Cost-effective Decarbonisation: System Costs in Energy Systems with High Shares of Nuclear and Renewables.

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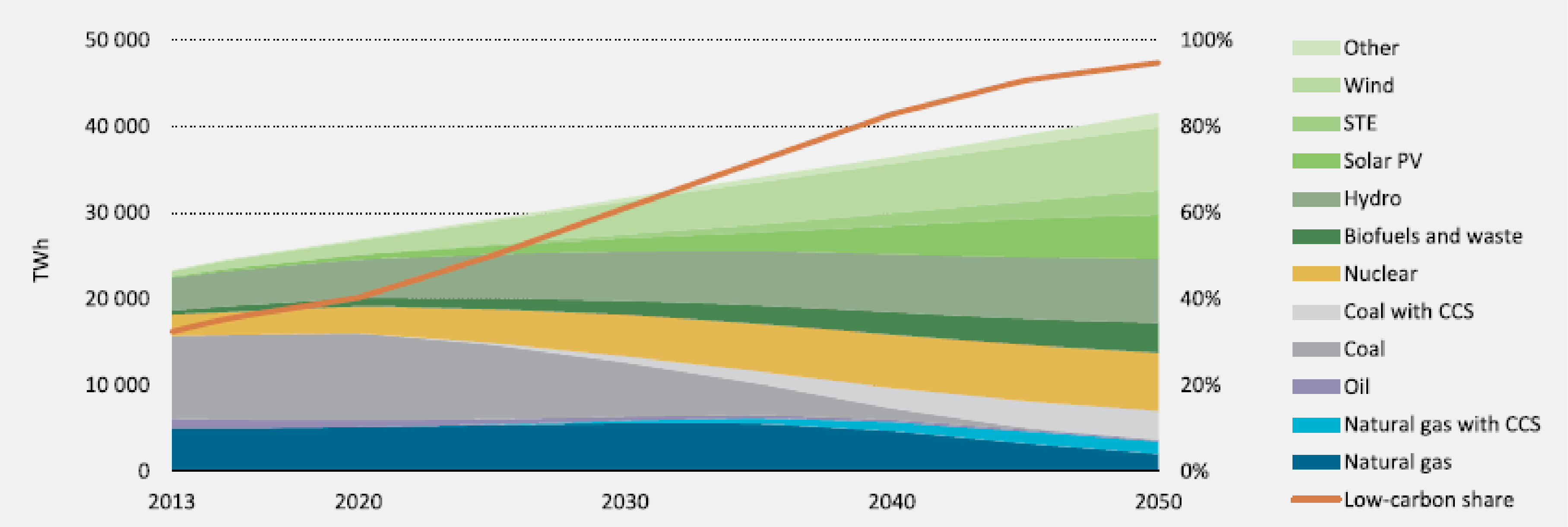
Power sector almost completely decarbonised in the IEA 2DS

Global electricity production and technology shares in the IEA 2DS



Source: IEA, ETP2016

68% fossil fuels
22% renewables
11% nuclear

533 gCO_2/kWh

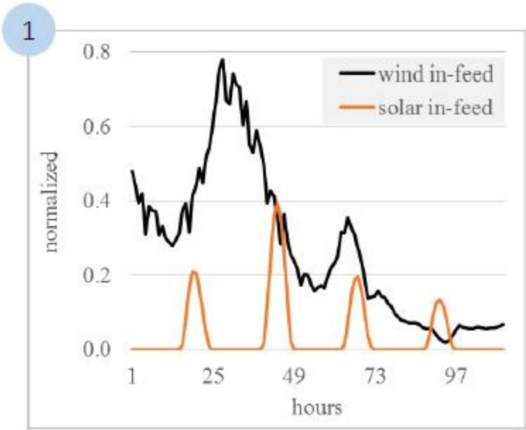
17% fossil fuels
67% renewables
16% nuclear

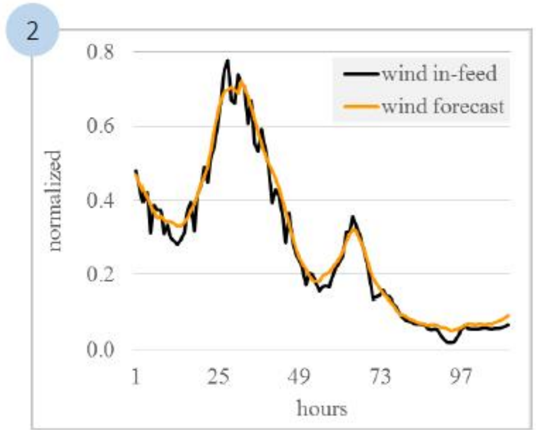
40 gCO_2/kWh

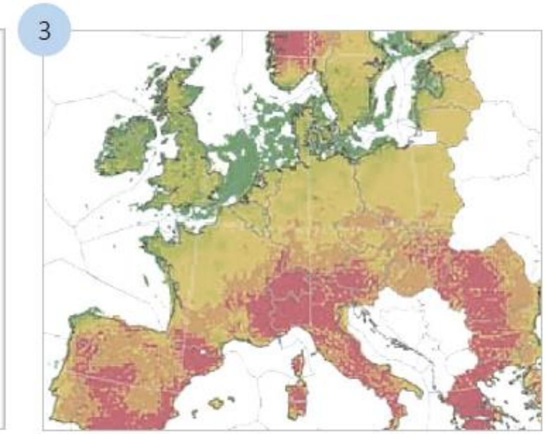
- A **complete reconfiguration** of the electricity generation system is needed by 2050.
- Rise of nuclear is accompanied by a *complete phase-out* of coal and oil, a drastic decrease of gas, development of CCS and a massive increase of renewable energies.
- **Colossal investments for the electricity sector**: 40 trn USD + 35 in energy efficiency
- **How to mobilise such large investments ensuring economic efficiency?**

VRE Characteristics and Three Main System Effects

System effects are mainly due to some characteristics that are intrinsic to VRE.







