Nuclear New Build: Institutional and regulatory conditions for gaining in efficiency into financing and project management

A synthesis of an OECD/NEA report

Marco Cometto, CFA

Energy Analyst

OECD/NEA Division of Nuclear Development

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Outline of the presentation

A. **COP 21, decarbonisation scenarios and investment needs in the energy sector**

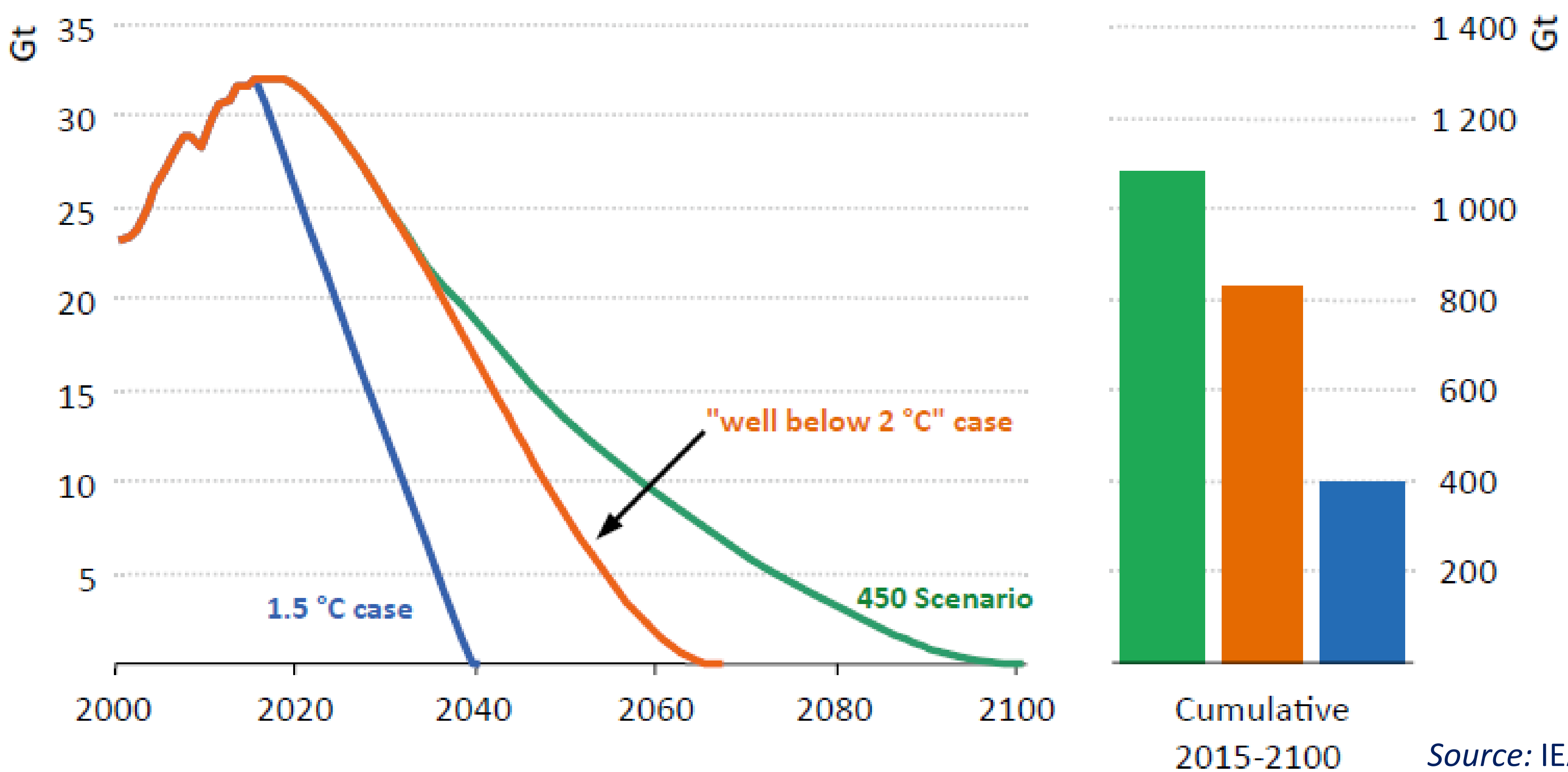
B. **Main findings from the NEA study on Nuclear New Built**

  - **Part I – Financing**
  - **Part II – Project Management Issues**

C. **Low-carbon technologies and Electricity Market Design**

Energy sector post COP 21

Indicative global energy sector emissions for different decarbonisation pathways

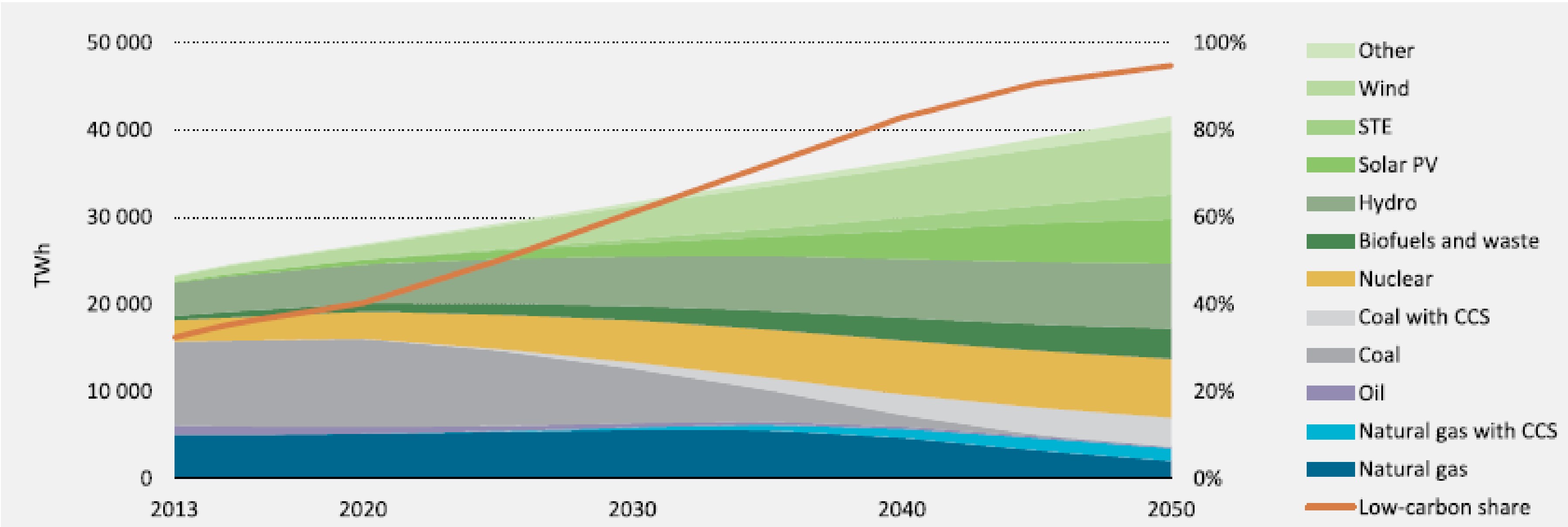


Source: IEA, WEO 2016

- NDCs are not sufficient to achieve climate objectives, leading to a 2.7°C increase.
- Challenges to achieve 2°C are immense, road to 1.5°C goes to uncharted territories.
- Colossal investments for energy sector: 40 trillion USD + 35 in energy efficiency (2°C).

