The competitiveness of nuclear power in a low-carbon energy mix:

results from recent OECD/NEA studies

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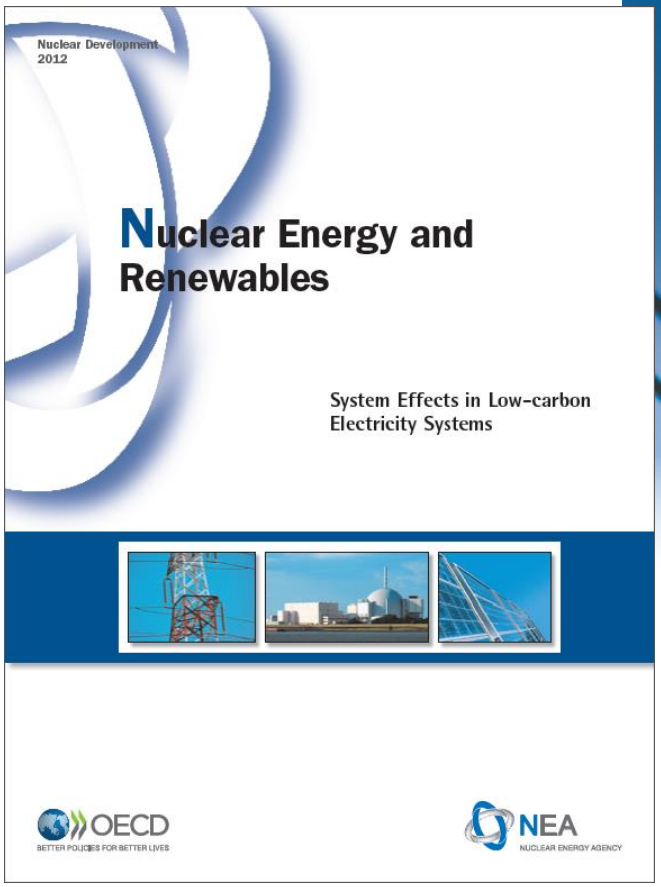
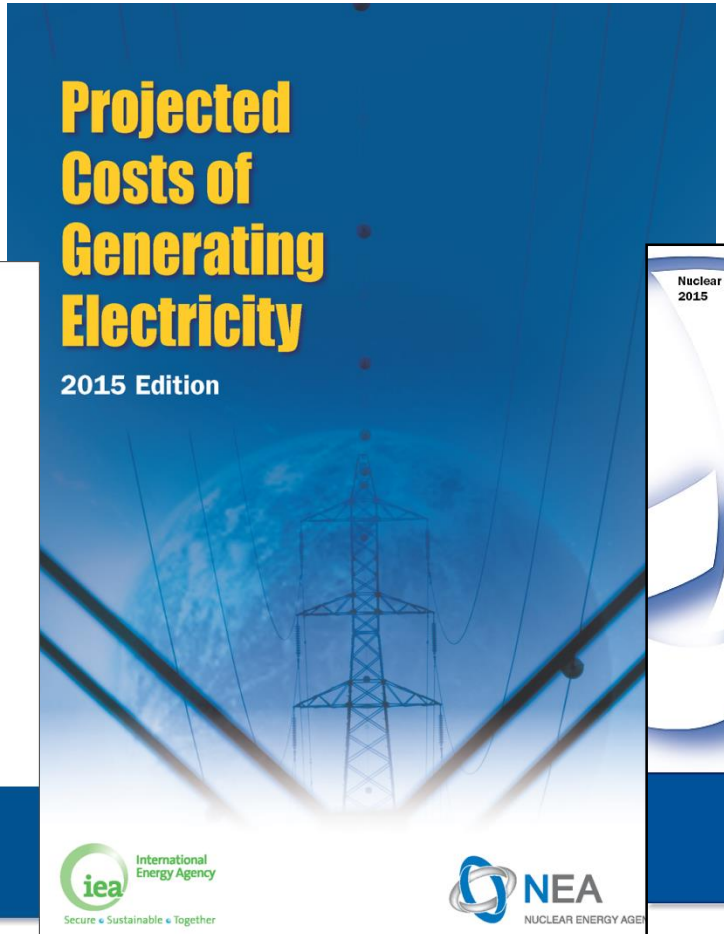
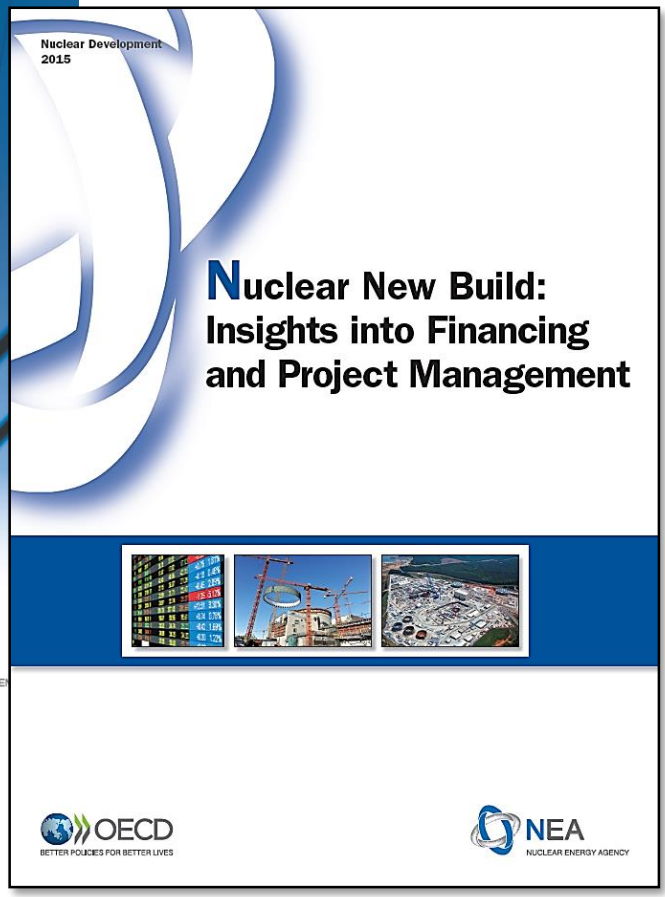
OECD/NEA Work on nuclear power economics