Wind does not always blow

Difficult to predict

Sites distant from load and may be dispersed

Source: L. Hirth

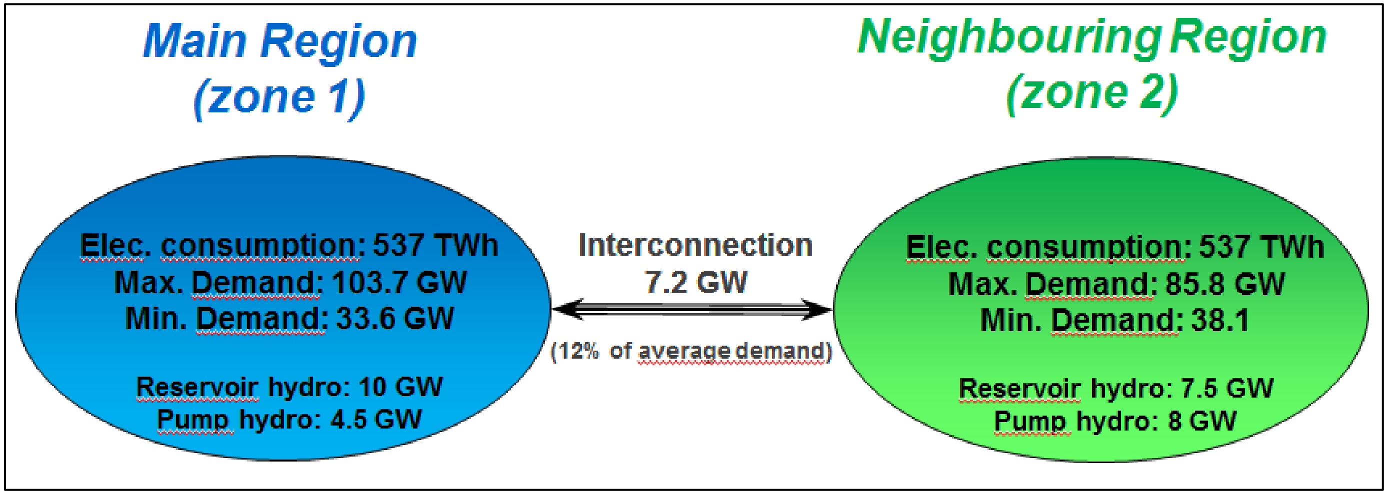
Profile costs

Balancing costs

Transmission and distribution costs

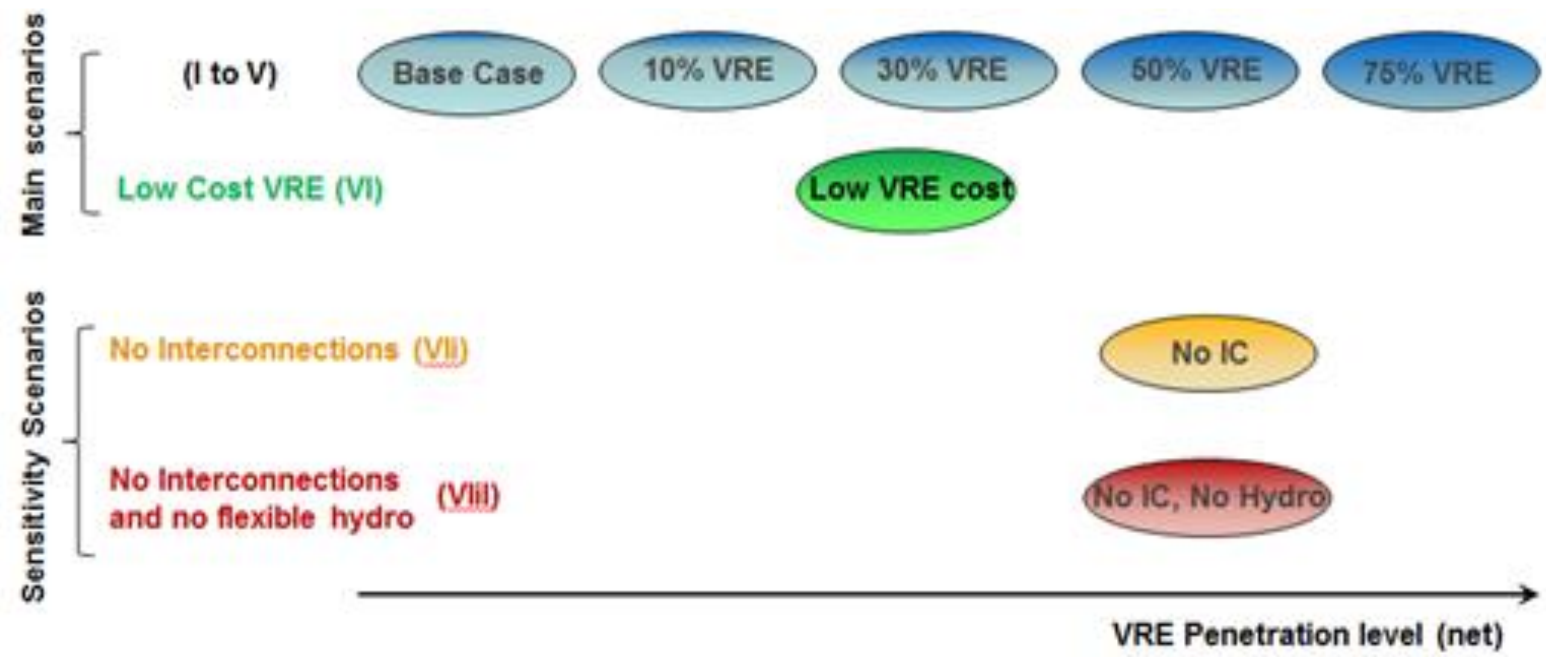
- System effects are **technology-** and **country**-specific, and depend on **penetration level**.
- Crucially important is the **time horizon**, when assessing economical cost/benefits and impacts on existing generators from introducing new capacity.
- The costs of grid-level system effects remain difficult to assess and can be **understood and quantified only by comparing two systems**.

NEA System Cost II study: Objectives of modelling effort



- Study the system costs of electricity systems with identical total demand and **carbon emission target** in scenarios with **different shares of VRE and nuclear**.
  - A CO_2 emissions objective is fixed at **50 g/kWh and the same for all scenarios**. This is compatible with carbon emission requirements in IEA 2DS or 450 ppm scenarios.
- Provide a **realistic** representation of a **large, well interconnected** power system.
  - It represent a large (continental scale), well interconnected system, with abundant hydro resources (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, observed VRE load factors).
- Economic assumptions derived from the **IEA/NEA 2015** study on electricity generation costs.

Definition of case studies



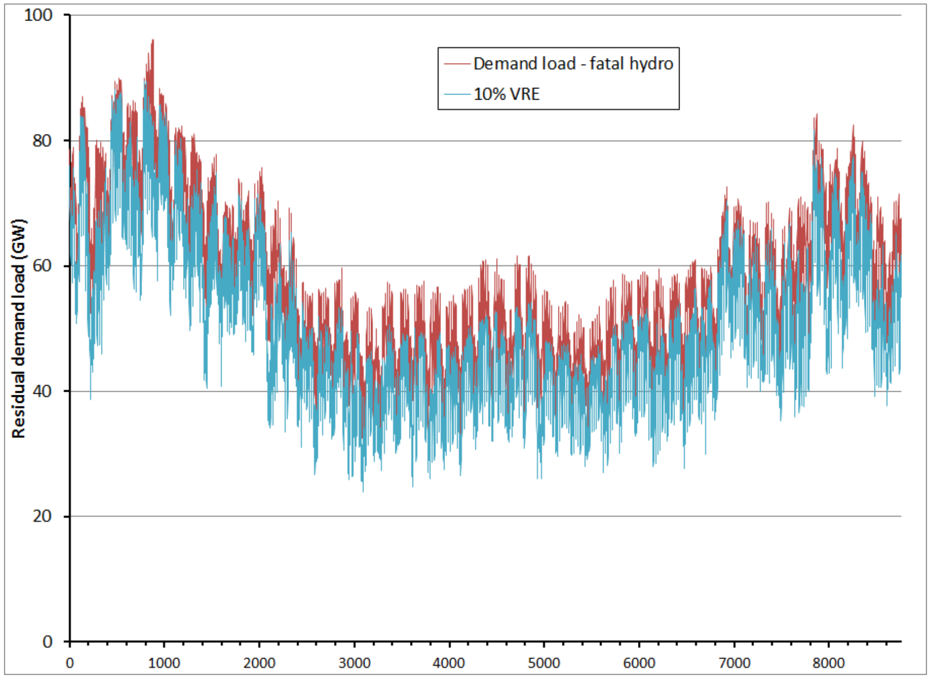
- Six Main scenarios with different shares of VRE imposed exogenously into the system including a scenario which assess a situation in presence of significant cost reduction for VRE technologies

  Base case with an imposed carbon price (leading to the same carbon emissions)

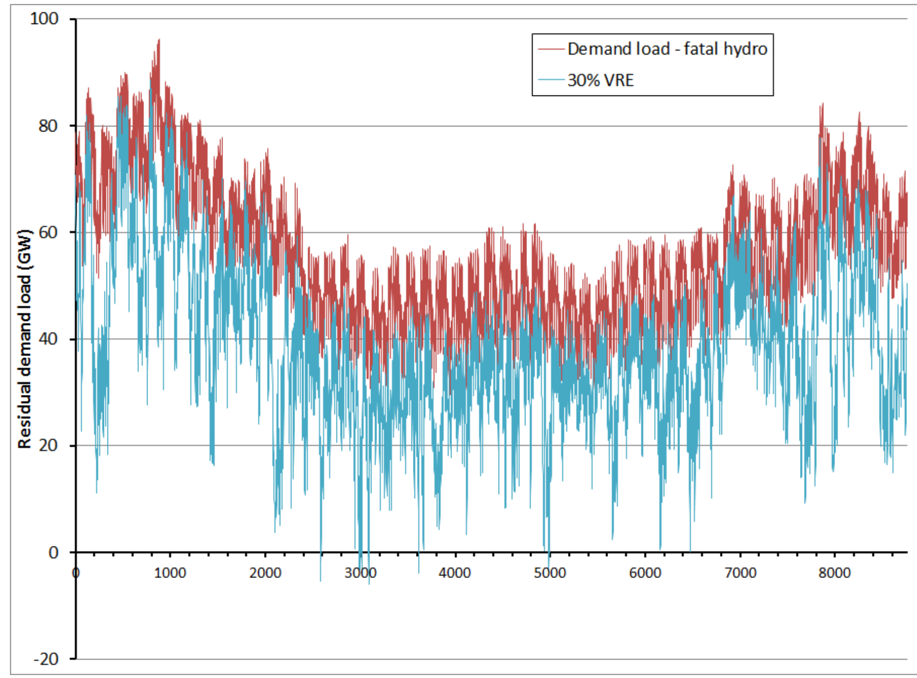
- Two sensitivity scenarios help to quantify the impact of having a isolated system, with limited potential for exchange with neighbouring countries (ex. Japan, Korea).
- Quantitative analysis performed with **state-of the art** modelling tools by a group of modellers from MIT.