Power sector almost completely decarbonised in the IEA 2DS

Global electricity production and technology shares in the IEA 2DS



Source: IEA, ETP 2016

68% fossil fuels
22% renewables
11% nuclear

533 gCO_2/kWh

17% fossil fuels
67% renewables
16% nuclear

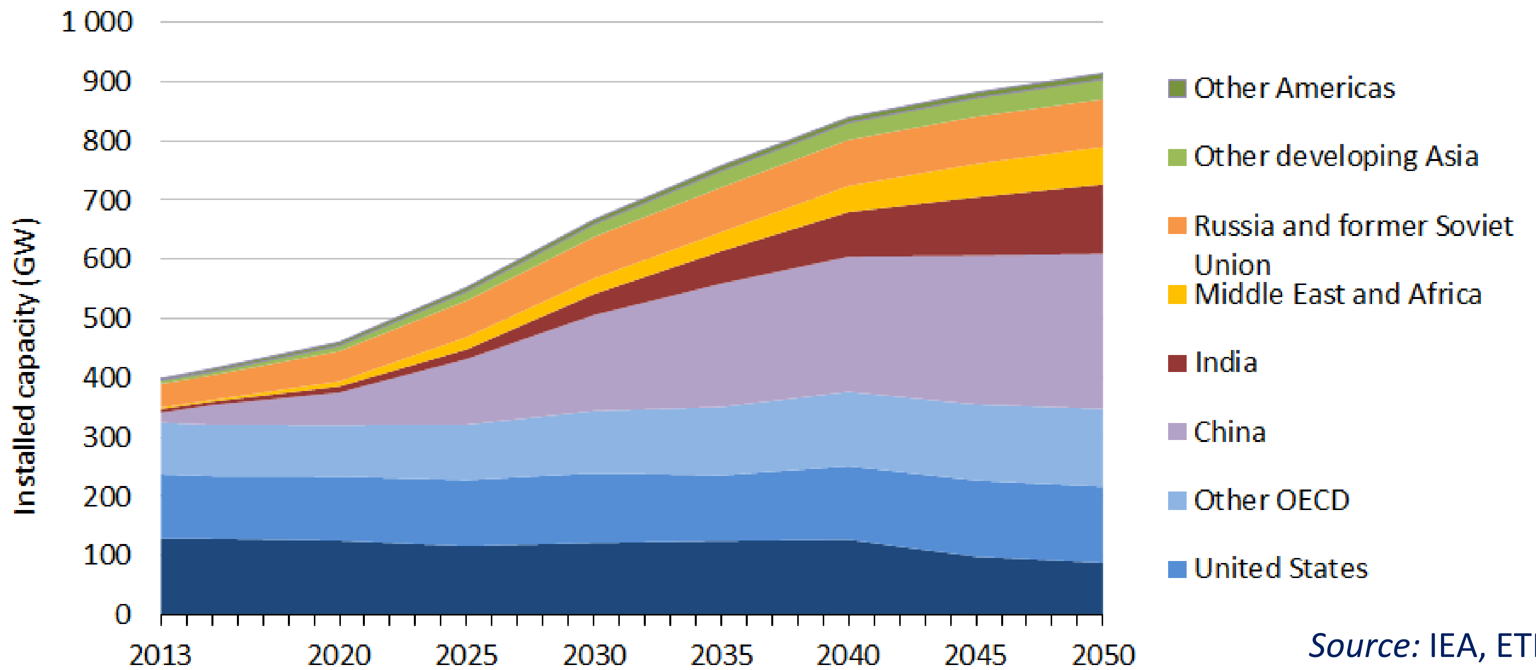
40 gCO_2/kWh

- A **complete reconfiguration** of the electricity generation system is needed by 2050.
- Trends: rise of nuclear, a *complete phase-out* of coal and oil, a decrease of gas, large development of CCS and a massive increase of renewable energies.

Technical challenge: **How to ensure the coexistence of ≈40% of VRE, 40% of low-C dispatchable capacity, 20% of hydro (*System Effects*).**

IEA 2DS: role of nuclear

Nuclear installed capacity in the IEA 2DS

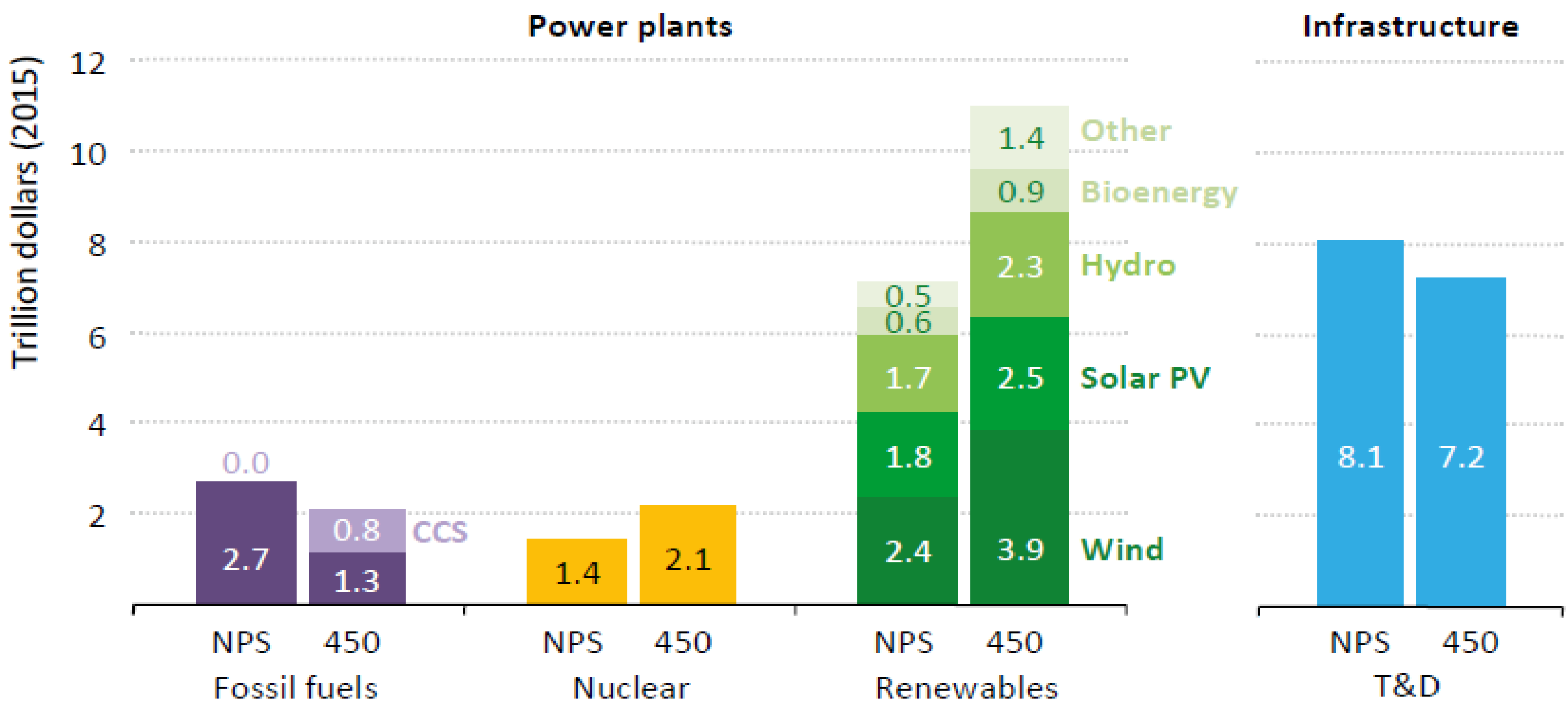


Source: IEA, ETP 2016

- 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%.
- IEA WEO sees a nuclear capacity for 2040 of 600 GW (NewPolicies Scenario) and 820 GW (450 ppm scenario). IAEA says 385 or 632 GW by 2030 (low or high growth).
- 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).

Investments in the power sector

Cumulative global power investments, 2016-2040



Source: IEA, WEO 2016

- By the 2020s, the investment needs for the power sector in a 450 Scenario overtake those for fossil-fuel supply.

Financial challenge: **How to ensure that low-C technologies and T&D infrastructure attract the capital required?**

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Context of the NEA study

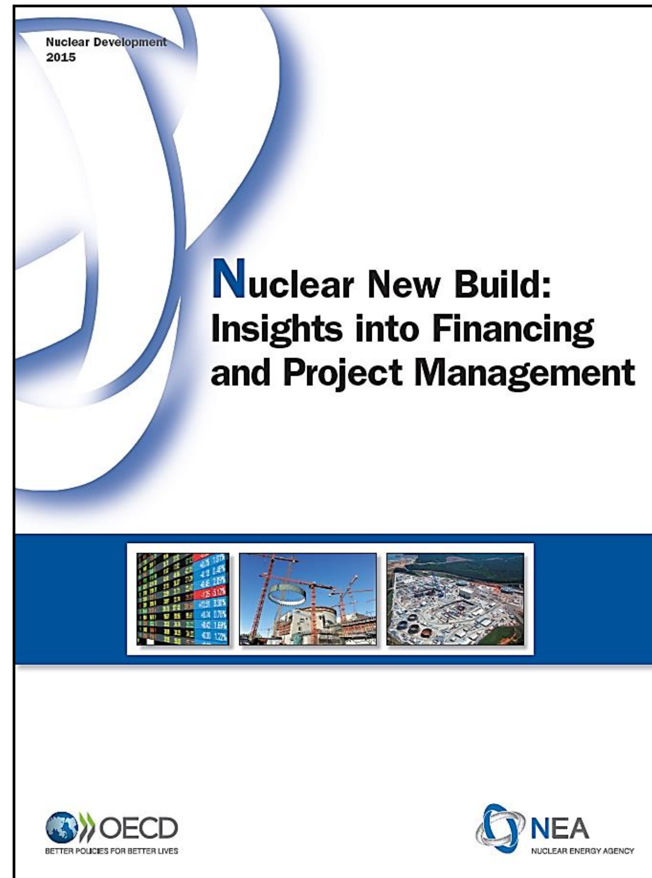
Results are based on study of the OECD Nuclear Energy Agency (NEA) *Nuclear New Build: Insights into Financing and Project Management* (August 2015) written by Jan Horst Keppler and Marco Cometto, both NEA NDD.