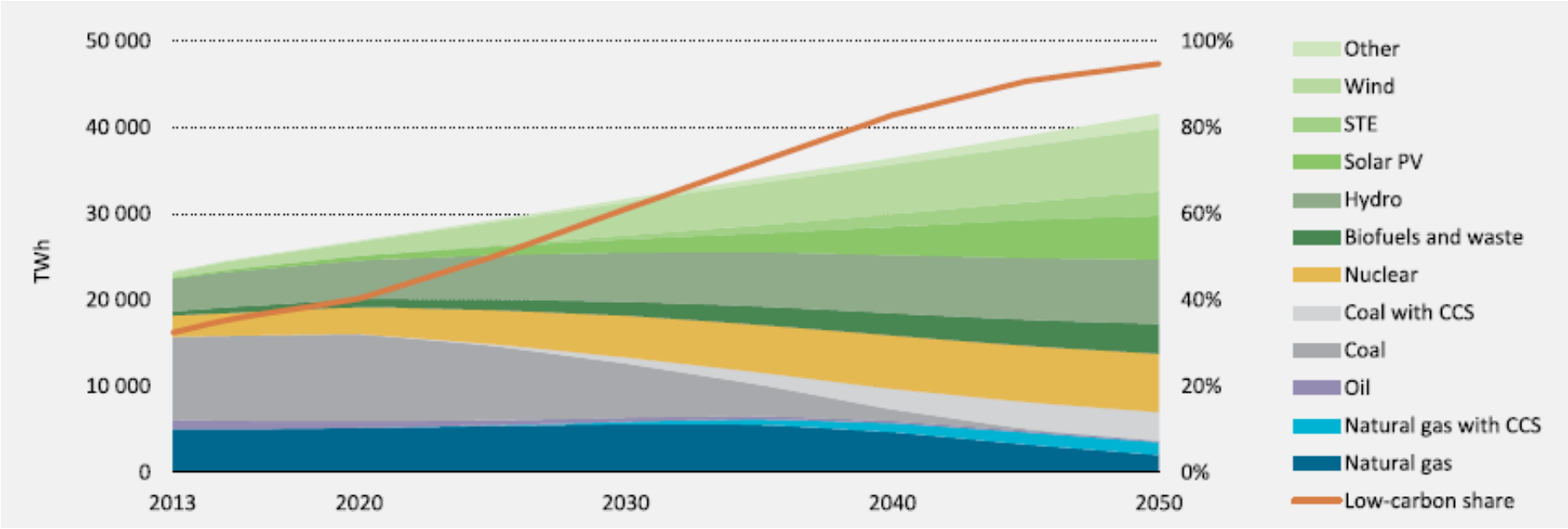






Power sector almost completely decarbonised in the IEA 2DS

Global electricity production and technology shares in the IEA 2DS



68% fossil fuels
22% renewables
11% nuclear

533 gCO_2/kWh

Source: IEA, ETP2016

17% fossil fuels
67% renewables
16% nuclear

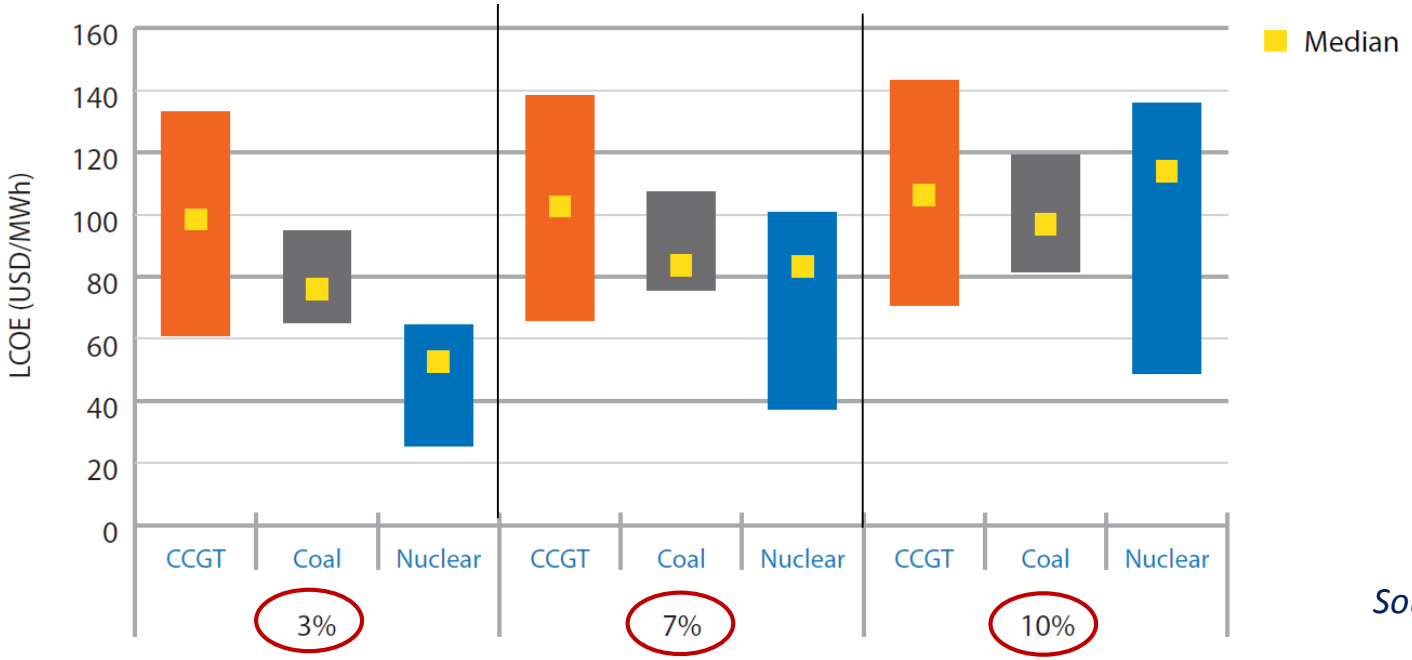
40 gCO_2/kWh

- 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.
- **Will nuclear industry meet the expectations and deliver on time and on budget?**

Economics of Nuclear Energy: LCOE

LCOE is the constant unit price of output ($/MWh) that would equalise the sum of discounted costs over the lifetime of a project with the sum of discounted revenues.