Impact of VRE on the system: Residual Load

10% Variable Renewables scenario

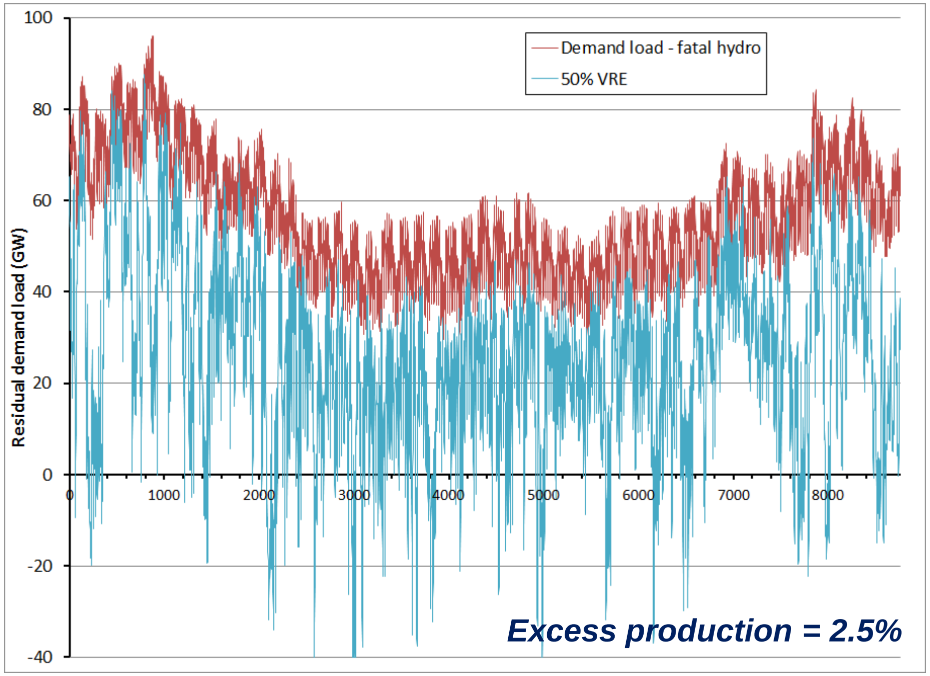


30% Variable Renewables scenario

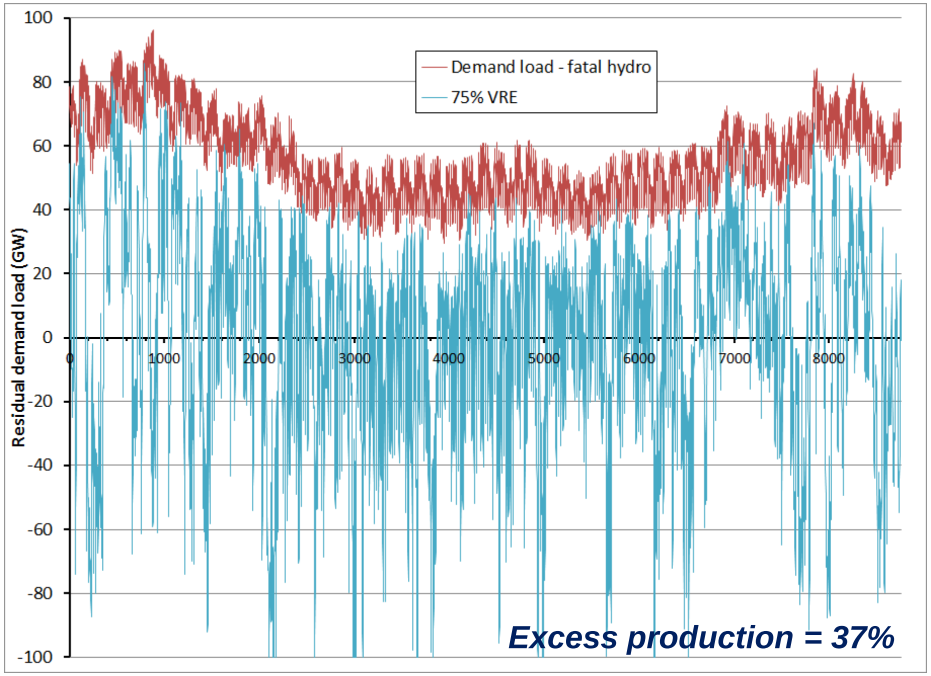


Impact of VRE on the system: Residual Load

50% Variable Renewables scenario



75% Variable Renewables scenario

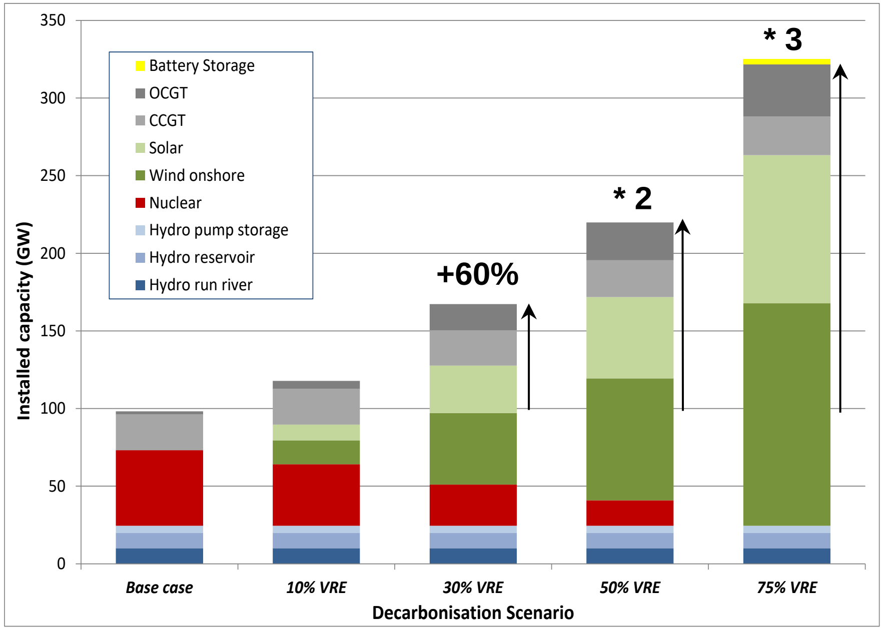


- Significant number of hours where VRE and fatal hydroelectric fully meet demand.
- Residual demand is determined more by VRE production than by the demand and loses its characteristics daily, weekly and seasonal patterns.
- Frequency of occurrence of large positive and negative gradients increases
- **With high shares of VRE in the system, the electricity demand becomes increasingly more volatile, unpredictable and difficult to meet.**

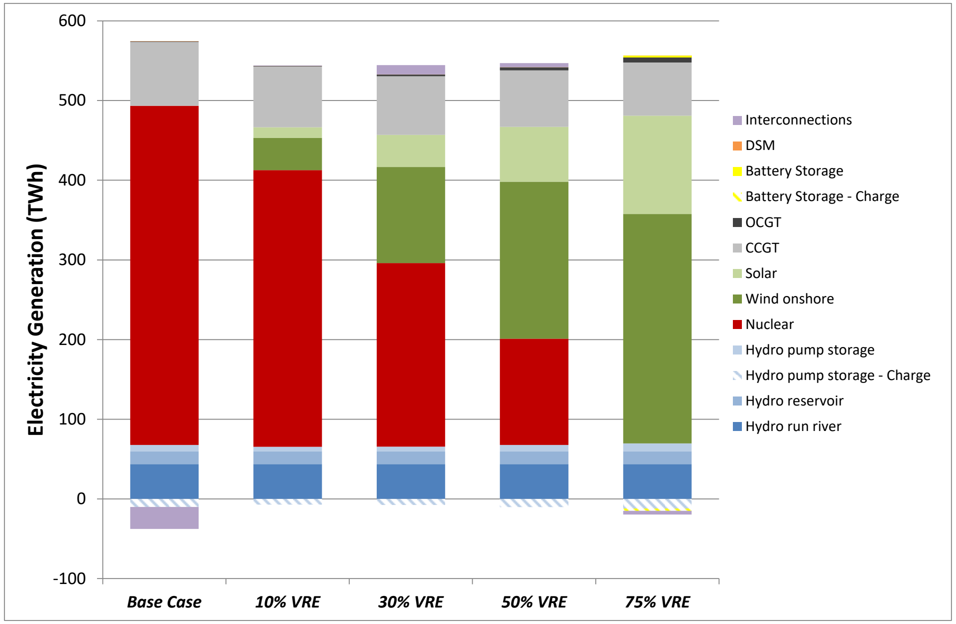
➡ **More and more flexibility is required from all components of electricity system.**

