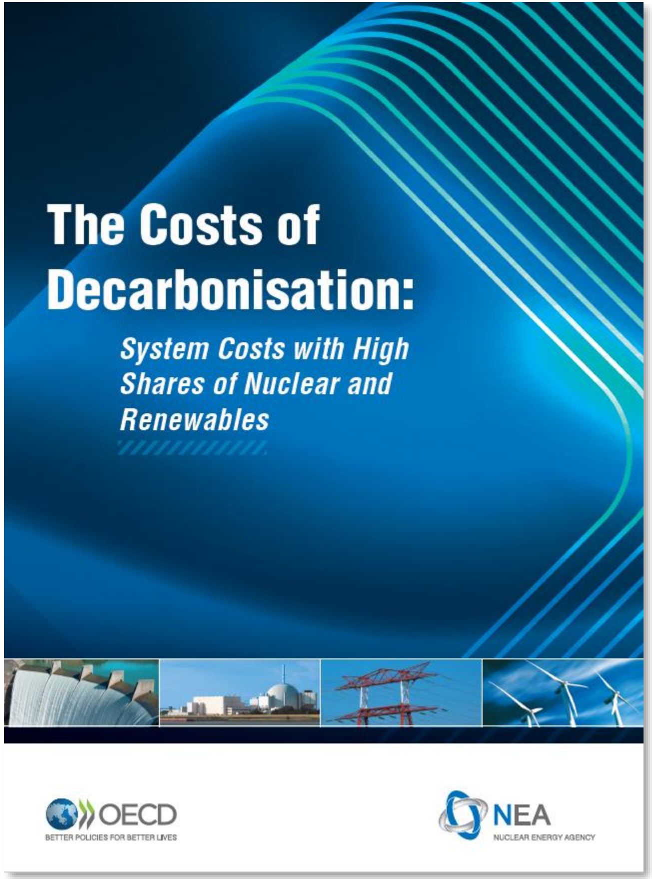


THE COSTS OF DECARBONISATION

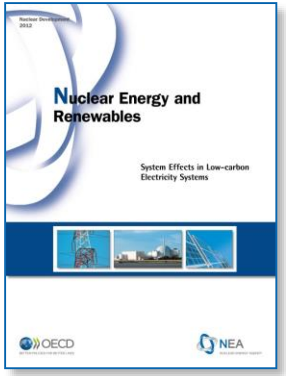
SYSTEM COSTS WITH HIGH SHARES OF NUCLEAR AND RENEWABLES

Dr. Michel Berthélemy

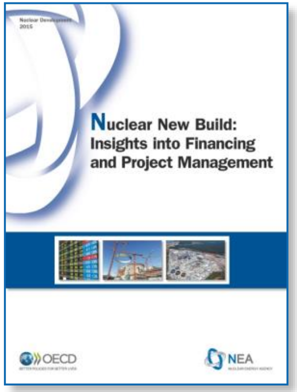
Division of Nuclear Technology Development and Economics (NTE)

Entretiens Européens, Helsinki, 12-13 November 2019

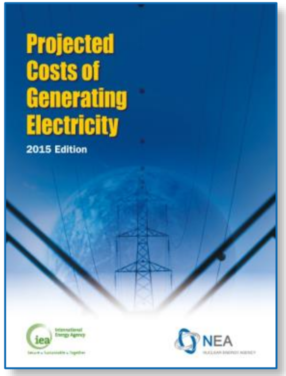
Ongoing OECD NEA Work on Cost of Electricity