LCOE (USD/MWh) for dispatchable baseload technologies



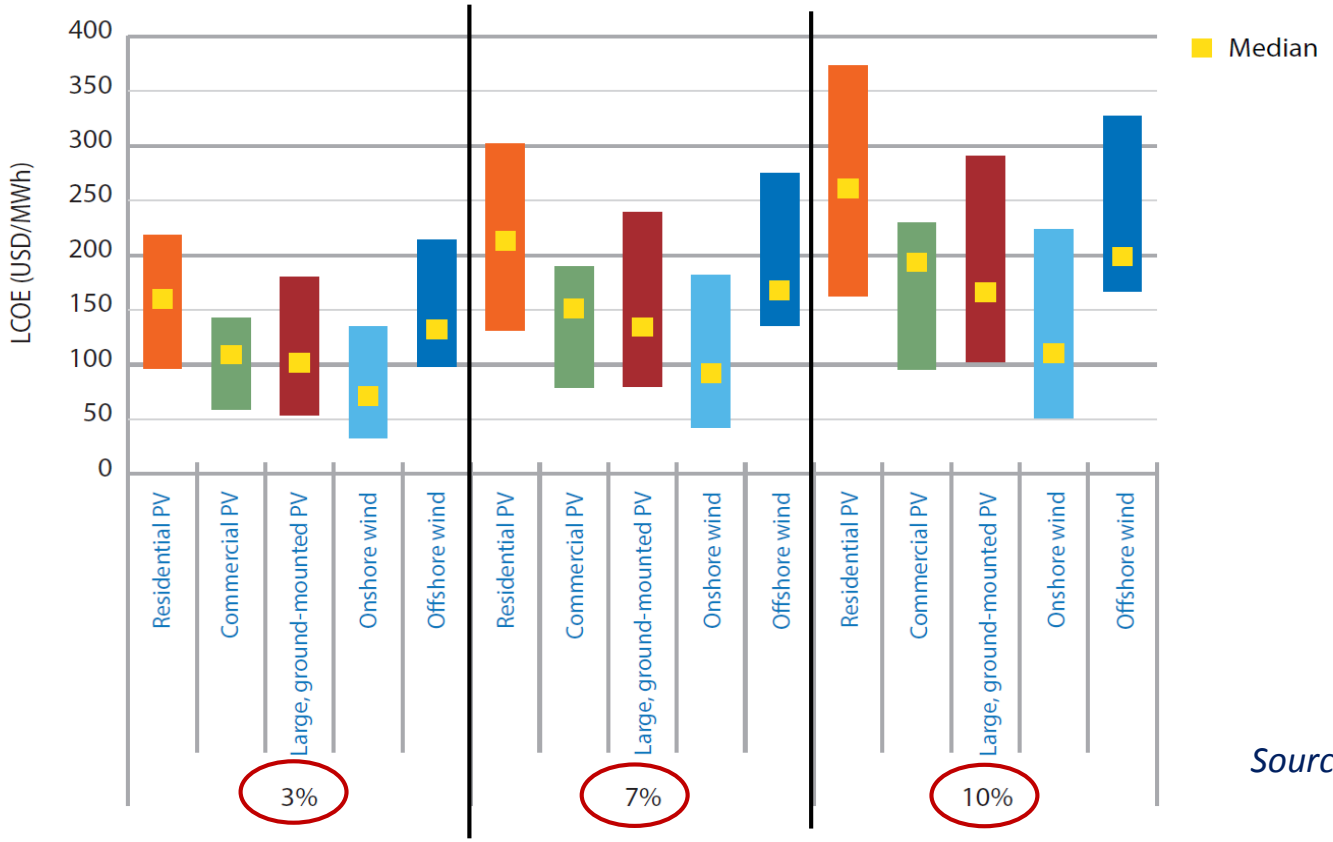
Source: NEA/IEA 2015

Note: Assumes region specific fuel prices for US, Europe, Asia; 85% load factor; CO2 price of 30 USD/tonne

- Large regional differences are observed.
- Nuclear is the lowest cost options for all countries at 3% discount rate.
- Median cost of nuclear is slightly lower than coal or gas at 7%, but is higher at 10%

Economics of Nuclear Energy: LCOE

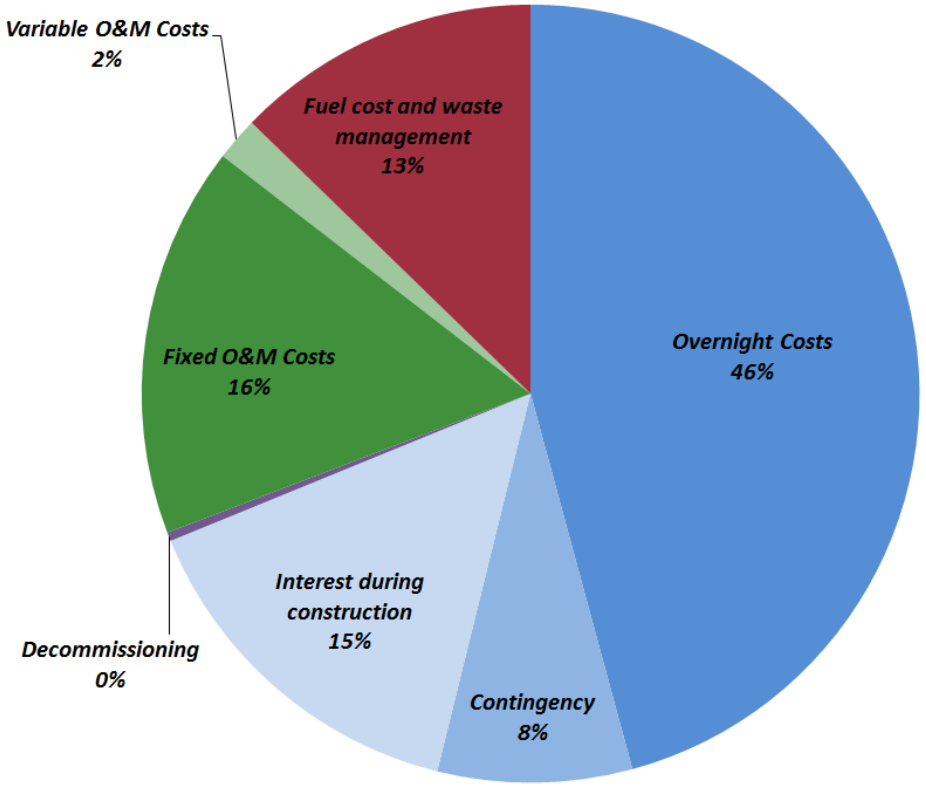
LCOE (USD/MWh) for wind and solar technologies