Generation mix and production

Installed capacity



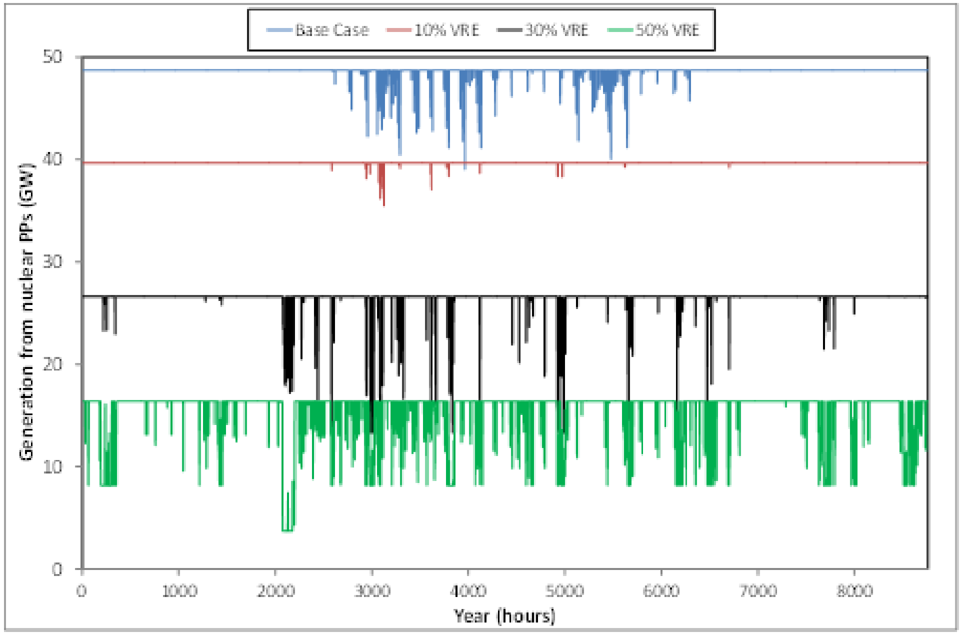
Electricity generation share



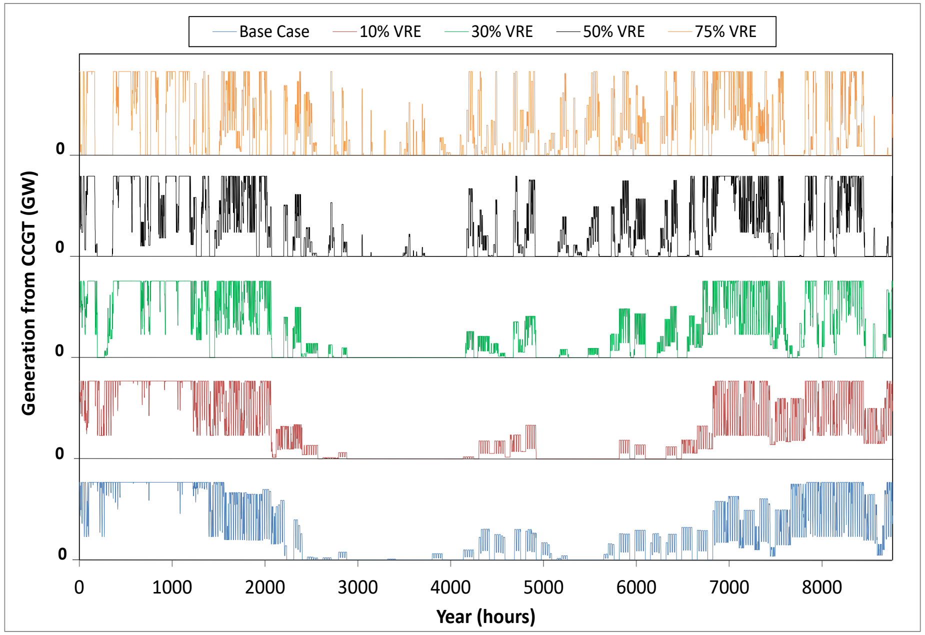
- Under a stringent carbon target, **no un-abated coal is deployed**.
- Due to the carbon constraint, the generation share from fossil fuels is (almost) constant, as well as that of low-carbon sources (VRE & nuclear).
- **Larger capacity installed** is needed as VRE targets increase.
- High VRE penetration requires **more OCGT capacity, CCGT operating at low LF**.
- Battery storage is deployed only at high VRE penetration levels.