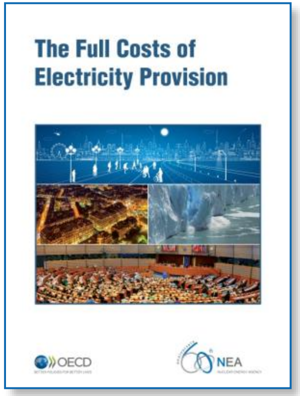
2012



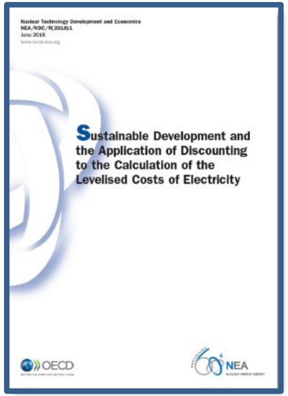
2015



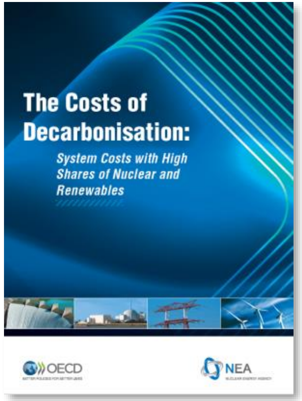
2015



2018

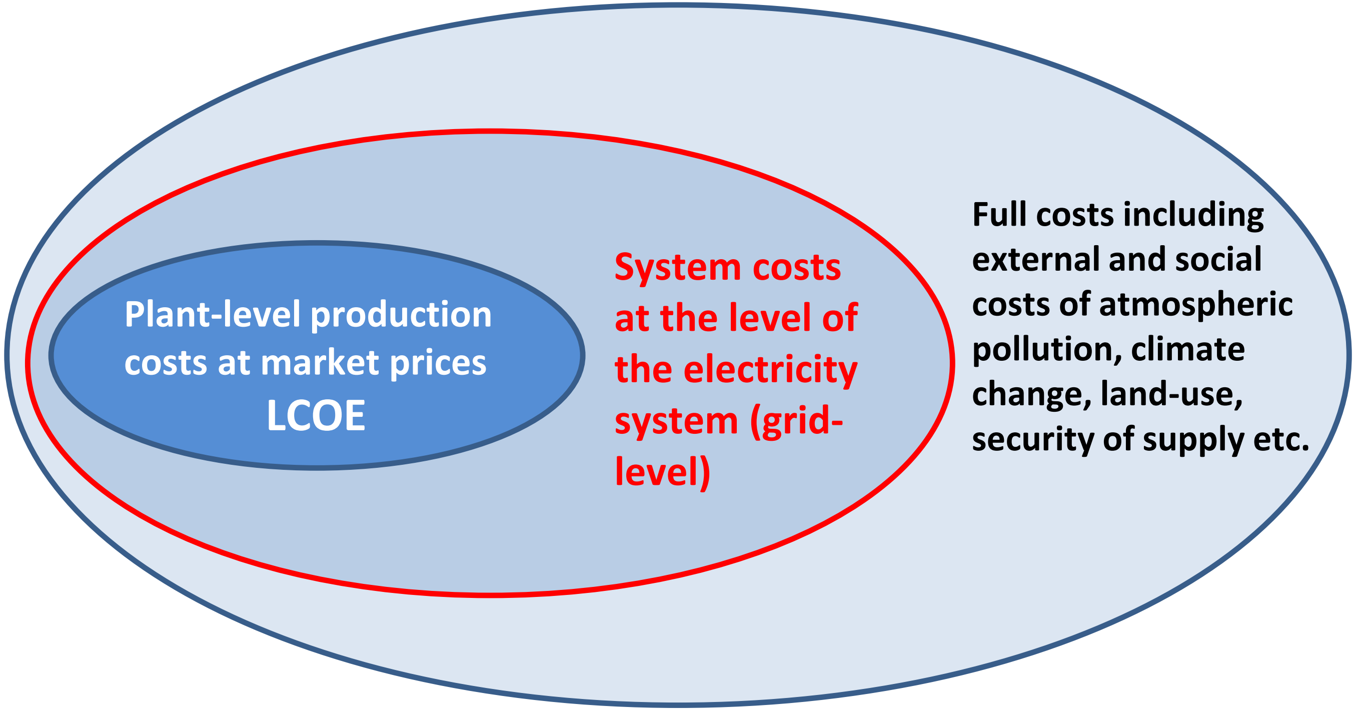


2018



2019

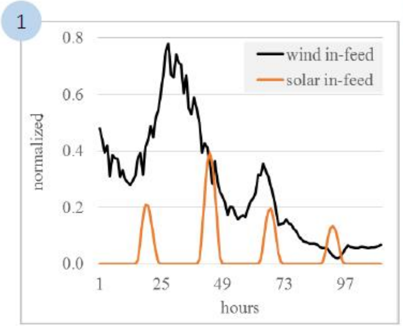
A Taxonomy of Costs



Assessing the total costs of electricity systems

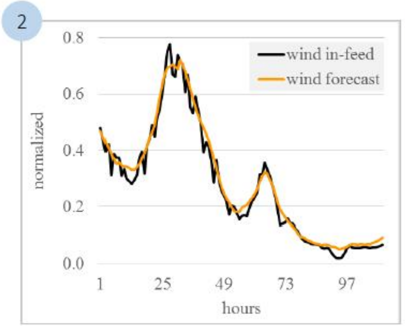
- Total system costs are the sum of plant-level generation costs and grid-level system costs
- System costs are mainly due to characteristics intrinsic to variable generation.

Source: L. Hirth



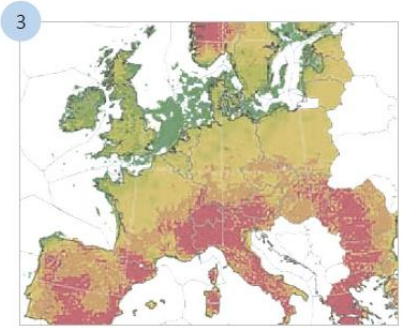
Wind does not always blow

Profile costs
(Changing mix)



Difficult to predict

Balancing costs
(Short-term variations)