Source: NEA/IEA 2015

- Cost of Renewables (in particular solar PV) has declined substantially since the last EGC and they are no longer cost outliers. Further cost reductions are expected.
- Plant-level costs are becoming of lesser importance. What is needed is the ability to ensure secure and cost-efficient supply at the system level.

Generation cost structure for nuclear: at 7% Discount Rate



Nuclear energy is capital intensive

- 70% capital costs (up-front)
  - 20% of which are interests.
- 85% of Fixed Costs
  15% of Variable Costs
- Decommissioning costs are negligible (*discounting*).

- Economics strongly depends on total investment costs (*overnight, lead time, discount rate*).
- Capital intensive technologies are highly sensitive to discount rate (*project risk*).
- Variable costs nuclear production are low, stable and well predictable over time.
- **Competitiveness of nuclear depends upon projects completion on time and budget.**

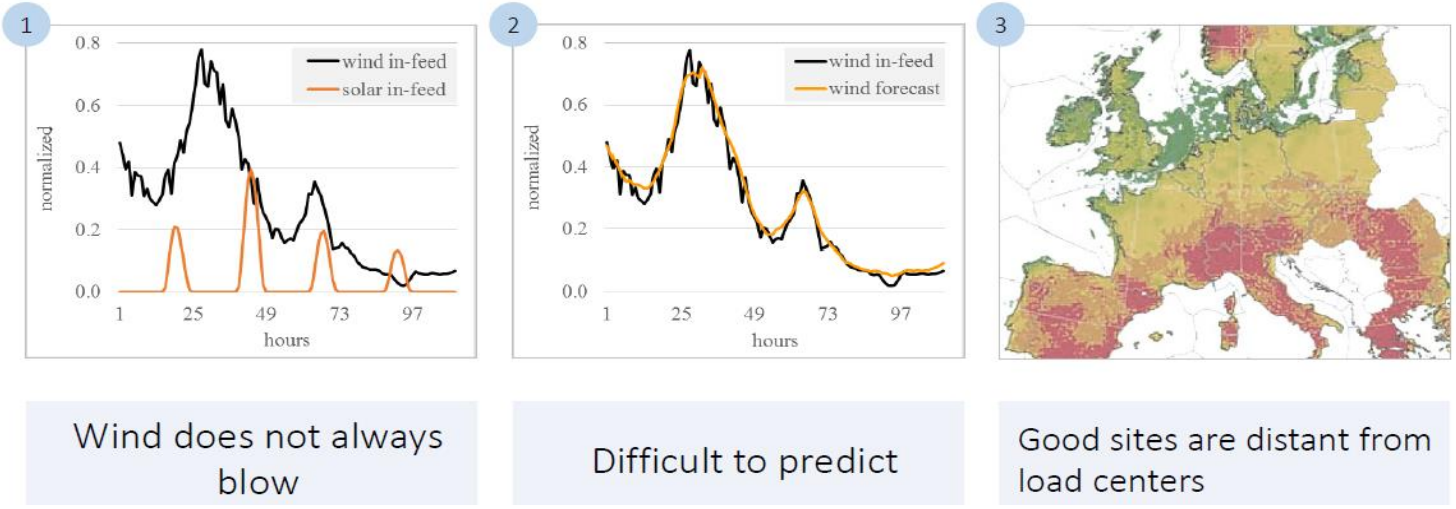
The cost structure of all low carbon technologies is very similar (high CAPEX, low OPEX), and they have similar "economic" characteristics.

LCOE and the "system value" of electricity generation

However, the LCOE has major limitations:

- Considers technologies in isolation (***Plant-level costs***) and does not take into account the interactions between that power plant and the others nor the implication of integrating that PP into the system (***System effects***).
- Is simply a measure of cost and does not tell anything about the "value" of electricity generated (*when* electricity is generated).
- LCOE indicates production costs at the power plant gate, and thus does not takes into account for connection, transmission and distribution (*where*).