Flexibility requirements: thermal power plants

Nuclear

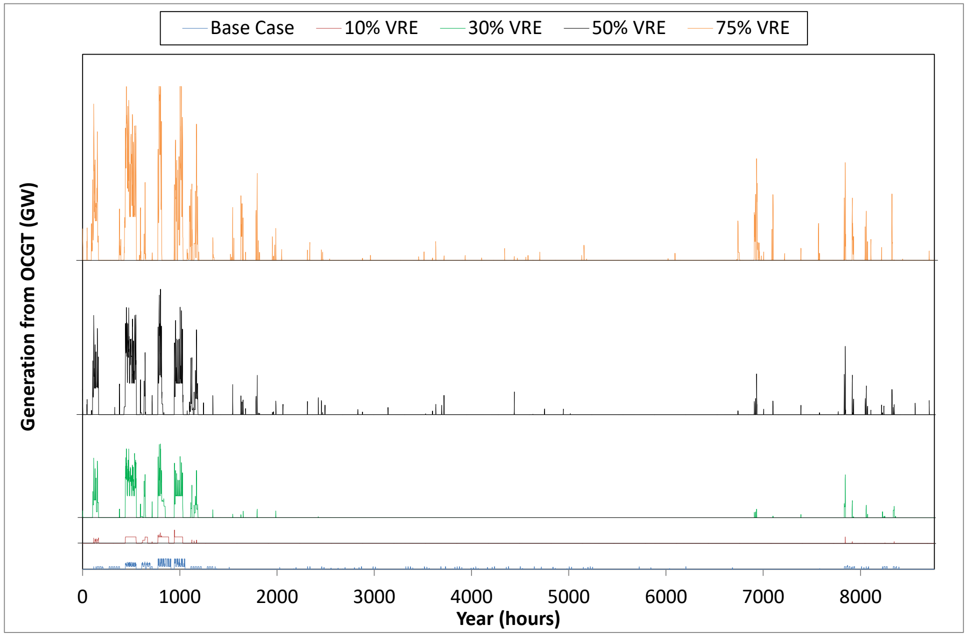


CCGT



Flexibility requirements: thermal power plants

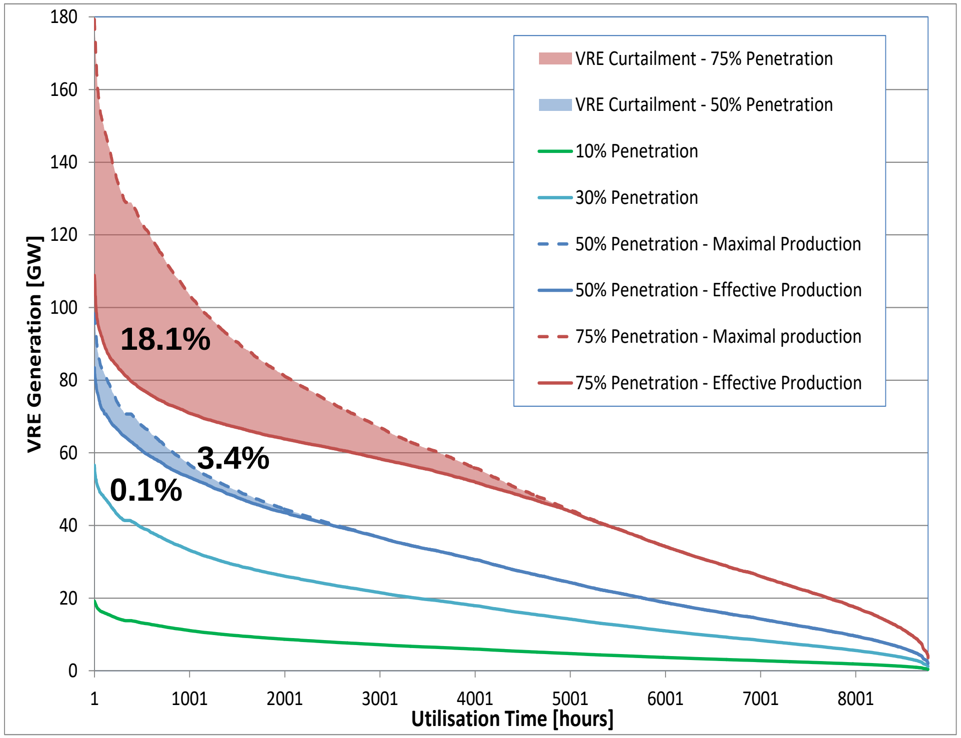
OCGT



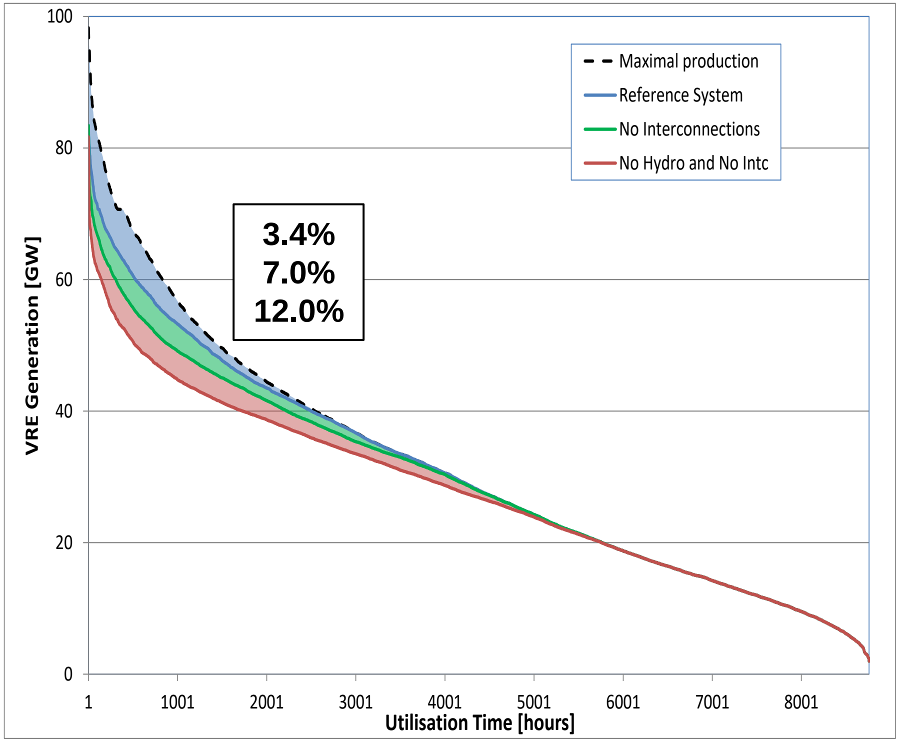
- With VRE deployment **all thermal plants are operated more flexibly**, and undergo more **frequent cycling** and **steeper ramping rates**, especially at VRE generation shares above 50%.
- Cycling of nuclear plants becomes important at 30% VRE penetration and is large at 50%.
- Capacity of CCGT is almost constant in all scenarios, but their **load factor decreases** markedly with VRE penetration.
- A **large increase of OCGT capacity** is observed at higher VRE generation share as they have to **balance the fluctuation in VRE production**.

VRE Curtailment

Main scenarios

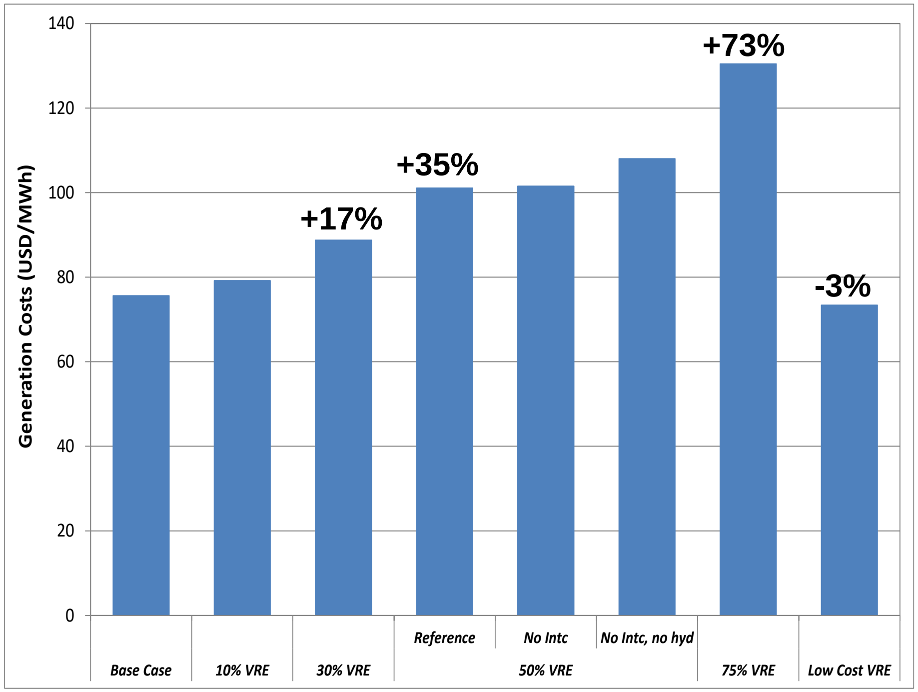


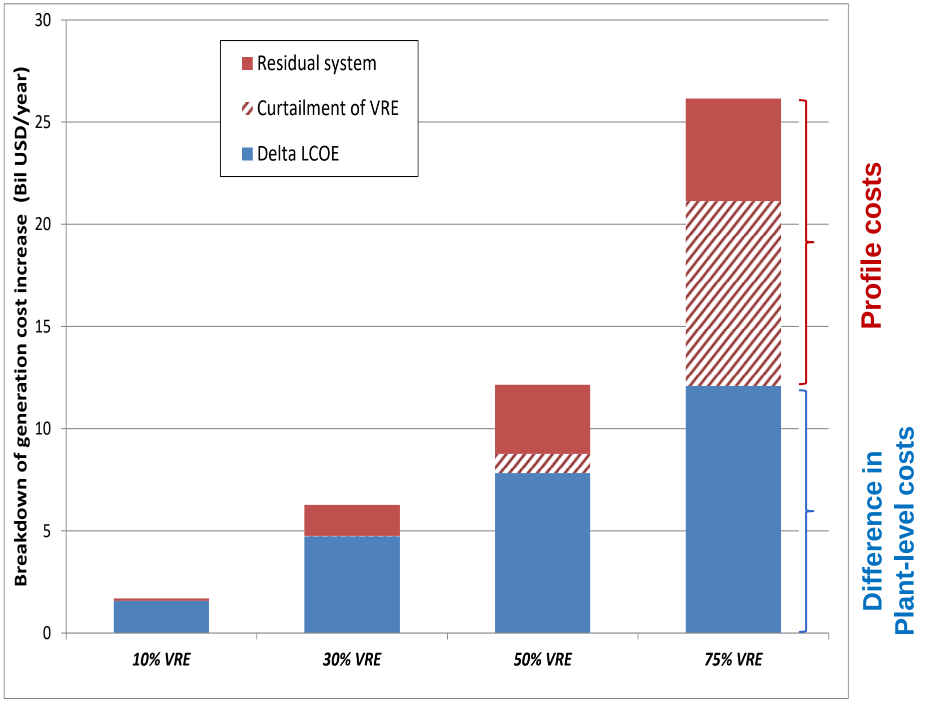
50% VRE: sensitivity analysis



- Curtailment of VRE starts to be noticeable at 50% penetration level and then increases significantly.
- Curtailment of the marginal unit is much higher (0.6%, >18% and >36%).
- VRE curtailment is even higher if interconnections and flexible hydro are not available.