Since 2000, the construction of 77 new reactors was started and 47 new reactors were connected to the grid. Vastly different forms of project management and financing in different contexts have generated ample experience.

Based on conceptual analysis, modelling, expert opinion and 7 case studies, study identifies **perspectives for commercially and economically sustainable new build** in two areas:

i. Managing long-term electricity price risk and allocating financial risk among stakeholders,

ii. Project and supply chain management.



Nuclear New Build in Transition

- Discontinuous technological change as Generation II nuclear power plants are substituted by larger 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 complex supply chain with quality control issues and varying degrees of externalisation.
- Very long time frames from design and licensing to construction, operations and decommissioning.
- Shifts in political and social support after Fukushima.
- Changes in the electricity market structure (at least in OECD Europe).

Nuclear New Build Today

Reactors Currently under Construction or Planned

Region	Under Construction	Planned
Europe	4	19
Russia and FSU	11	30
China	27	56
Rest of East Asia	10	10
West Asia	2	8
South Asia	7	24
South East Asia	--	4
Africa	--	1
North America	5	7
South America	2	--
SUM	68	227

Source: WNA

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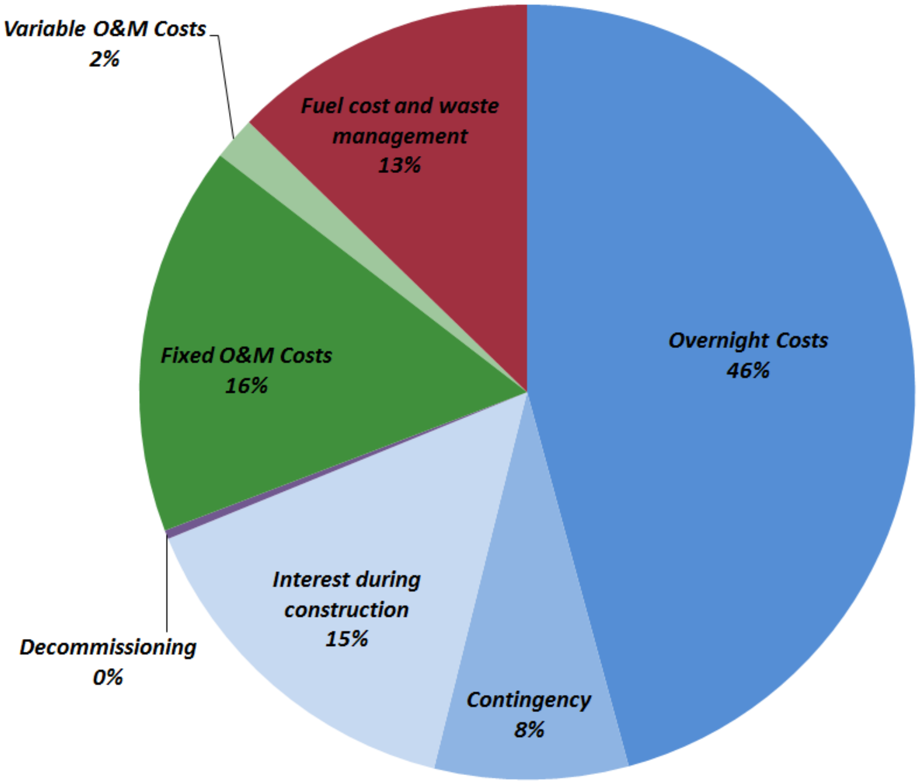
Generation cost structure for nuclear: at 7% Discount Rate



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*).

Impact of discount rate

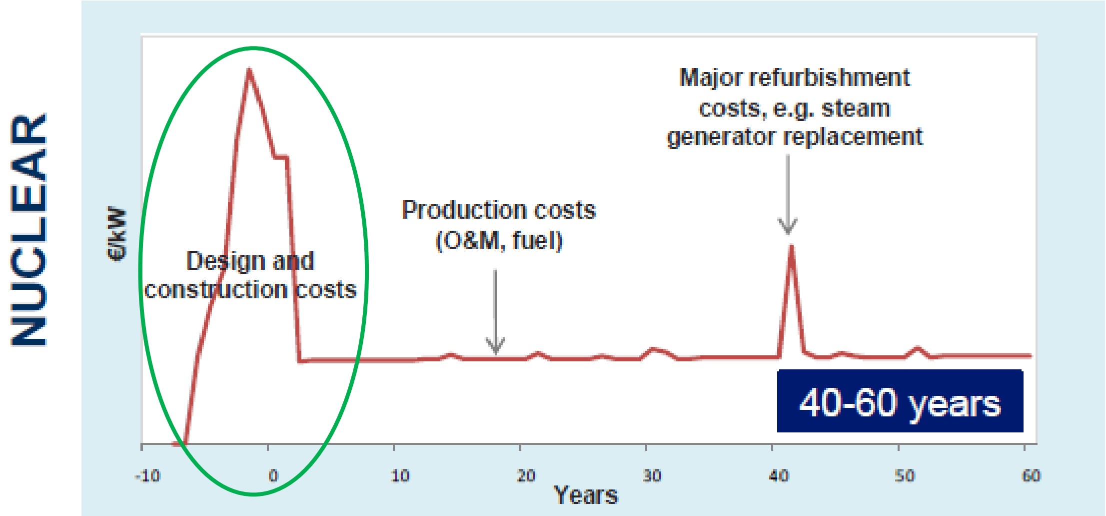
- Capital costs represent:
  - 50% at 3% discount rate.
  - 80% at 10% discount rate.

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

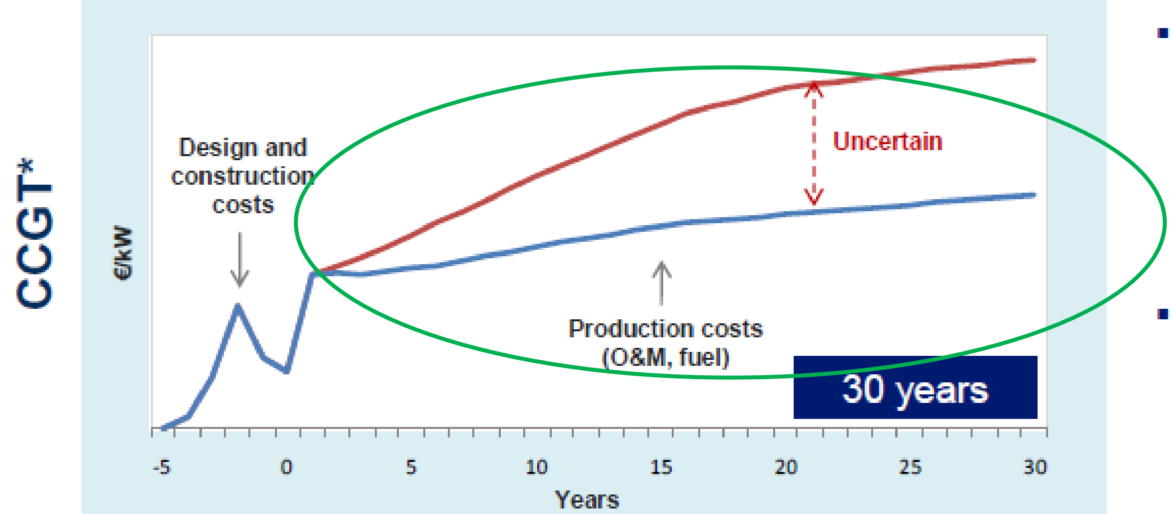
- Economics strongly depends on total investment costs (*overnight, lead time, discount rate*).
- All capital intensive technologies are highly sensitive to discount rate (*project risk*).
- Variable costs of low-C electricity production are low, stable and well predictable over time.

