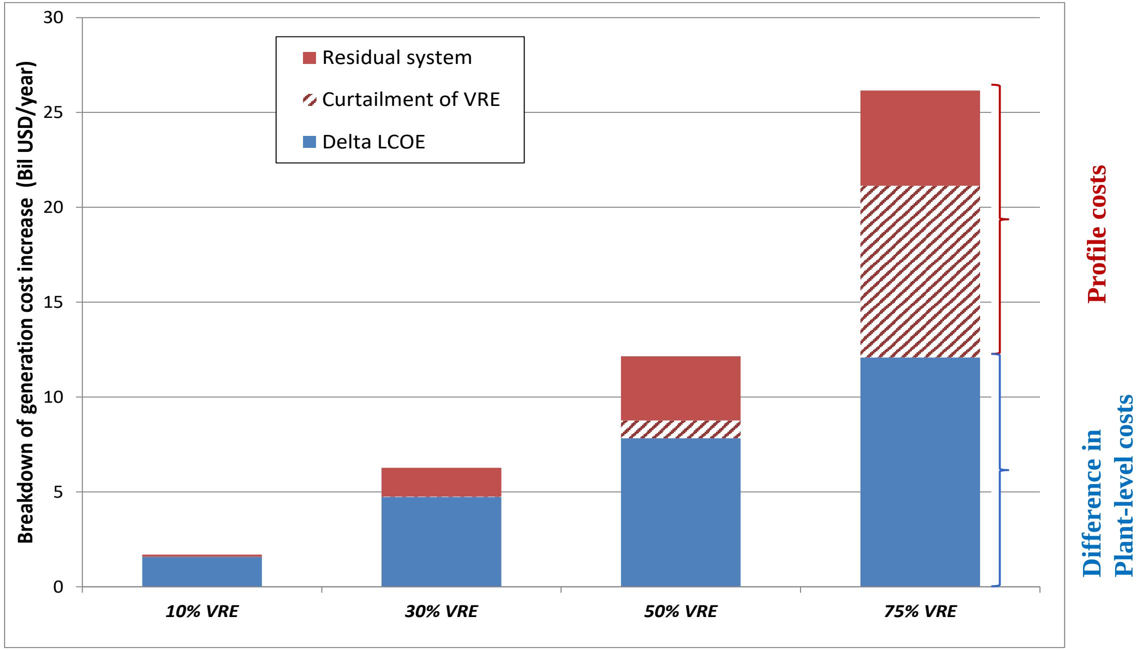
Curtailment of wind essentially means that the wind plant operates at a lower effective load factor then achievable, thus producing the same amount of electricity requires more capacity.

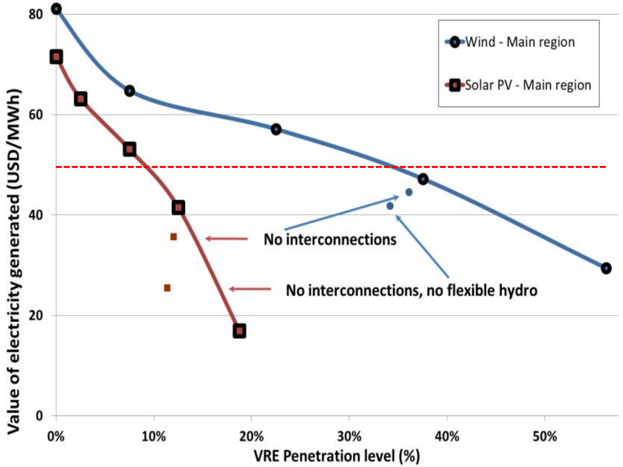
- Curtailment has a direct impact on the generation costs (LCOE) of a technology.
- The amount of curtailment depends on the characteristics of the system and on the generation share considered.



In the NEA study **curtailment of VRE is considered as a part of their profile costs** as it is an additional cost in comparison to their reference LCOE.

SC analysis is simply to try to identify and explain the key driver of costs





The optimal share of VRE is the one for which marginal system costs (profile, balancing, T&D, etc.) equate the difference in plant-level costs

Concluding remarks on methodology

- All system should be optimised.
- Hypothesis and cost assumptions should be the same in all scenarios.
- Important to take a long-term view
- Marginal vs average costs

Policy recommendations for efficient decarbonisation and the internalisation of system costs

- **Theoretical first best optimum:** operate a competitive EO-market with no interventions except a prohibitive carbon price with long-term credibility; first best-optimum would have volatile prices, question of completeness of hedging opportunities.
- **Pragmatic second best transition:** provide stable revenues through long-term pricing arrangements for *all* low carbon technologies; high, but not necessarily prohibitive carbon price allowing for fossil-based flexibility provision at the margin.

Comparison of NEA/IAEA system costs approach with IEA VALCOE approach I

- The following remarks concern the treatment of profile costs. The VALCOE approach distinguishes an *energy*, a *flexibility* and a *capacity* component.
- We will concentrate on the energy component. The differentiation between the three categories is arbitrary, depending on product definitions and country-specific market arrangements. One could easily conceive of a relevant VALCOE metric in an electricity system that corresponds to the theoretical benchmark of an EO-market with VOLL-hours.
- The VALCOE energy component for each technology *i precisely* captures the lower market value of VRE or the higher market value of peak-load-serving technologies:

$$VALCOE_i = LCOE_i + \underbrace{(\text{average electricity price} - \text{average earnings of technology } i)}_{\text{system costs of technology } i}$$

Comparison of NEA/IAEA system costs approach with IEA VALCOE approach II

1. Most importantly, VALCOE is calculated also for non-equilibrium constellations, which limits its “epistemological value”; *i.e.* given that much of a technology’s value is baked in by past, sub-optimal government decisions, which guidance does it provide?
2. Calculations of VALCOE without a carbon constraint have, in the past, provided confusing messages about the value of fossil fuel-based technologies.
3. However, VALCOE can, if appropriately adapted, provide valuable indications on how to move towards a least-cost equilibrium. Costs are minimised by choosing the technology with the lowest VALCOE (including a carbon adder). At the optimum, all technologies would have the same VALCOE!