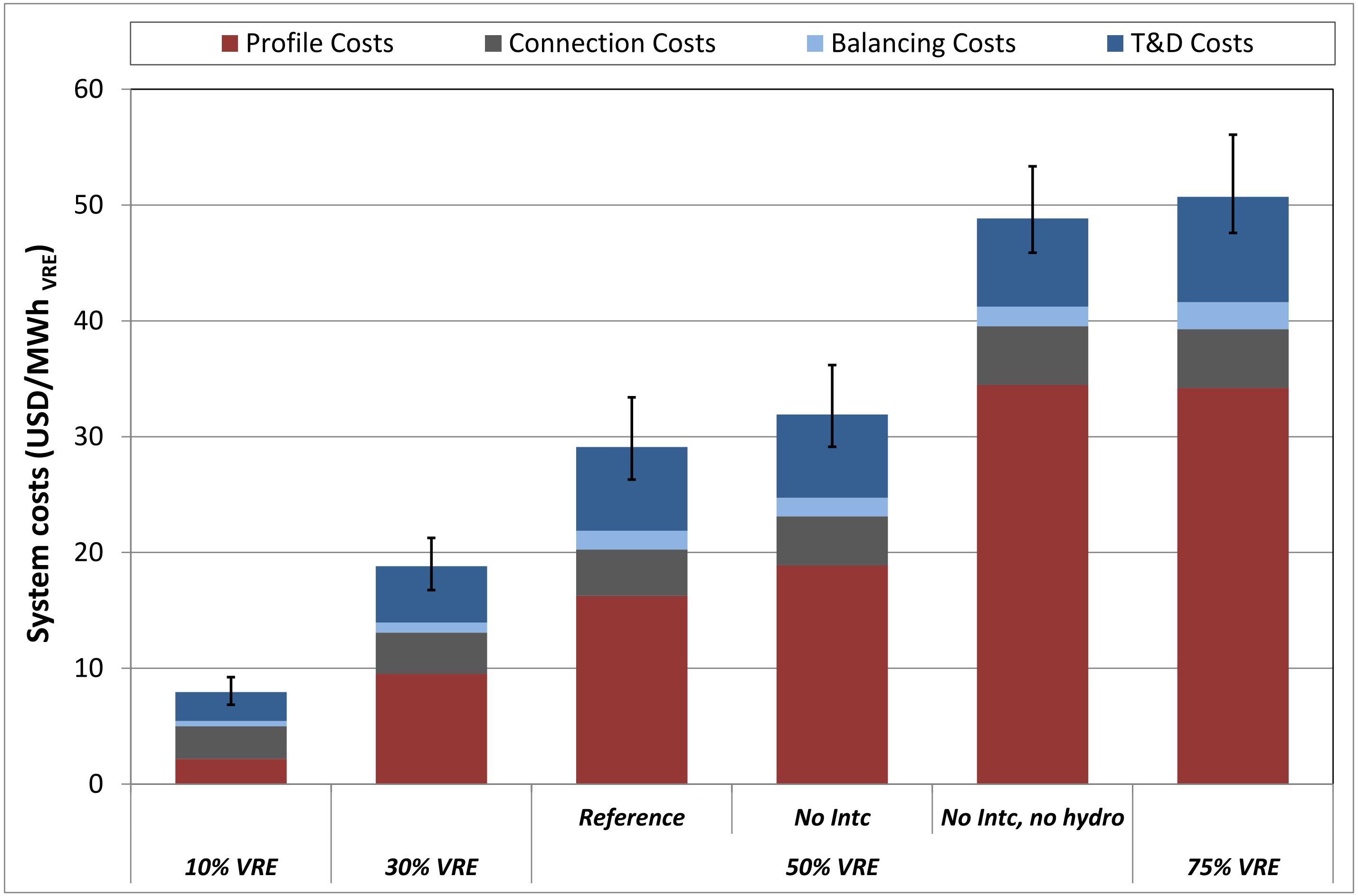
Total costs of generation: a breakdown





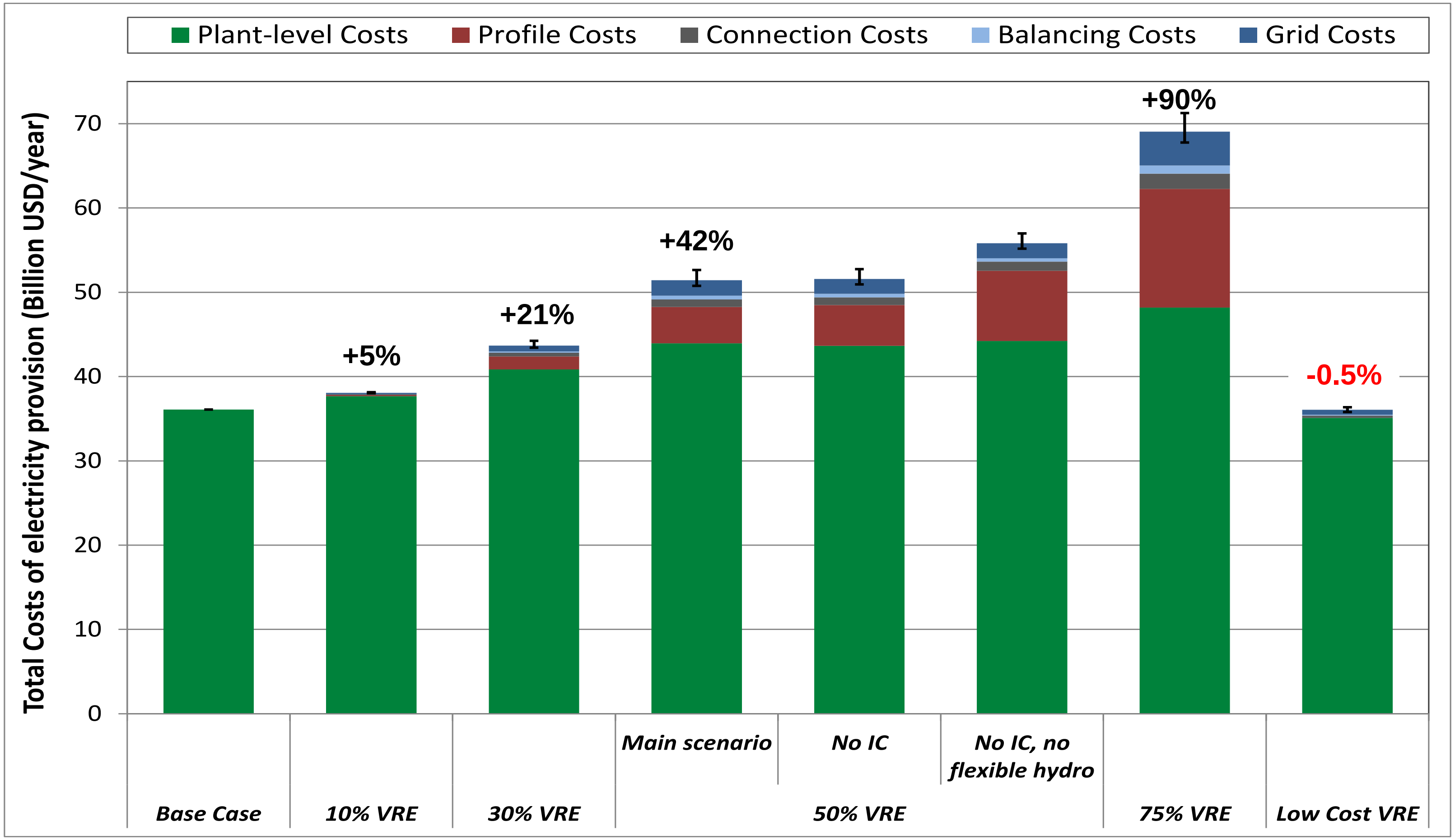
- The cost of generation increase with the share of VRE deployed in the system.
- Increase in cost of generation can be attributed to three different components:
  - The LCOE of VRE is still higher than that of the alternative low-carbon technology.
  - At high Penetration Level, the curtailment of VRE increases its costs.
  - The residual system becomes more expensive.