Risk is function of technology and time: Gas vs nuclear: a comparison

The economic profiles of nuclear and CCGT *(Courtesy of EdF)*



- **Very high CAPEX** during the development and construction period
- **Regular and comparatively lower OPEX** during the operating period

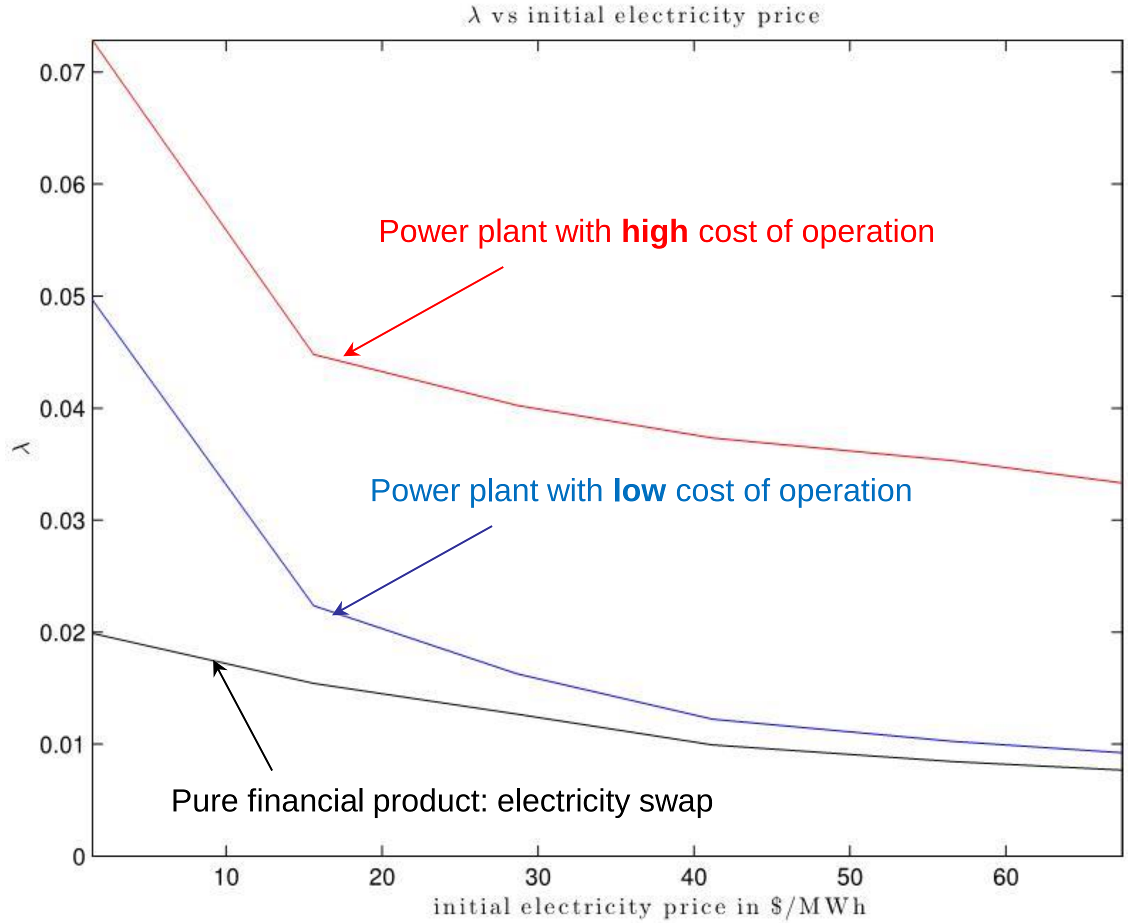


- **Very low CAPEX** during development and construction, but comparatively higher production costs due to the significance of fuel costs
- **High and uncertain fuel and CO_2 prices** and consequently high uncertainty on future production costs

*Note: CCGT plant in base load operation, 8,000h

Risk is function of technology and time: Risk premiums

Risk premium of different electricity plants once operating



Source: John Parsons and Fernando de Sisternes , MIT

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

Key risk factors for a new NPP project

- ***Construction and supply chain risk*** – delays in commissioning the plant, increase in over-night costs, misrepresentation of design.
- ***Regulatory and licensing risk*** – delays in obtaining construction and operating licences, additional requests set by the regulatory authorities.
- ***Political / energy policy risk*** – change of attitude of governments toward nuclear (new tax policy toward nuclear / electricity), additional regulatory requirements, premature shut-down of NPPs.
- ***Operational Risk*** – Reduction on load factors due to equipment failure or natural events, additional outage's costs.
- ***Fuel supply risk*** – Increase in fuel costs or delays in fuel supply.
- ***Waste Management and decommissioning risk*** – Increasing requirements for fuel disposal and decommissioning, failure to establish a national facility to move spent fuel.
- ***Electricity Market Risk***
- ***Public Acceptance Risk***
- ***Reputational Risk***

Part I: Financing

Methodology

- ✓ NPV calculations following methodology *Carbon Pricing* study (NEA, 2011) based on average daily prices for gas, CO_2 and electricity.
- ✓ Cost data from *Projected Costs of Generating Electricity* (IEA/NEA, 2010).

Objectives

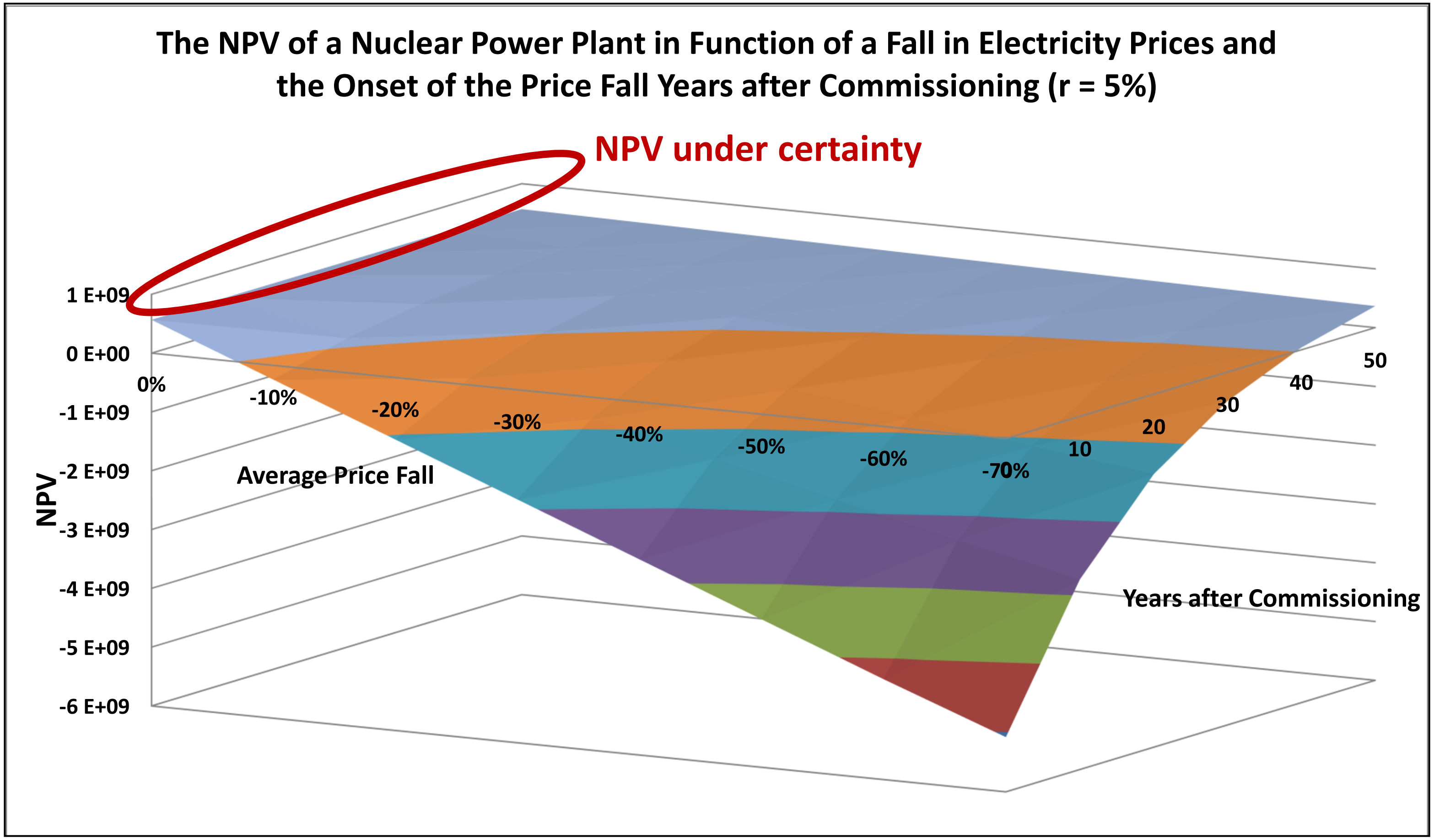
1. Illustrate different behaviours of technologies with high and low investment requirements in the face of **electricity price risk** and assess their respective ***option value*** with respect to market risk:
   - Share of fixed investment costs in nuclear: 73%-85%.
   - Share of fixed investment costs of gas: 8%-13%.
2. Additional research on modelling ***investor risk*** taking into account tax effects, the capital structure, and the main sources of risk:
   - *Construction Risk* (uncertainty in overnight cost level and construction length)
   - *Operational Risk* (uncertainty on achievable load factor)
   - *Electricity Market Risk*