Challenges of VRE integration



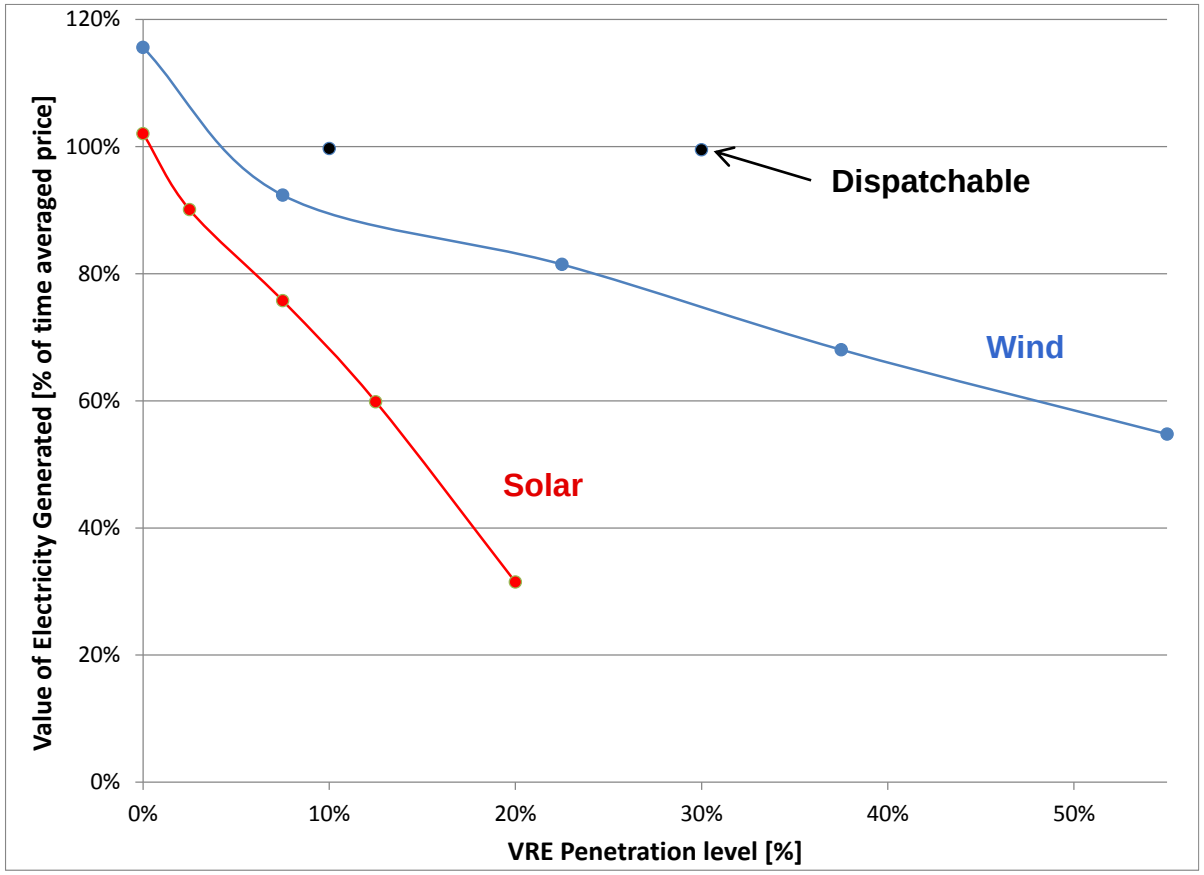
Wind does not always blow

Difficult to predict

Good sites are distant from load centers

At low financing costs, nuclear is a very competitive low carbon technology, especially when system effects are appropriately taken into account

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.
- Such effect is not observed for a dispatchable plant.

Co-existance of VRE and nuclear: Technical and economic challanges

Short-term

- Significant reduction in wholesale electricity prices: several PPs are unable to recover variable costs (peakers, OCGT, CCGT, but also capital intensive plants).
- The financial situation of several utilities has strongly deteriorated, jeopardising their ability to take on new investments.
- Risk-perception of the electricity sector has increased (higher cost of capital).

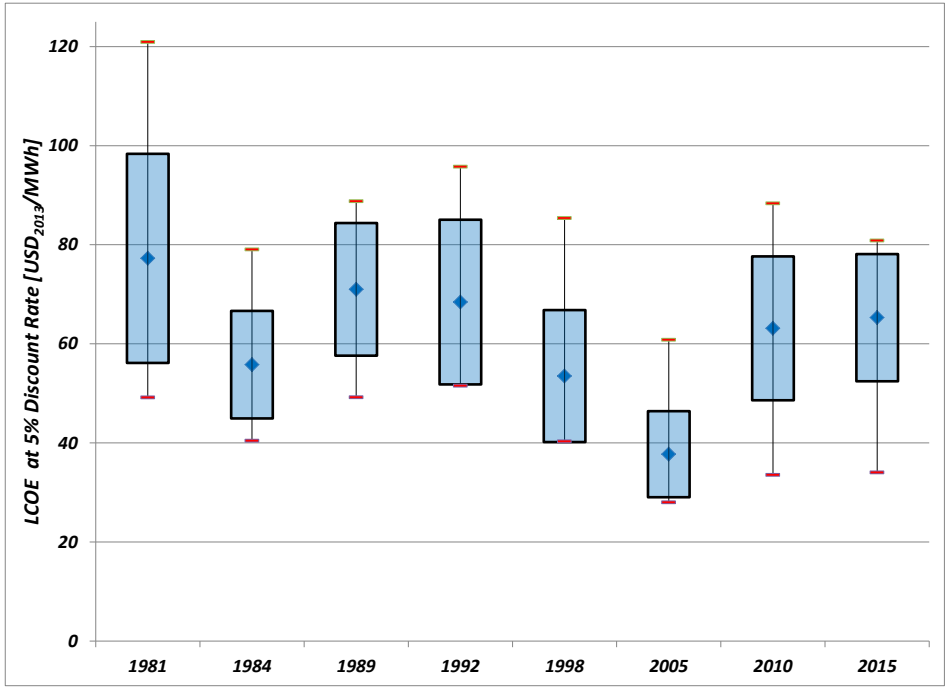
Long-term

- Need for more flexibility in to the system (storage, interconnection and market design, demand side management, **dispatchable and VRE generators**).
- Declining load factors for NPPs (especially at high VRE shares or under strong carbon constraint).
- More frequent and less predictable load-following operations.
- More frequent and steeper ramping rates and more challenging operations.
- Thousands hours with zero or very low electricity prices.
- Very skewed and less predictable wholesale market revenues, relying in few hours with high scarcity prices: electricity price risk increases markedly.