From profile costs to system costs



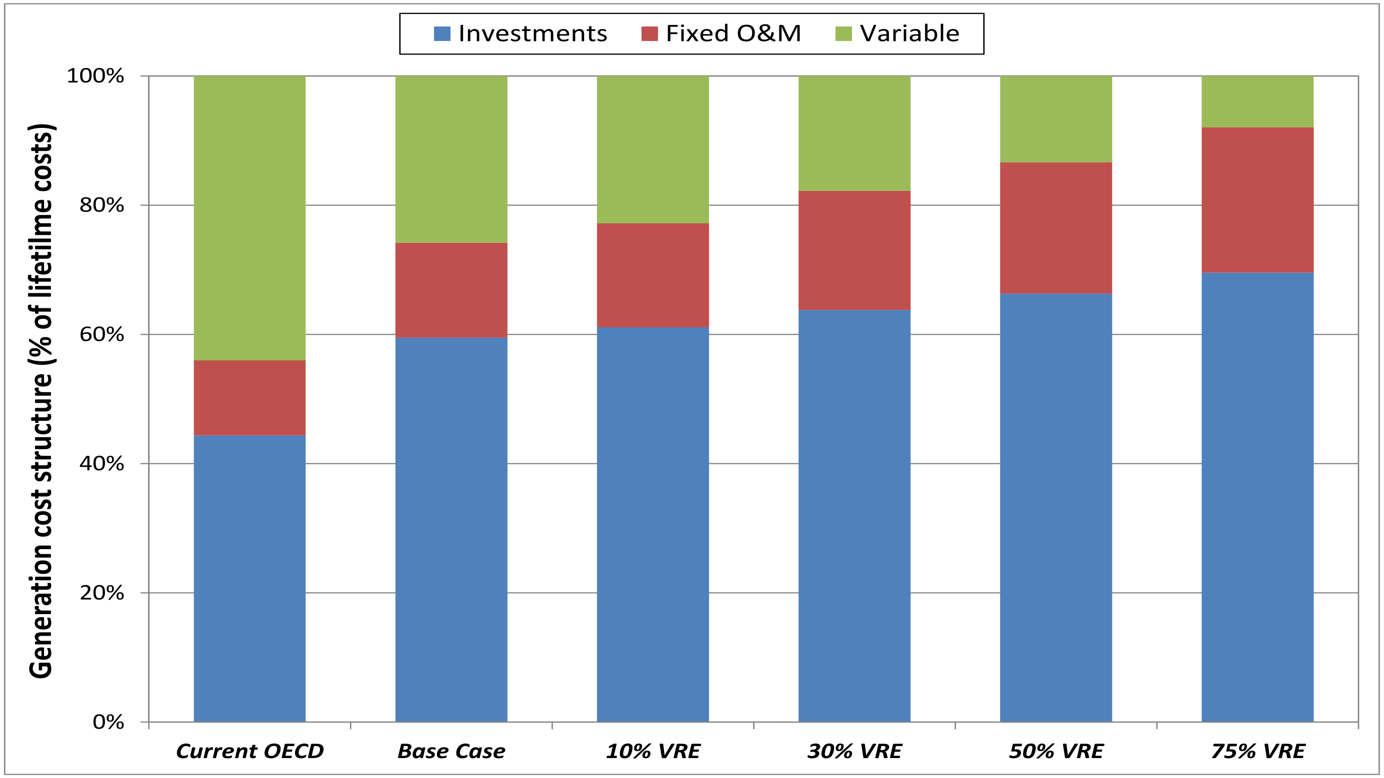
- Estimate of system costs with data from literature (T&D, connection and balancing).
- System costs are large, and increase with VRE generation share.
- Profile costs are the dominant component, especially at high VRE generation share.

Total costs of generation including all system costs



- Estimate of total cost of electricity provision, including all system costs.
- The cost of generation increase with the share of VRE deployed in the system.

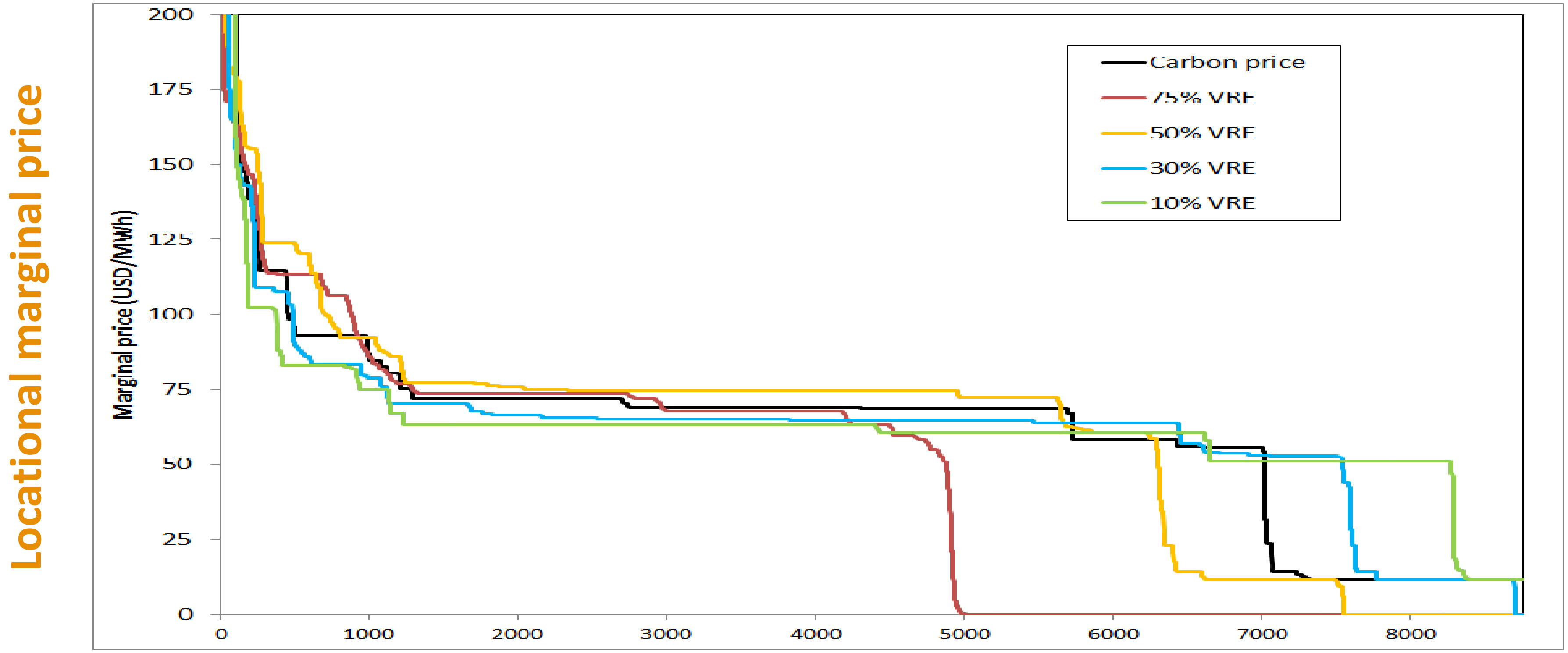
Towards a more capital intensive generation mix



Low-carbon scenarios

- A low-carbon generation mix is inevitably more capital intensive than current mix.
- The choice of low-carbon technology has impact on the ratio fixed/variable costs.
- Ratio fixed to variable costs has an impact on the **financial risk** faced by investors and on the **structure and volatility of electricity prices**