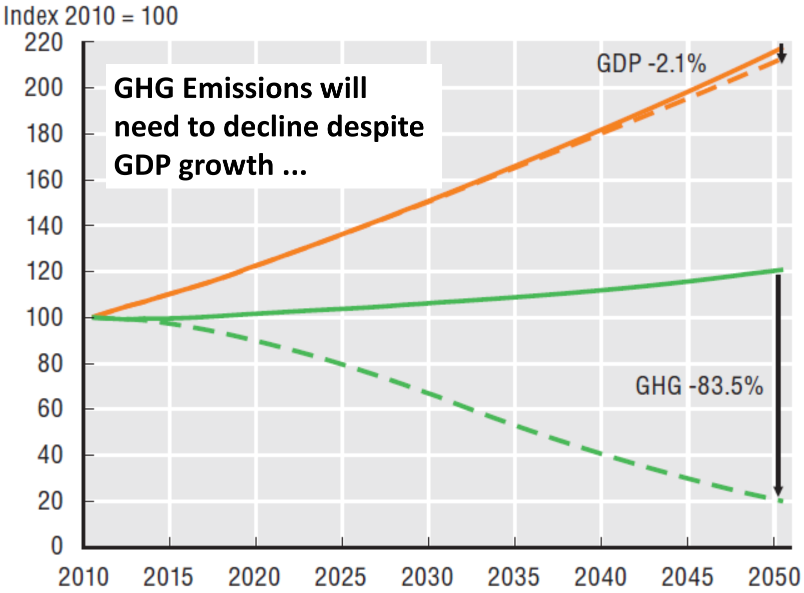
Good sites are distant from load centers

Transmission and distribution costs

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.



Source: OECD Environmental Outlook

Paris Agreement implies a 50 gCO_2/kWh target

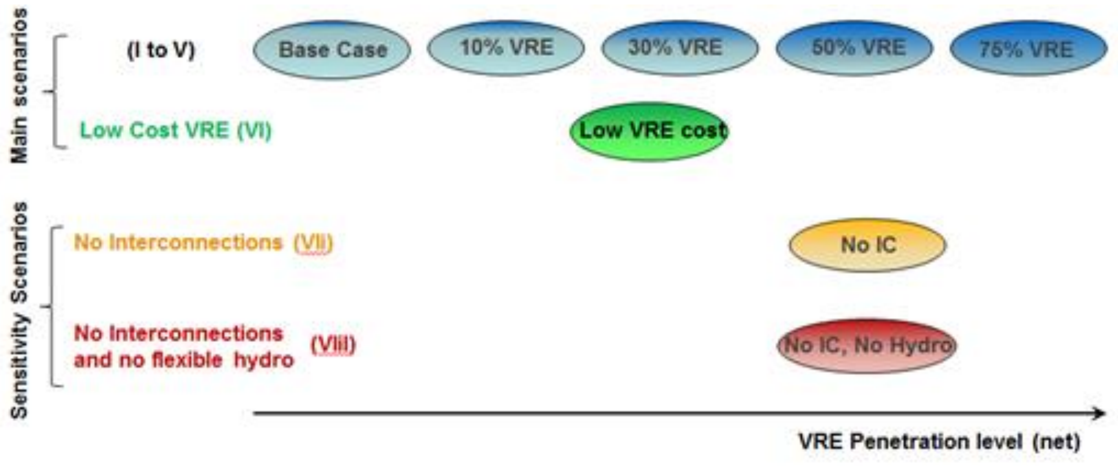
- Meeting the 2°C Paris Agreement implies limiting Greenhouse Gas (GHG) emissions to 450 ppm of $CO_{2\ equiv.}$
- Annual CO_2 emissions will have to be reduced by 43% (global) and 61% (OECD).
- Electricity contributes 40% of global CO_2 emissions and will play key role. Annual emissions from electricity will need to decline 73% (global) and 85% (OECD).
- Current emission intensity is 570 gCO_2/kWh (global) and 430 gCO_2/kWh (OECD).

➢ **Electricity generation in OECD will need to become low carbon at around 50 gCO_2/kWh.**

➢ **With hydro limited, Variable Renewable Energies (VRE) and nuclear will need to substitute fossils fuels.**

➢ **New NEA study analyses system costs of different electricity mixes at 50 gCO_2/kWh.**

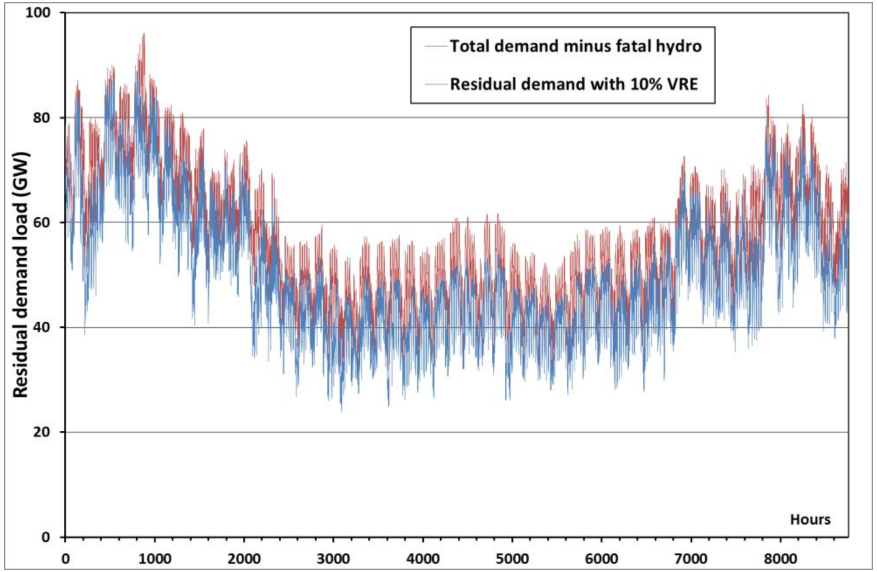
Eight Scenarios with identical constraint of 50gCO2 per kWh