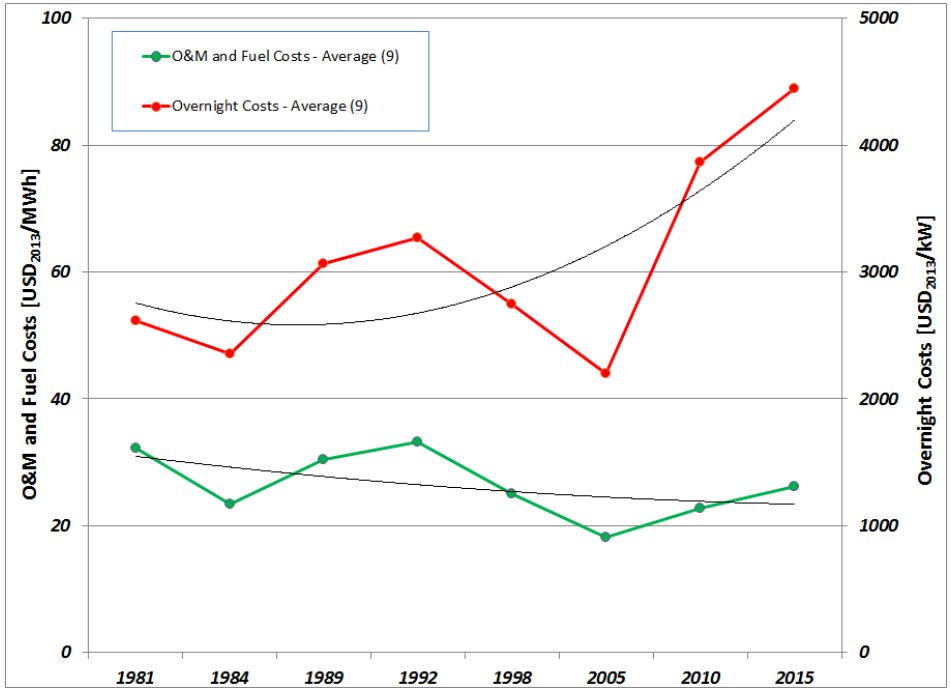
Is a new market design needed for low-carbon generation (VRE, nuclear)?

Evolution of nuclear generation costs (IEA/NEA estimates)

Levelised Cost of Electricity (LCOE)



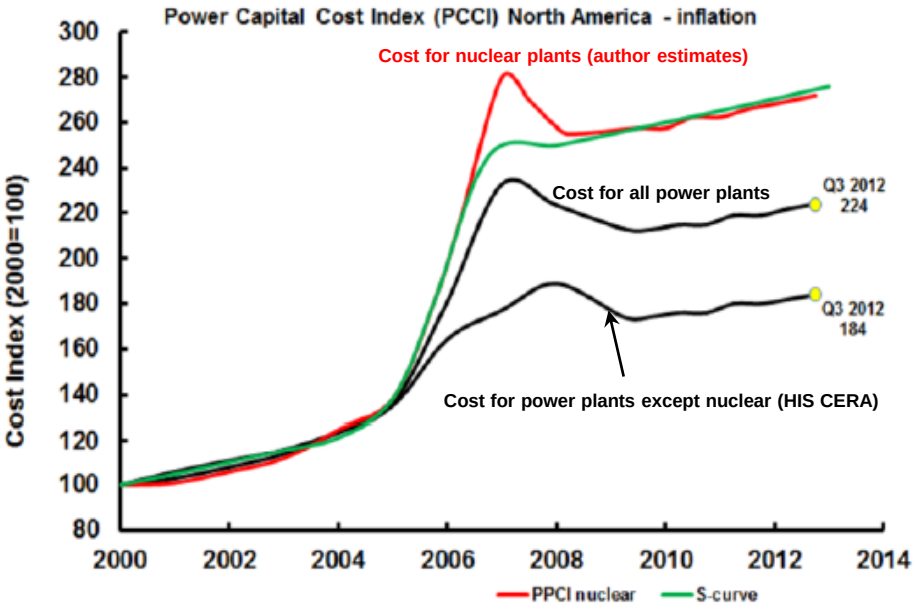
Overnight and variable costs



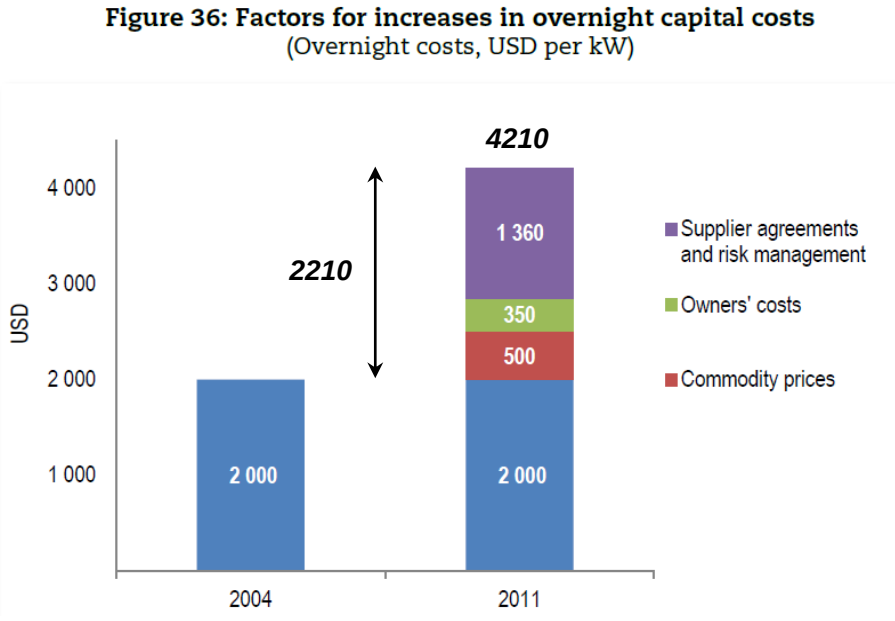
Note: Results are averages of 9 countries (Bel, Can, Fin, Fra, Ger, Jap, Kor, UK, US).

- Large increase in Overnight Costs, in particular since 2010 edition.
- Decrease in O&M and fuel costs
- Progressive increase in Lifetime and Load factors

Cost escalation for nuclear: two analysis



* W. D'haeseleer: Synthesis of the economics of Nuclear Energy



* University of Chicago: "Analysis of GW-Scale Overnight Capital Costs"

- Construction costs for nuclear has increased more than other PPs and much more than inflation (and fuel costs).
- Results for Europe show similar trends.