NPV and Price Risk with High Fixed Costs: Nuclear

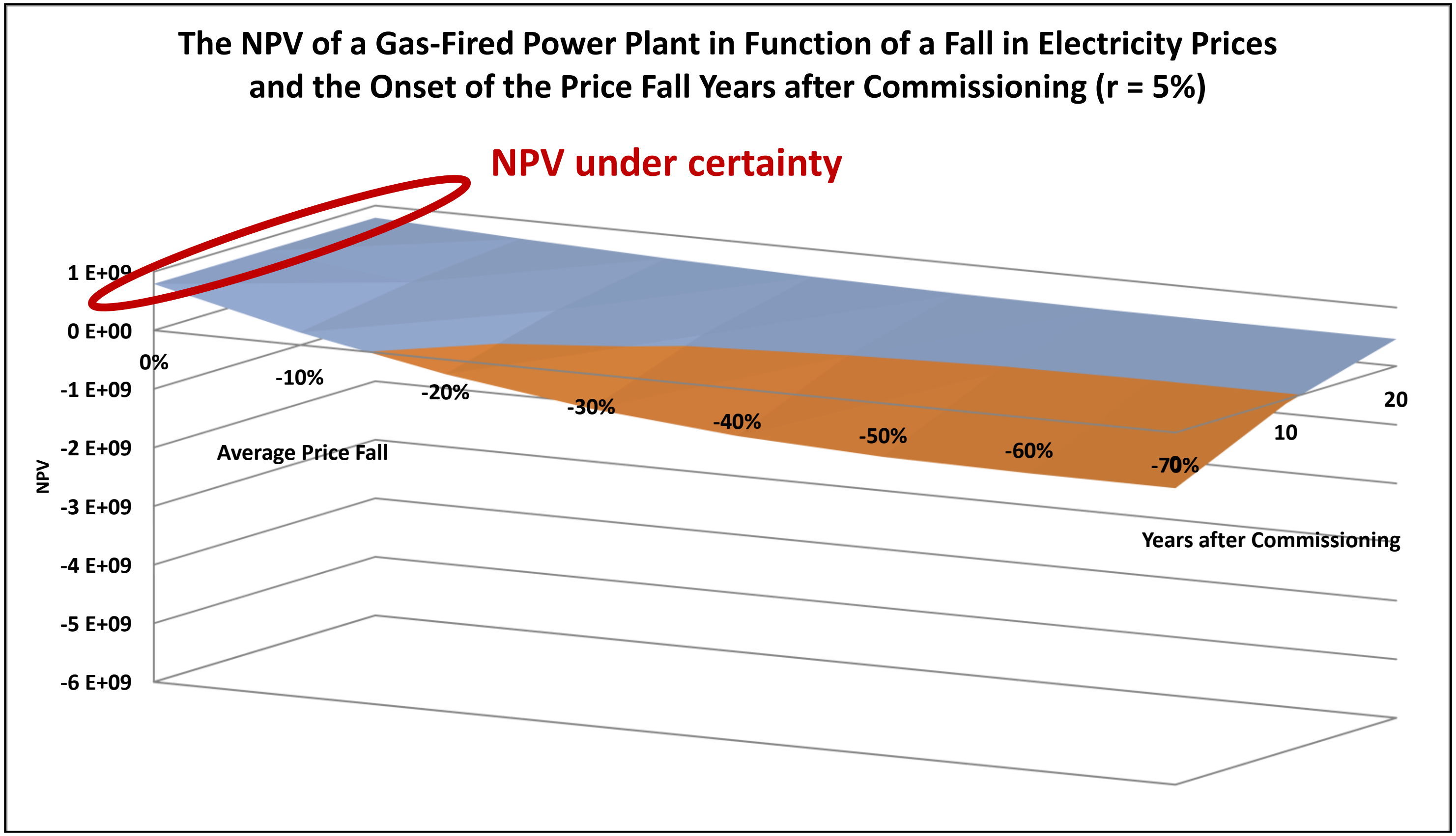
NPV calculation for nuclear and gas plants under different electricity price scenarios.

Both technologies yield the **same NPV** at base price (by adjusting overnight costs).

Permanent price fall [-10% to -70%] occurs after commissioning [0-50 years].



NPV and Price Risk with Low Fixed Costs: Gas



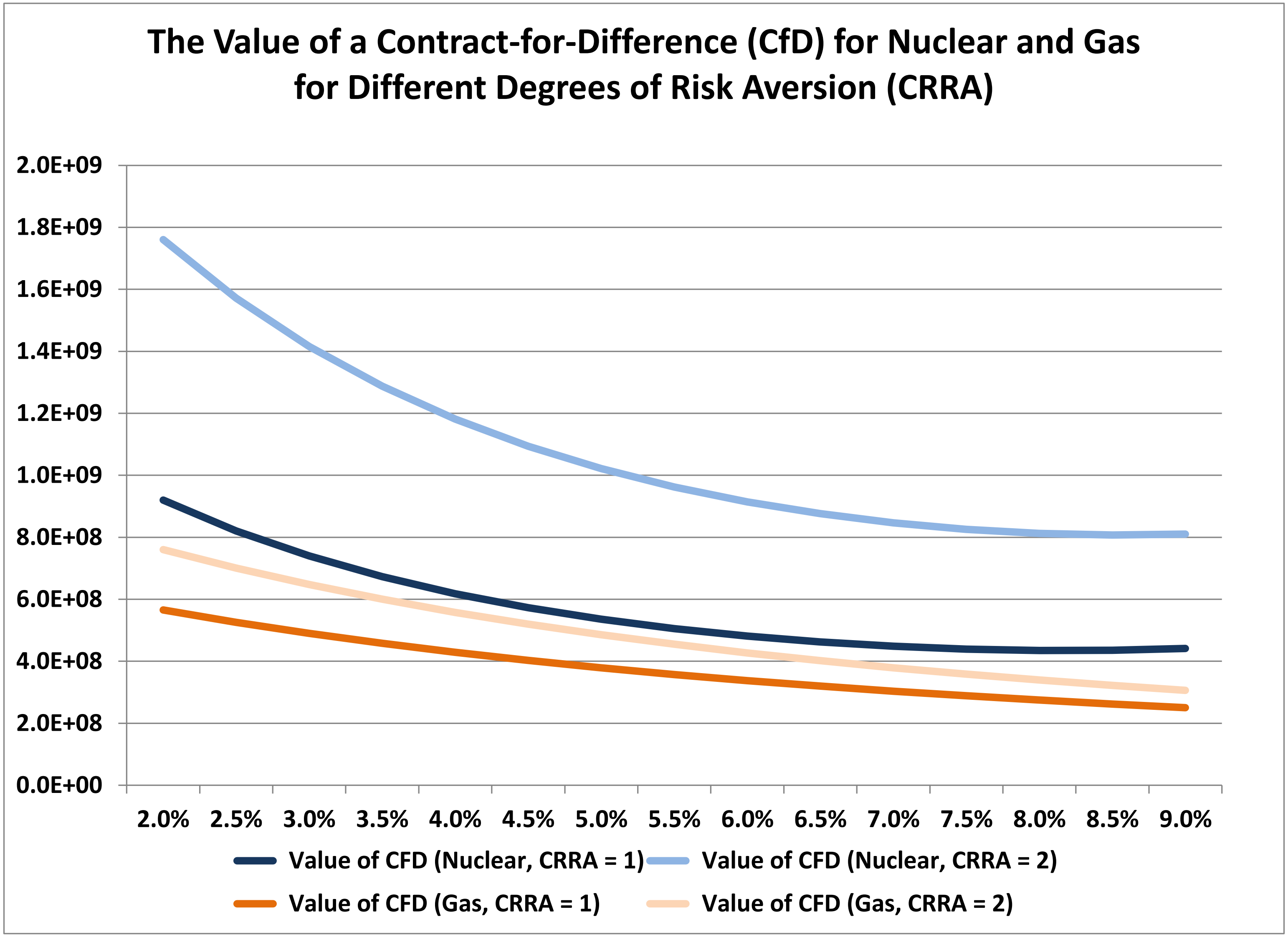
Gas plants can leave the market with losses limited to the investment costs.