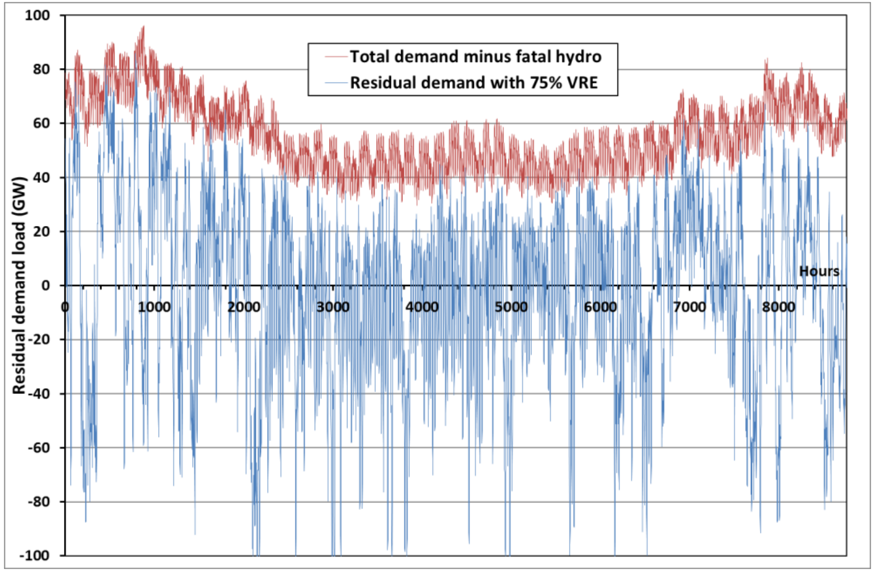
- Detailed least cost linear programming, hourly resolution, two zones, technical constraints in cooperation with group of modellers working at MIT.
- Identical demand curve, carbon emission target (50 gCO_2/kWh) and fixed hydro resources; realistic data for VRE loads; costs from IEA/NEA *Projected Costs* (2015).

High VRE share de-structures the remainder of the system I

10% Variable Renewables



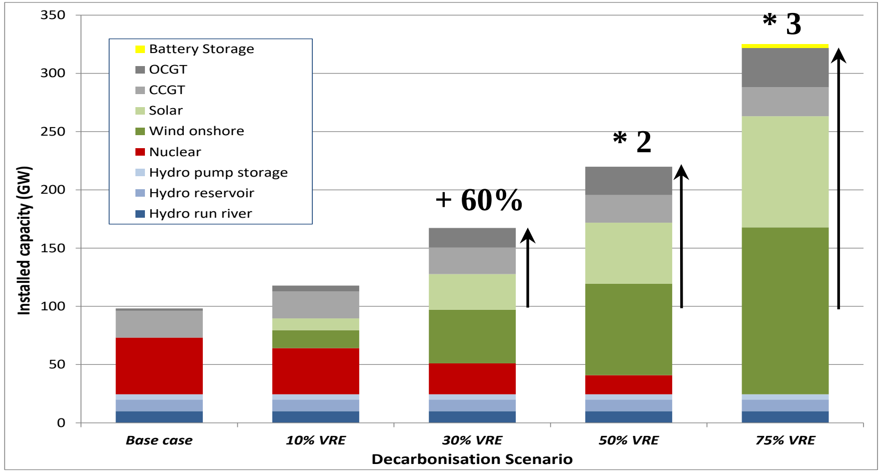
75% Variable Renewables



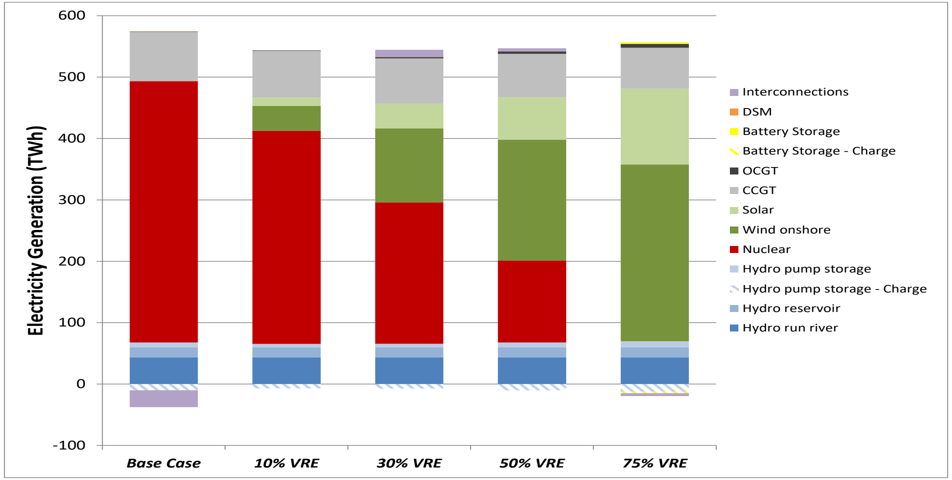
- High VRE shares result in challenges for system management.