- Increase in overnight costs is partially explained by higher commodities prices
- Importance of the **project structure** and **agreements**: who is taking risk?
- Importance of **industrial organisation** and **regulatory framework**

Nuclear New Build in Transition

- Massive and discontinuous technological change as Generation II nuclear power plants are substituted by larger, more expensive and often more complex Generation III+ plants (FOAK risks as well as licensing and regulatory change).
- Transition from West to East.
- Loss of expertise and human capital in many countries, as projects are few and far between (with the exception of China and Russia).
- Need to reconstruct a supply chain in most OECD countries after several years of low- or no-construction levels.
- A particularly complex supply chain with quality control issues and varying degrees of externalisation.
- Very long time frames at all levels of the value chain: from design and licensing to construction, operations and decommissioning.
- Shifts in political and social support after Fukushima.
- Changes in electricity markets and questions on the role of baseload power in EU.

Lessons Learnt

on Financing

Decarbonisation and NNB require in addition to carbon taxes **long-term electricity price arrangements** (long-term contracts, PPA, CfD) **:** the more stable are electricity prices, the lower are the financial risks and required interest rate and the more competitive is nuclear.

on Project Management

a. Different models of project management offer different trade-offs between internal and external transaction costs.
b. Advance the convergence and standardisation of engineering codes and quality standards in the global nuclear industry.
c. Modularisation holds promises, but requires front-up investments and scale.
d. Design completion and long lead-times for preparation are required.
e. Transfer of lesson learned should be consciously organised.
f. Promising new technologies (automatic welding, 4-season site shelters, high performance concrete, seismic stabilisators)
g. Design standardisation (site specificity and regulatory level)
h. Importance of “Soft issues” such as leadership, team building, experience, incentives and trust.

Forthcoming NEA Study: Reducing the Costs of Nuclear Power Generation

- **Growing concern about the competitiveness on nuclear power in NEA countries.**
- Some relevant material has been published and some work is ongoing in this area:
  - NEI, MIT (*The Future of Nuclear Energy* study)
  - WANO, WNA (CORDEL, World Nuclear supply Chain: Outlook 2035, Project structuring)
  - IAEA, NEA
- Areas for potential cost reduction may arise in 2 main areas:
  - Construction costs (Design, Manufacture, Procurement and construction)
  - Operational Costs (Reduction in outage duration, Longer cycles, Reduced man-power)
- Report will look broadly at the initiative currently ongoing and potential for costs reductions for both the new built and existing plants:
  - Industrial structure, Supply arrangements, Market competition
  - Reactor design and innovation, Role of safety
  - Analysis of specific examples of successful new build projects (i.e. UAE)
- The project will be undertaken under the supervision of an Expert Group in 18/19.

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

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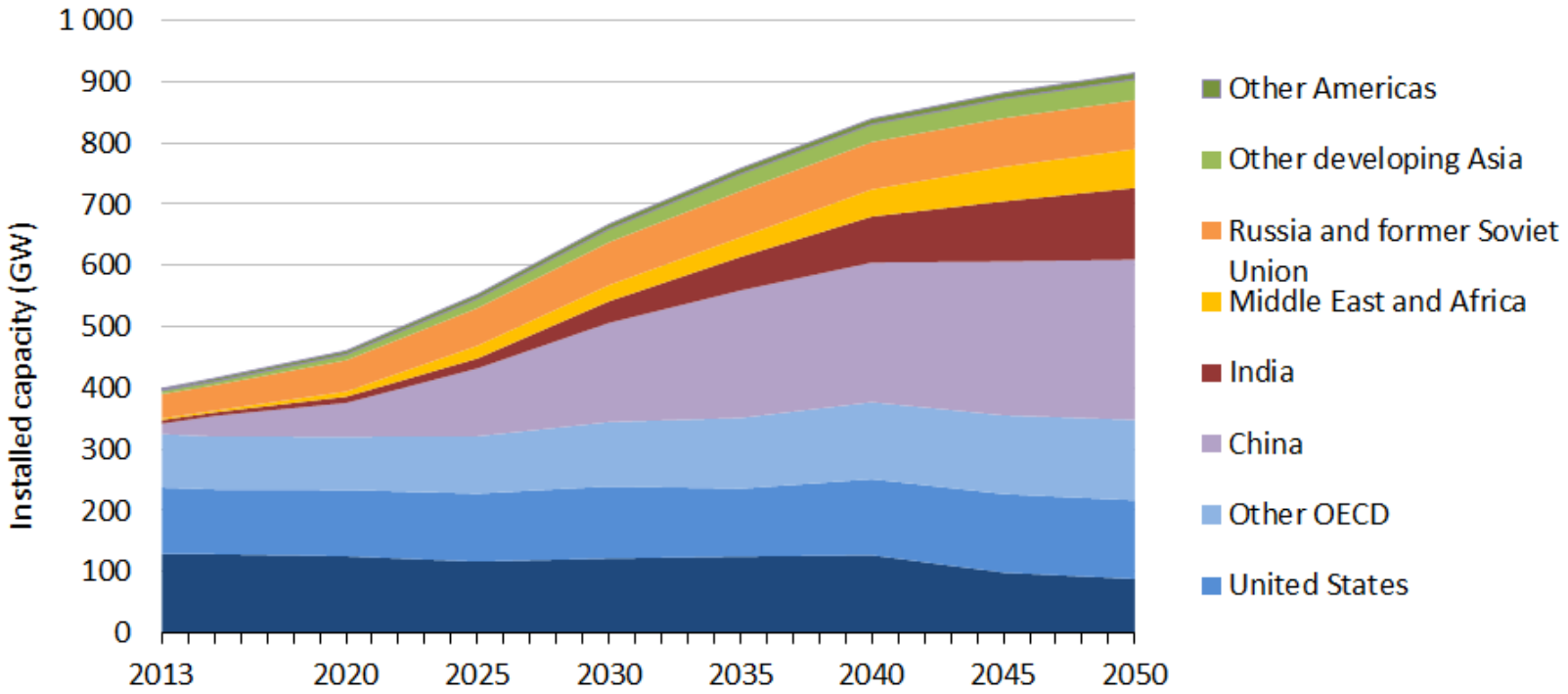
IEA 2DS: role of nuclear