Nuclear keeps producing at decreasing net revenue levels, but losses for investors are higher.

Option value of exiting the market is consistently higher for a gas than for a nuclear PP.

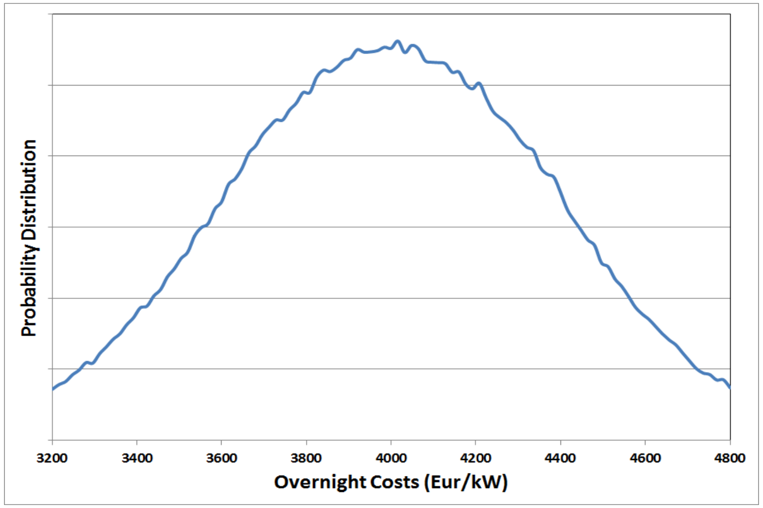
Investor in a capital-intensive technology would greatly benefit from a PPA or CfD.

The Value of Price Stability
(Strike price corresponds to average of past prices)



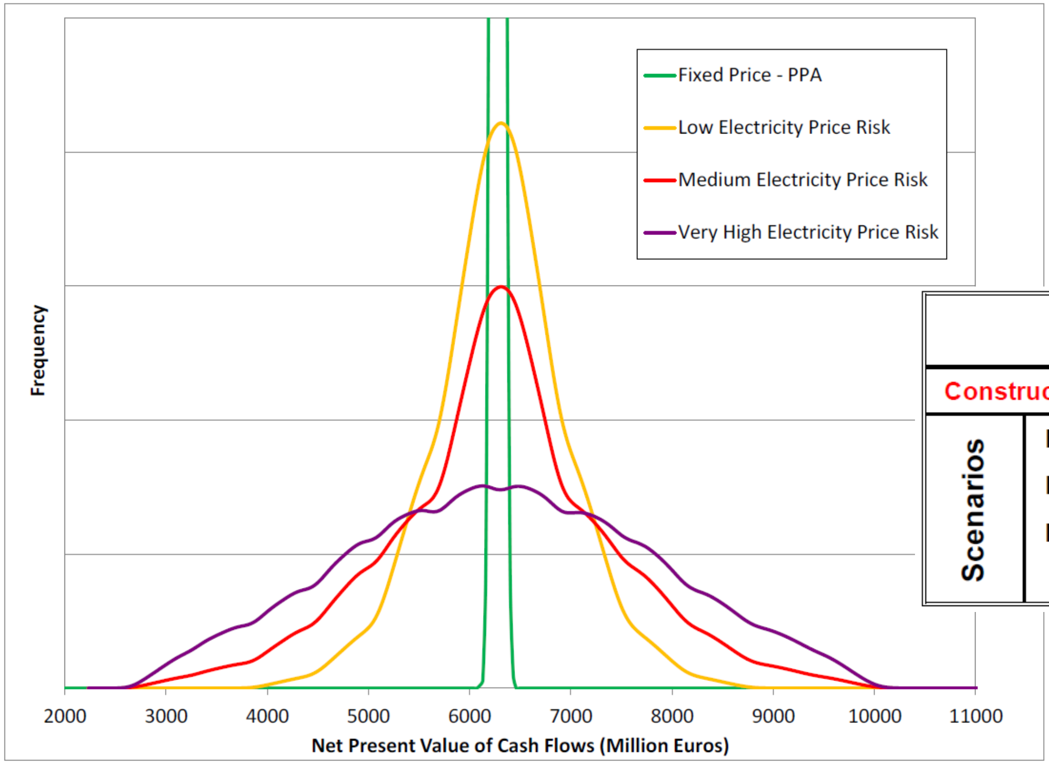
Modelling Investor Risk with Electricity Price and Construction Cost volatility

Modelling choices of a private investor, taking into account the effect of taxes, depreciation and the capital structure of the project



- ***Construction risk***
  - ✓ Uncertainty regarding overnight costs
  - ✓ Uncertainty on length on construction period (IDC)
  - ✓ Correlation of construction delays and overnight cost
- ***Operation and political risk***
  - x Political and policy risk
  - ✓ Uncertainty on load factor: triangular distribution between 75% and 95%
- ***Electricity market risk***
  - ✓ Short-term variability of prices
    - First-order auto regressive model: $P_{t+1} = P_t + \alpha(\mu - P_t) + \varepsilon_t$ (random component)
    - Possibility to suspend production when electricity prices are below variable costs
  - ✓ Long-term changes in the price trajectory
    - Parametric study (-50% → +50%, i.e. ±40 €/MWh)
    - Creation of 3 scenarios of electricity price variations (low to high price risk)

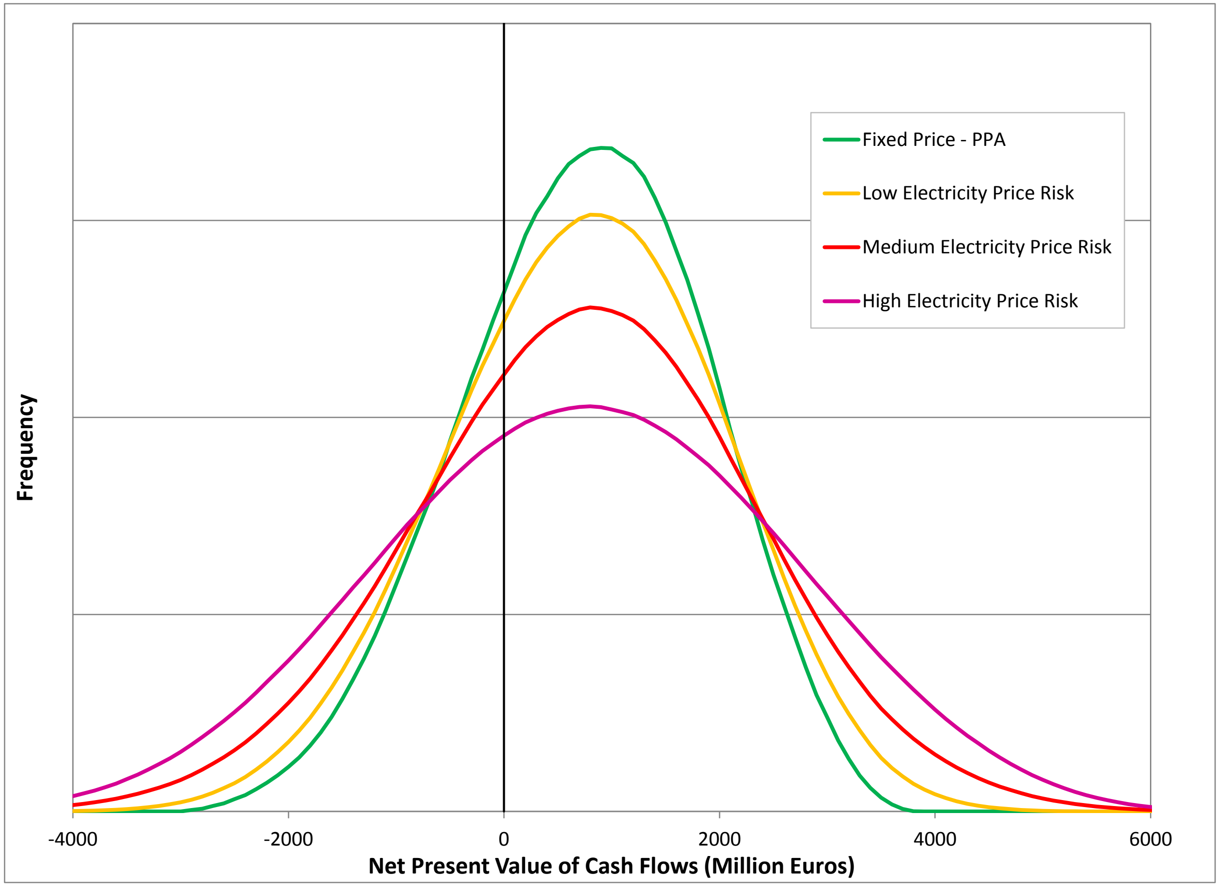
NPV Distribution of Positive Cash Flows Once Plant Has Been Commissioned



		Average [Mio Eur]	StDev [Mio Eur]	[%]
Construction Cost		5500	920	16.8%
Scenarios	Fixed Price - PPA	6300	40	0.7%
	Low Electricity Price Risk	6300	620	9.9%
	Medium Electricity Price Risk	6300	1100	17.5%
	High Electricity Price Risk	6300	1490	23.6%

- Statistical distribution of future cash flows ***once the plant has been build***.
- CfD or long term contract reduce significantly the variability of future cash flows.
- Construction cost risk is of a similar magnitude of electricity market risk in medium/high electricity price risk scenario.