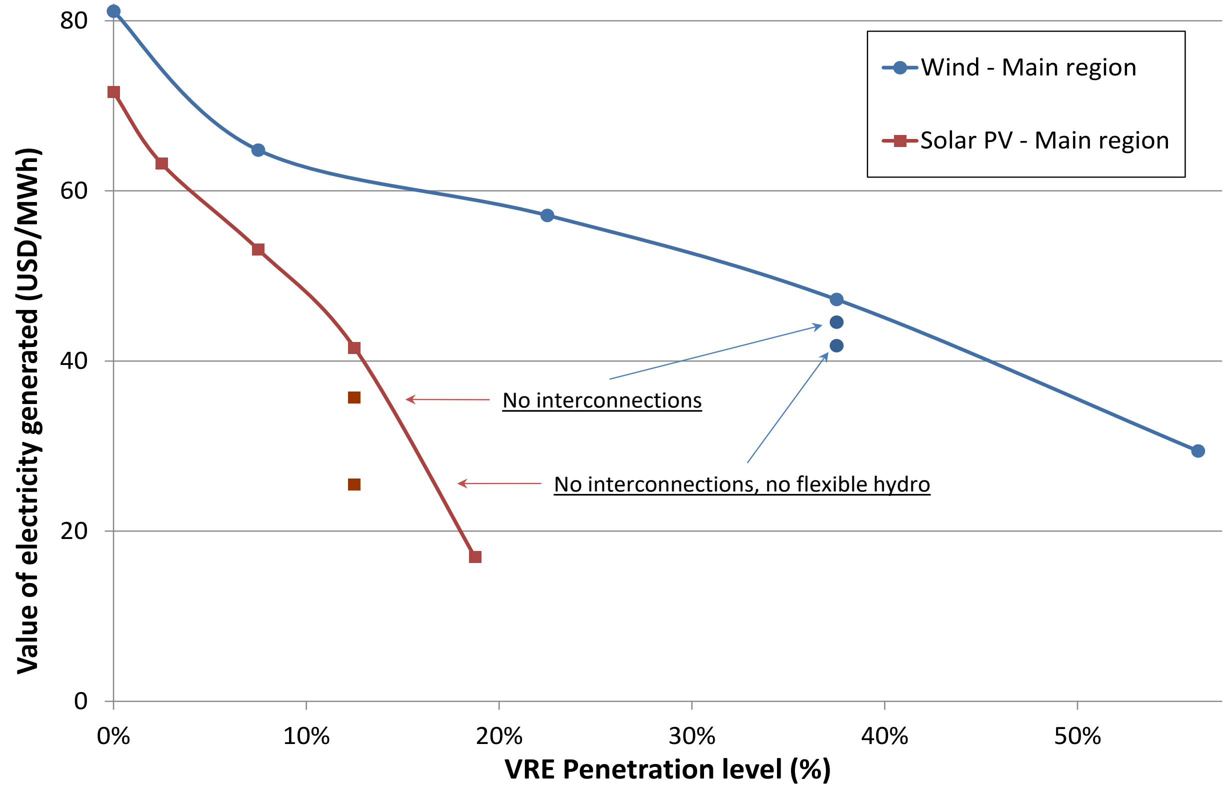
Price duration curve

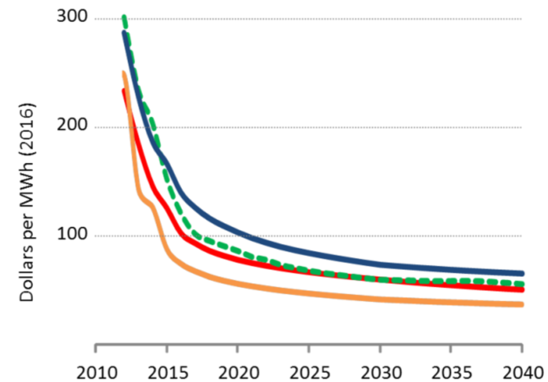


- More demanding VRE targets increase the number of hours with zero price.
  - No hours with zero price at low penetration levels, appear at 30% penetration level.
  - Over 1200 hours at 50% VRE and over 3750 hours at 75% VRE.
- Compensated by an increase of hours with high electricity prices (>100 USD/MWh)
- Increase in the volatility and unpredictability of electricity market prices.

➡ Are current market designs suited for investments in low-C technologies?

Auto-correlation and declining market values of VRE





Will VRE always need to be subsidised ?

Is their LCOE declining faster than their value?

- The *auto-correlation* of VRE production reduces its effective contribution to the system and thus its **market value** at increasing penetration level.
- The decrease is much larger for solar PV than for wind.
- Absence of interconnections and storage further reduce the value of VRE.

➡ **Is there an economic limit to high shares of VRE and what is the optimal generation share of VRE resources ?**

Policy Implications I

Radically decarbonising the electricity sector 50 gCO_2/kWh in a cost-effective manner while maintaining high levels of security of supply requires **specific policy measures.**

This is primarily due to the high capital intensity of *all* low carbon solutions for electric power generation.

The NEA System Costs study has identified **five pillars** of a relevant policy framework:

1) **Carbon Pricing is indispensable complement of decarbonising electricity supply**
   a) Carbon taxes are economically efficient and provide price certainty but will increase the cost of electricity supply.
   b) Emissions trading is an attractive alternative but makes for uncertain prices.

2) **Competitive Short-term Markets**
   a) **Energy-only markets** proven to be effective for the **cost-efficient dispatch** of generators.
   b) However, they are providing an **inadequate framework for** generating sufficient **investment** in new generation capacity.
   c) Hours with zero or even negative prices are here not a sign of malfunction but an indicator that there is excess electricity production in the system (and misaligned incentives).

Policy Implications II

3) Frameworks for long-term investment in low-carbon technologies

Capital-intensive low-carbon generation capacity requires **special financing frameworks providing certainty to investors**. These may include regulated tariffs, contracts for difference (CFD), feed-in tariffs (FIT), **feed-in premium s (FIP) or direct capital costs support** (e.g. through loan guarantees).

This gives huge new responsibilities to regulators and network operators. They will have to pay attention, in particular, to the *system value* of different options, as market prices and investment decisions are correlated only when using **FIP**s or **direct capital support**.

4) Adequate provision of capacity, flexibility and infrastructures for transmission and distribution

Low carbon electricity systems, especially with VRE, require added flexibility resources. The latter include dispatchable generation capacity for high demand-hours, storage and demand response. All flexibility resources require tightly meshed and robust transmission and distribution networks.

NB: All flexibility resources also have high ratios of fixed to variable costs, which again poses the question of appropriate financing mechanisms.

5) Internalising system costs to achieve highest economical efficiency

System costs such as profile costs, balancing cost as well as grid connection and extension costs accrue frequently outside the cost perimeter of the plant that generates them. Appropriate rules (exposure to market prices, balancing obligations, connection costs) can however totally or partially internalise them and avoid over-investment in high cost options.

Main findings

- Radically decarbonising the electricity sector in a cost-effective manner represents an enormous challenge for OECD countries and requires the **rapid deployment and coexistence** of **all low-carbon technologies** available (VRE, hydro and nuclear).
- The total cost of electricity supply increase significantly with VRE penetration level (from 36 ➡ 38 ➡ 44 ➡ 52 ➡ 71 billion USD/year).
- System costs increase over-proportionally with VRE (+8, 20, 30, 50 USD/MWh_{VRE})
- Flexibility needs from thermal plants (and from NPPs) increase with VRE penetration
- Imposing stringent carbon target shifts the cost structure of electricity provision toward more fixed costs and less variable costs, whatever is the low-carbon mix (more nuclear or more VRE).
- Increase of the hours at zero price with higher VRE targets (1000 and 3750 hours !).
- Market value of solar PV and wind is significantly reduced (autocorrelation).
- System costs are large and should be internalised to the maximal extent possible.
- Carbon pricing remains the first and best policy option.

Thank you for your attention

NEA studies are available on-line

http://www.oecd-nea.org/ndd/pubs/2012/7056-system-effects.pdf

http://www.oecd-nea.org/ndd/pubs/2015/7195-nn-build-2015.pdf

http://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf

http://www.oecd-nea.org/ndd/pubs/2018/7298-full-costs-2018.pdf

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Few consideration on modelling

- Need to model at least a full year, and not limit the analysis to "representative" periods.
- Results are driven by assumptions on future costs and technology progress , BUT the value of each technology for the system tend to decrease with its deployment.
- Implicit assumptions made even in *"state of the art"* models may have an impact on results, especially at high VRE generation share.
  - Perfect foresight.
  - Representation of a single year, no stochastic variability of RES generation.
  - Dynamic of the system at sub-hourly levels (inertia and system stability).
  - Copper plate approach within regions (no congestion, no transmission losses)
  - Hydro is considered as fully flexible, without accounting for environmental and technical constraints.
  - Risk neutrality for the investor.
- Not considering all system cost components in the optimisation process may lead to suboptimal outcomes.