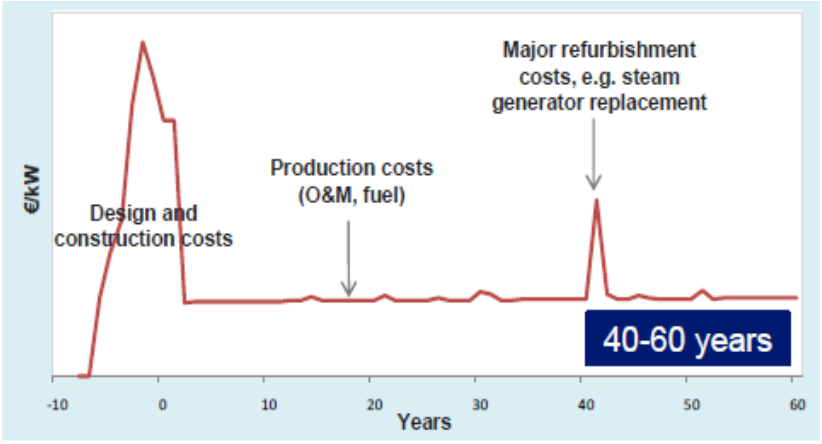


- Current nuclear capacity of 390 GW to more than double by 2050 to reach over 900 GW, share of nuclear electricity would increase from 11% to 16%.
- China sees largest increase in installed capacity and becomes largest nuclear power producer.
- Formidable challenge: multiply current capacity by 2.3 in 35 years and increase investments in nuclear up to USD 110 billion/year over the period 2016-2050 (21 USD billion in 2015).

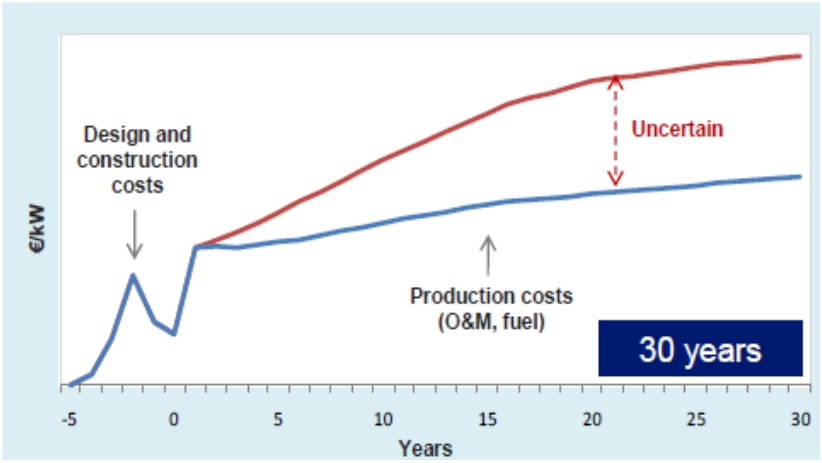
- *Similar trend by WNA and IAEA: WNA's objective of achieving 25% of supply by 2050. IAEA says 385 or 632 GW (low or high growth) by 2030.*

Risk is function of technology and time

NUCLEAR



CCGT*

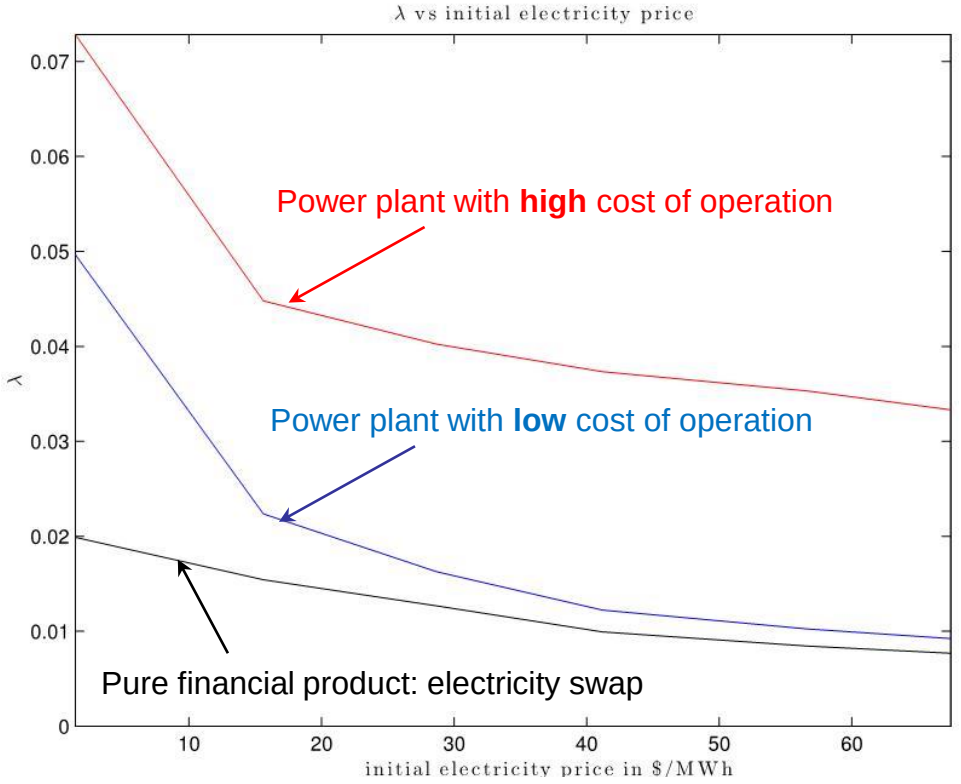


During operation, the revenues risk of a NPP is lower than that of a power plant with higher operational costs (CCGT, coal), and of a Variable Renewable Plant (solar, wind).

Nuclear

- Large uncertainty in the construction phase
- Once a NPP is operating, rather stable and predictable production costs

Risk premium of different power plants once operating



Source: John Parsons and Fernando de Sisternes , MIT

Quantification of profile costs

We compare two situations: the residual load duration curve for a 30% penetration of fluctuating wind (blue curve) and 30% penetration of a dispatchable technology (red curve).