NPV Distribution of the whole nuclear project



- Distribution of NPV for a NPP including construction.
- CfD or long term contracts reduce NPV variability, but construction risk remains important.
- Shortfall risk as an alternative metric for investor risk.

Two measures of a project risk: shortfall Risk and average NPV Shortfall

		Change in electricity price					
		±50%	±40%	±30%	±20%	±10%	Stable
Scenarios	Low Electricity Price Risk	0%	0%	1%	5%	20%	48%
	Medium Electricity Price Risk	1%	2%	5%	10%	15%	34%
	High Electricity Price Risk	3%	5%	8%	12%	14%	16%

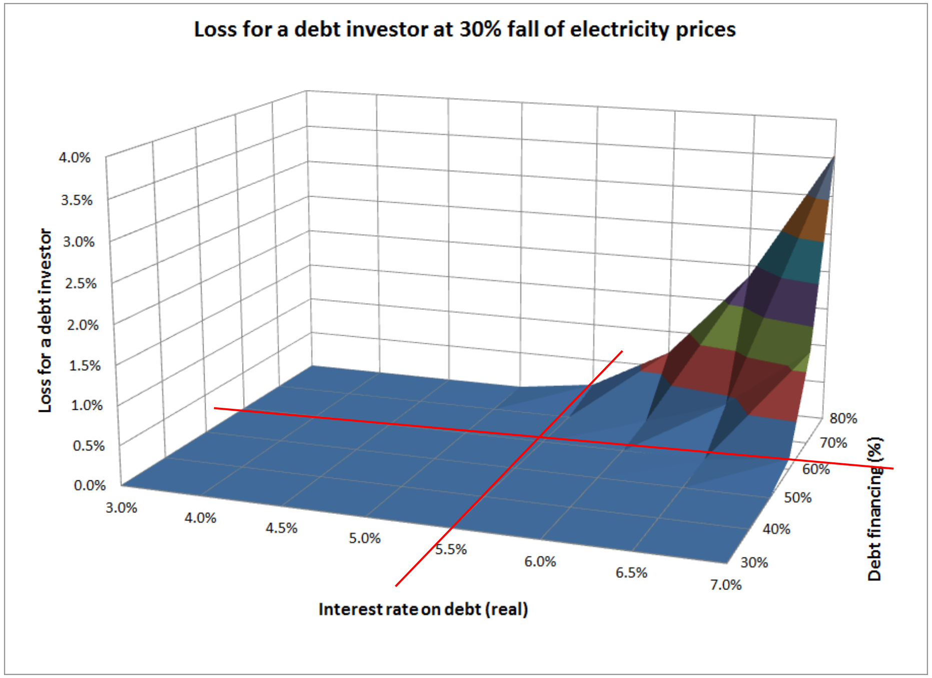
Capital Cost 7% Debt Cost 5%	*Probability of negative NPV*			
	Fixed price	*With market risk*		
		Low	*Medium*	*High*
Unleveraged	40.9%	42.2%	43.8%	45.5%
30% Debt	32.0%	34.2%	37.1%	40.0%
40% Debt	29.2%	31.7%	34.9%	38.3%
50% Debt	26.9%	29.3%	32.9%	36.6%
60% Debt	24.4%	27.1%	30.9%	34.9%
70% Debt	22.1%	24.8%	28.9%	33.2%
80% Debt	19.7%	22.7%	26.9%	31.5%

Capital Cost 7% Debt Cost 5%	*Average NPV Shortfall [Mio Eur]*			
	Fixed price	*With market risk*		
		Low	*Medium*	*High*
Unleveraged	-316	-378	-492	-625
30% Debt	-223	-280	-389	-515
40% Debt	-197	-252	-358	-481
50% Debt	-173	-226	-329	-449
60% Debt	-151	-202	-302	-419
70% Debt	-131	-180	-276	-390
80% Debt	-113	-159	-252	-362

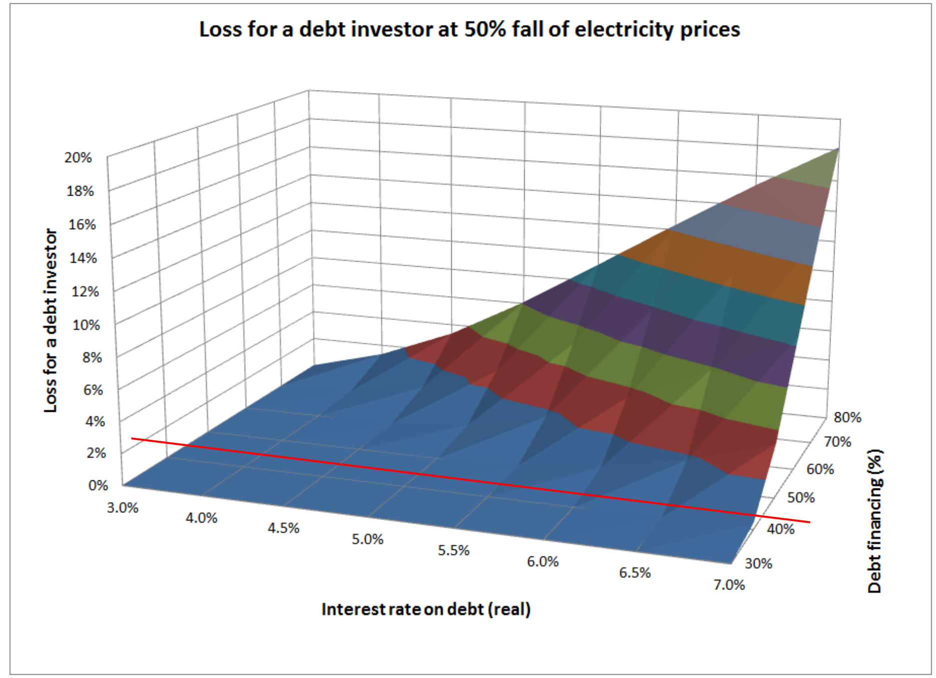
- CfD reduces greatly both the **shortfall risk** and the **average NPV shortfall**.
- How much an investor would value this risk reduction in term of required *cost of capital*?