Result 1: Considerable excess capacity needed to meet demand

Installed Capacity



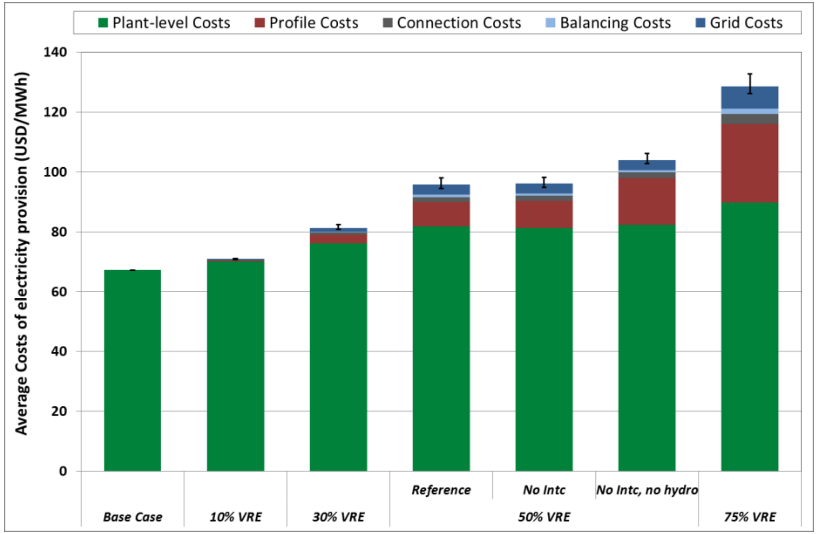
Electricity Generation



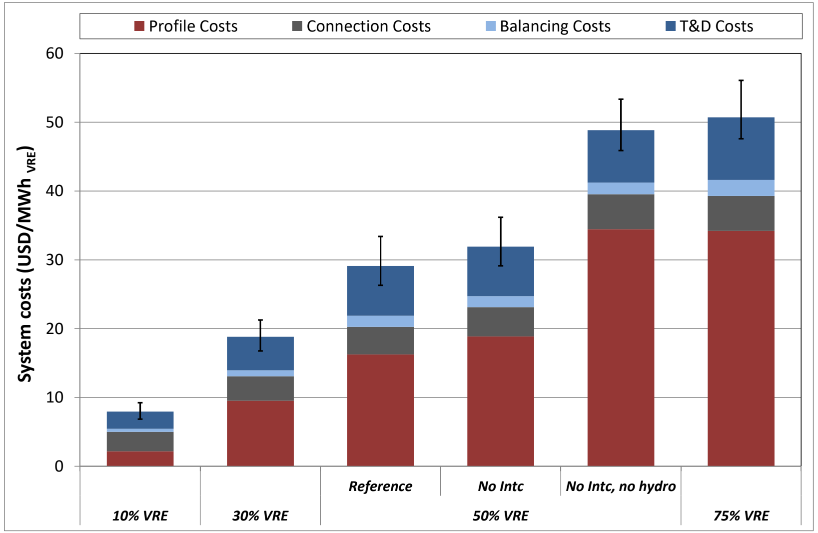
- Rising VRE share results in significantly larger capacity needs.
- Due to carbon constraint, coal no longer included, but gas provides flexibility. Battery storage deployed only at high VRE penetration levels.

Result 2: As VRE share increases system costs become a concern

Total Costs

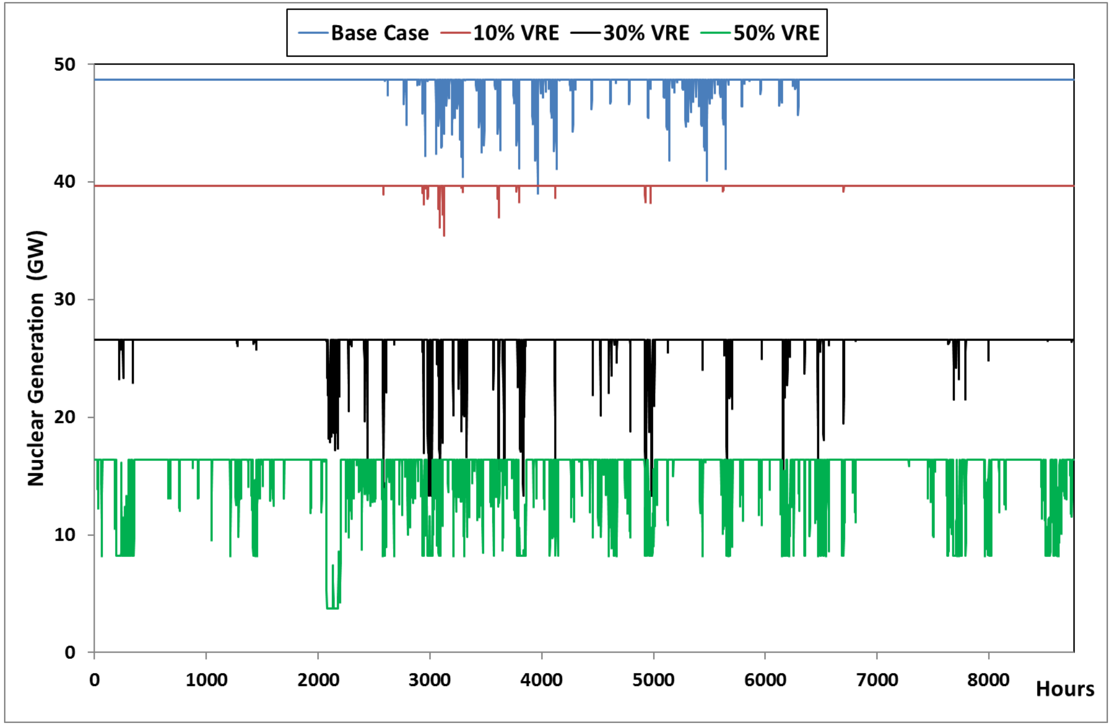


Breakdown of System Costs



- 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.

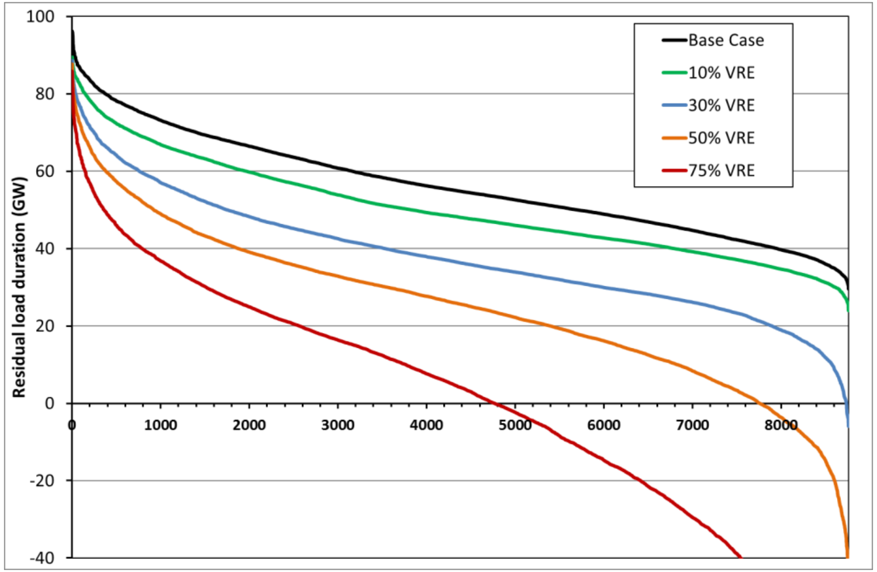
Result 3: Increasing demand on flexibility of nuclear power plants



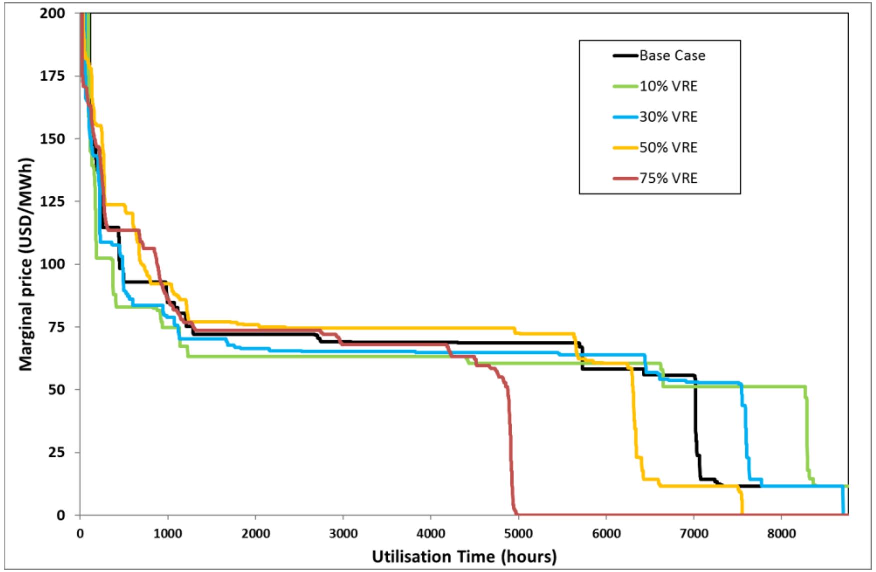
- With increasing VRE shares nuclear capacity declines.
- The number and steepness of the ramps for load following (cycling) increases.
- This poses the question of sector coupling, *i.e.*, combining electricity generation with the production of another “storable” product (heat, desalination, hydrogen…).

Result 4: Decreased load and volatile electricity prices discourage investment

Residual Load Duration Curves



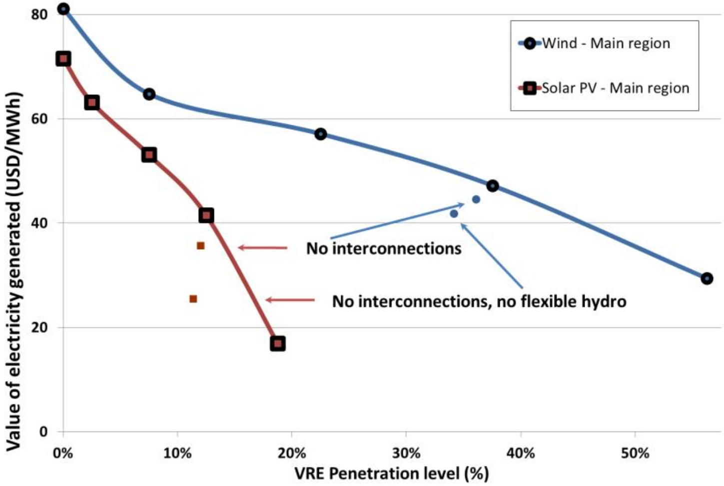
Price Volatility



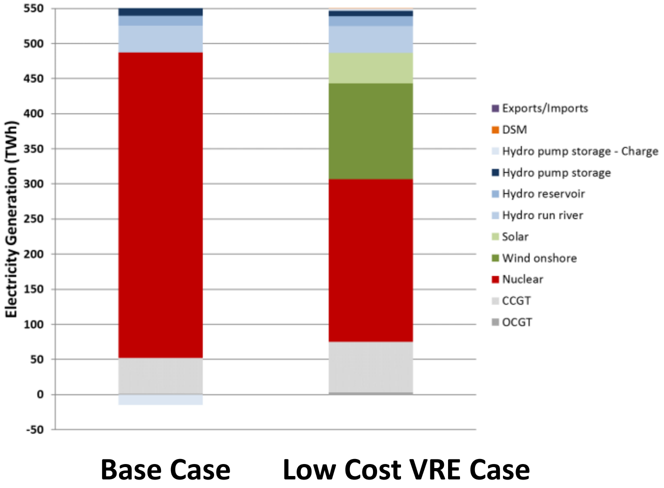
- Increase of hours with zero price (over 3750 hours *p.a.* at 75% VRE), compensated by an increase in high-price hours (>100 USD/MWh).
- Price volatility increases uncertainty, investment costs and risks to capacity adequacy.

Result 5: Market-based introduction of VRE is intrinsically difficult

Declining Market Value of VRE



Even Low Cost VRE Limited Market Entry



- VRE earn less than average market prices due to auto-correlation during production hours. This effect increase with their share and is larger for solar PV. Flexibility resources improve value.
- Future expected cost declines of VRE (e.g., 60% PV, 50% wind off-shore, 33% wind on-shore) will allow self-entry into the market. The level will depend strongly on local conditions.

General policy recommendations for efficient decarbonisation

Radically decarbonising the electricity sector to 50 gCO_2/kWh in a cost-effective manner while maintaining high levels of security of supply requires five complementary policy measures:

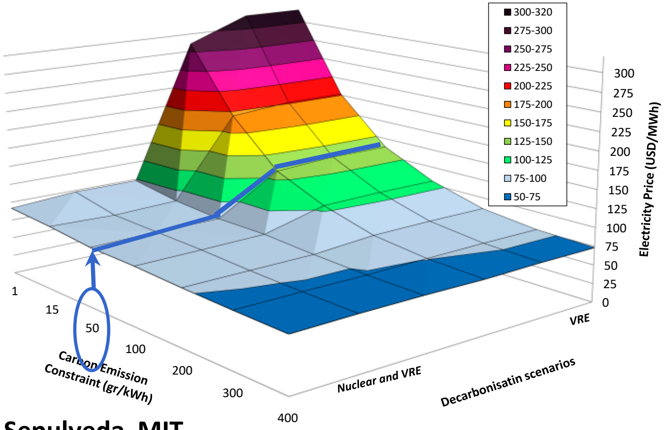
- Implement **carbon pricing**, as the most efficient approach for decarbonising electricity supply;
- **Policy stability for investors** to encourage new investments in all low-carbon technologies
- Foster **competitive short-term markets** for the cost-efficient dispatch of available technologies;
- Ensure **adequate levels of capacity and flexibility**, as well as **transmission and distribution** infrastructure;
- Recognise and **fairly allocate the system costs to the technologies that cause them**.

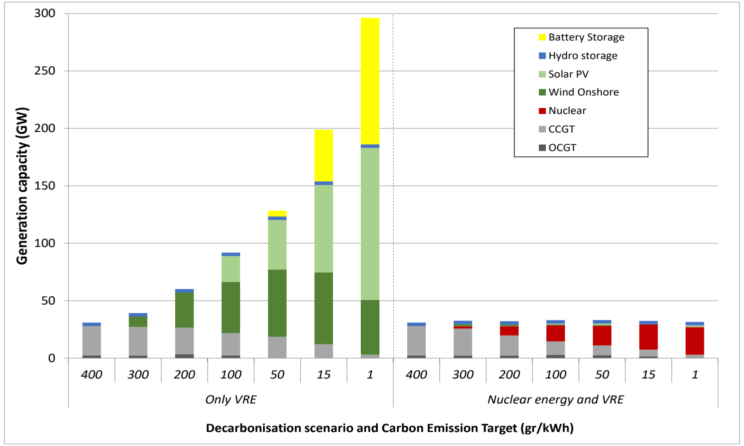
Successfully decarbonising the electricity sector requires suitable policies for the rapid deployment of *all* available low-carbon technologies in the most cost-effective manner

Thank you for your attention

The Cost of Electricity Is a Function of (1) Carbon and (2) VRE Targets

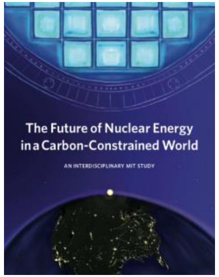
(How Do the Results of the NEA SC2 Study Compare with Alternative Targets?)





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.



Lessons of the NEA system cost study

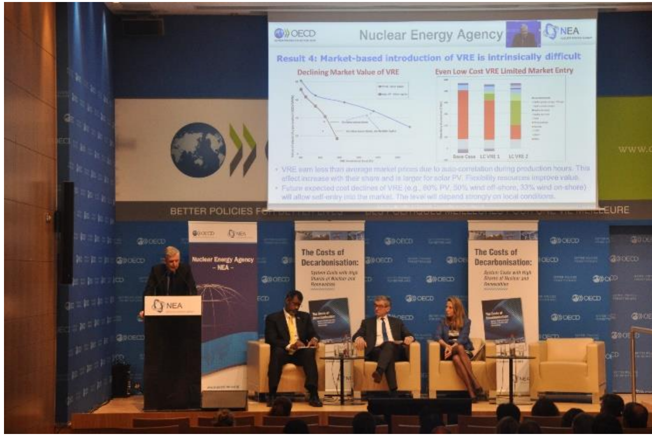
The NEA study on *The Cost of Decarbonisation* compares different low carbon electricity mixes satisfying the same stringent carbon constraint cost of 50g per kWh consistent with the *Paris Agreement* and the objective to keep the rise of global mean temperatures below 2°C. In different scenarios, generation from VRE is substituted for nuclear generation 1:1. Given current technologies and costs, the study allows for the following conclusions. A higher share of VRE and a lower share of nuclear imply:

1. **Considerably higher system costs (up to USD 50/ MWh_{VRE}) as energy value of VRE declines;**
2. **Higher overall costs (under LCOE cost assumptions in IEA/NEA (2015); as VRE costs decline, future *least-cost systems* will contain both VRE *and* nuclear;**
3. **Considerably higher capacity (with implications for land-use, externalities etc.);**
4. **Higher price volatility (up to 3750h of zero prices, compensated by prices above USD 100 per MWh);**
5. **Higher technical stress for residual system (nuclear, gas) due to ramping and cycling, whose implications cannot be modelled here.**

Future low carbon systems will require considerable attention from policy-makers and regulators, both as far as investments and as far as operations are concerned.

Dissemination and Follow-Up

- 17 January 2019 - Pre-Launch Webinar:
  - With DG Magwood, Bernard Salha (EdF R&D), Jan Horst Keppler, Sama Bilbao y León;
  - Highest number of viewers after one month;
  - Lowest cost per download of all NEA webinars in 2018/19.
- 25 January 2019 – Official Launch in Hungary
- Presentations in Australia, France (CEA, DGEC and APE), Belgium and Slovakia (V4 – Meeting); further planned presentations in Germany, Slovenia, Spain, United States
- Webinar with NICE Future Initiative (April 25, 2019)
- High visibility at CEM-10 in Canada (May 28-31, 2019)
- More than 5 000 downloads until April 2019
  - NEA Bestsellers have about 10 000 downloads per year.



TAKE-HOME MESSAGE OF *THE COSTS OF DECARBONISATION*

Radically decarbonised electricity systems will rely on variable renewables and nuclear energy as their main pillars.

Economic system cost analysis is the key stone that will allow to identify opportunities and challenges as well as to organise their complementarities into a coherent whole.

Collaborating on System Cost Modelling with NEA Member Countries: The SC3 Project

- NEA has decided to make experience gained in energy system modelling available to interested member countries in what is called the System Cost 3 (SC3) project.
- Depending on internal approval by OECD and NEA selected non-Member countries can also participate.
- Collaboration requires input from variety of stakeholders (see next slide)
- While the methodology is general, it needs to be understood that results will depend strongly on
  - The specific situation of the individual country,
  - The specific policy questions being advanced,
  - Modelling tools being employed.

Possible Policy Questions for an Interested NEA Member Countries

Rapidly changing electricity systems can confront policymakers confronted with questions that are difficult to answer without the help of integrated energy system modelling:

- What is the economic cost of attaining different targets for either VRE deployment or carbon emission reductions? Should these targets be pursued separately or jointly?
- What is the impact of such targets on the shares of different technologies, in particular low-carbon generators such as nuclear and hydro?
- What happens to the load factors of nuclear and other dispatchable generators?
- How does the market value of VRE electricity decline as their capacity and share increases?
- How good are a given country's existing flexibility resources? What would be the benefits of additional flexibility resources?
- What is the level and volatility of electricity prices, including hours with zero or negative prices? What is the likely impact on the cost of capital of such volatility?
- What are the key inflection points? What are possible trajectories from the present to new equilibria?

NEA System Cost Modelling with Individual Member Country