Risk exposure for debt-holders

30% Decrease in electricity prices



50% Decrease in electricity prices

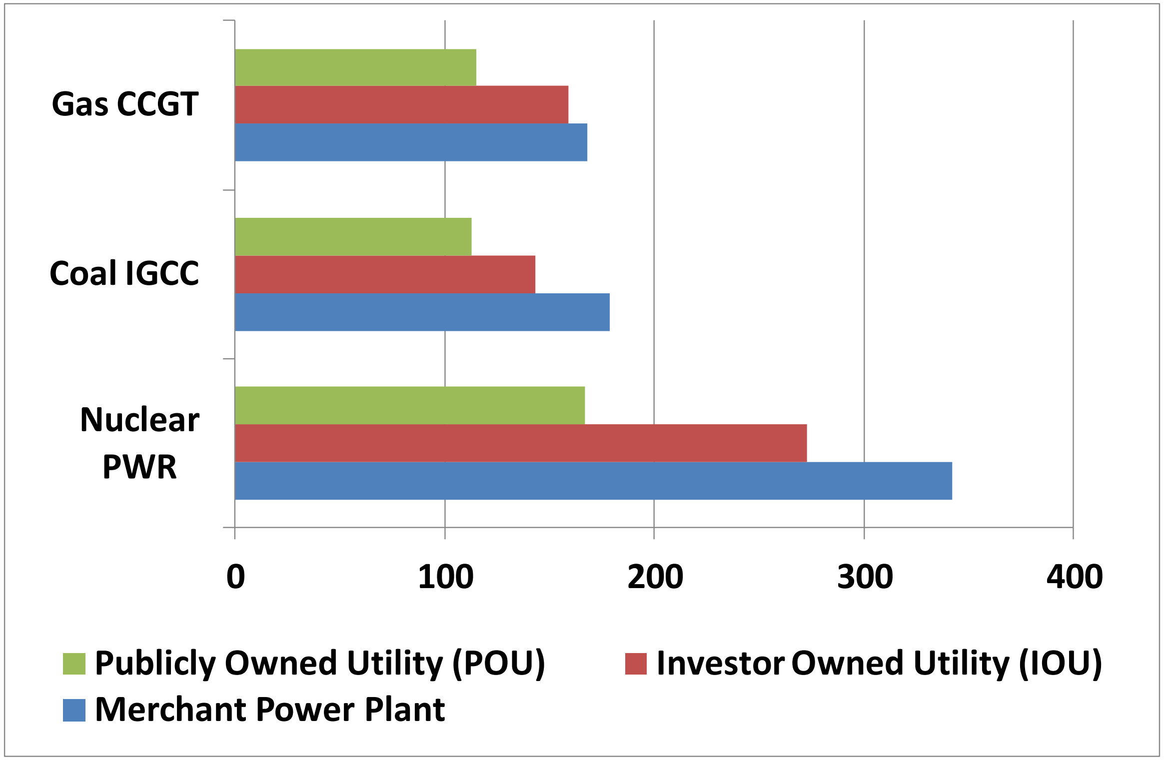


- Metric for risk: total value of the debt losses as percentage of total financial investment.
- No losses for bond-holders in a wide range of scenarios even at 30% to 40% price falls.
- At low debt ratios risk for bond-holders is limited even for large electricity price falls.
- At 70% DR and above, electricity market risk for bondholders starts to be important.
- For debt-holders the major source of risk is that the plant is never completed.

Choices about Electricity Market Design are Technology Choices

Levelised Costs of Electricity (LCOE) under Different Financing and Regulatory Arrangements

(USD/MWh, Commissioning 2018)



Source: California Energy Commission (2010), *"Comparative Costs of California Central Station Electricity Generation"*

The relative competitiveness of technologies is strongly influenced by the market design in which they are competing.

Summary Results of Case Studies on Long-Term Finance

- **Akkuyu**
  - Most of the project risk are taken by the Project Company (governmentally owned)
  - Long-term power purchasing agreement (PPA) between the Project Company and the Turkish Gvt:

Table 1: Present value of the power purchase agreement at different discount rates (USD/MWh)

	Value (in USD 2011 per MWh) of the purchase price agreement at different discount rates								
	2.0%	***2.5%***	***3.0%***	***3.5%***	***4.0%***	***4.5%***	***5.0%***	***5.5%***	***6.0%***
Constant price trajectory	92.10	85.76	79.92	74.53	69.56	64.98	60.73	56.81	53.18
Maximal value	93.74	87.66	82.04	76.83	72.00	67.53	63.37	59.52	55.93

- **Barakah**
  - Costs and risks are shared by the government of Abu Dhabi (30%), Export Import Bank of Korea (50%), US Export Import Bank (10%) and commercial banks (10%).
  - Level of electricity tariffs not yet decided.

- **Vogtle**
  - Three shareholders of the projected all work in regulated environments with stable revenue stream
    - ✓ Georgia Power, rate-regulated by Georgia Public Service Commission
    - ✓ Oglethorpe Power, long-term PPAs with Electric Membership Corporations (EMCs), part-owners
    - ✓ MEAG Power, owned by municipalities who are also sole customers.
  - Production tax credit and loan guarantees

Key Results of Part I

- Long-term electricity price volatility is a major source for risk and uncertainty facing investors in nuclear (and in technologies with high fixed costs) and needs to be appropriately managed.
- This is valid for all technologies with high fixed to variable costs ratios, which are mostly low-carbon technologies
- Appropriate **long-term arrangements** *(long-term contracts, PPA, CfD, FIT) for all low-carbon technologies* are needed to reduce electricity risk.
  - Absence of such arrangements will favour fossil-fuel technologies and increase GHG emissions
- **Institutional choices (regulated vs. deregulated markets) are neither technology-neutral nor environmentally neutral**.
- Independent of the competitiveness of different technologies, current electricity market prices would not allow *any new* dispatchable (and VRE) capacity to be built on a pure market basis.

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Vertical Integration vs. Competition

- Nuclear new build characterised by large scales, long time frames, complexity and externalities ("an accident anywhere is an accident everywhere").

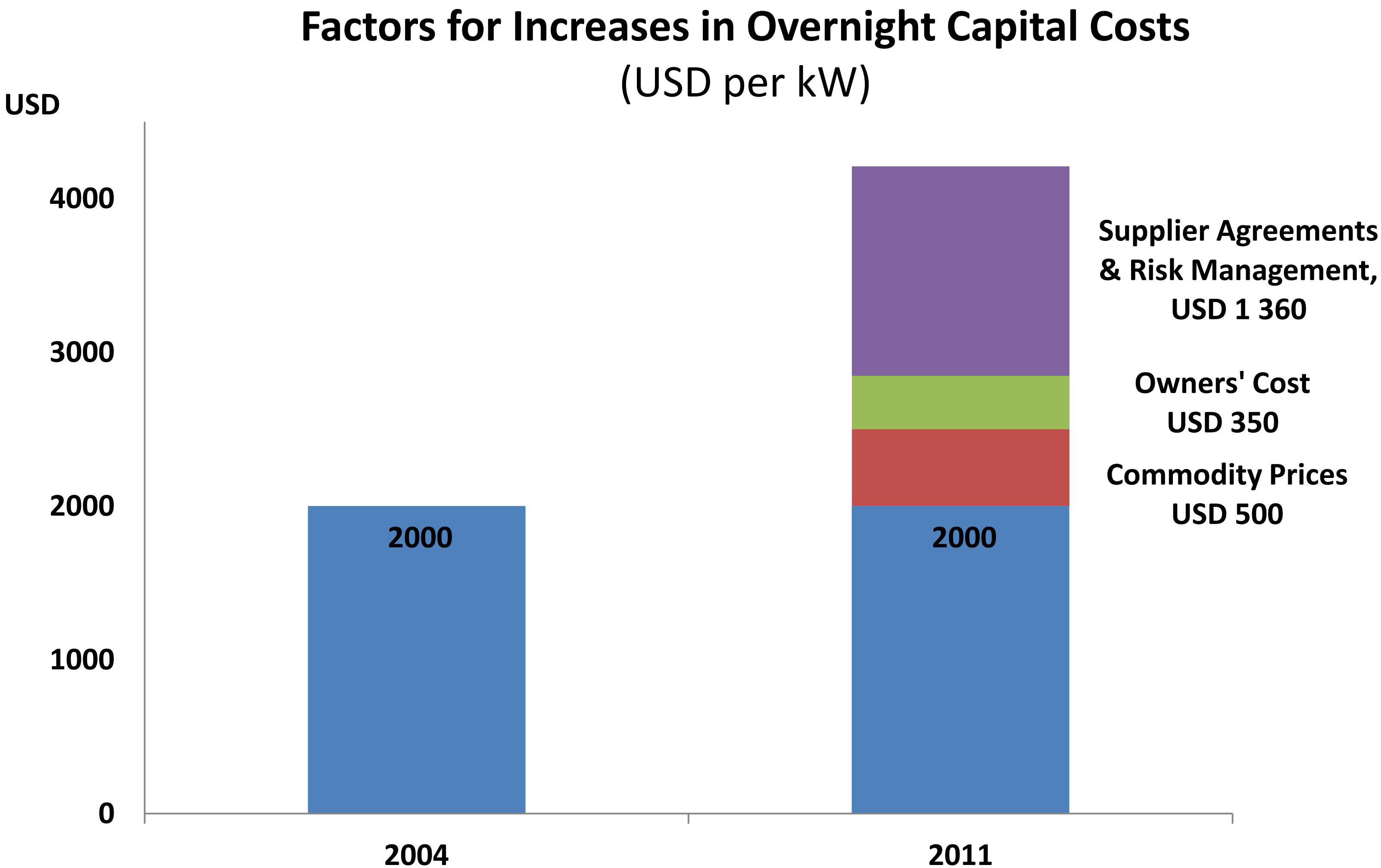
- Three basic models of project management:
  1. Turnkey project by integrated reactor vendor
  2. Operator-assembler works with key sub-contractors
  3. EPC contractor working with competitive procurement

- The theory of transaction costs (Coase, Williamson) holds that vertical integration should substitute for contractual relationships if there are:
  a) High frequency of transactions ➡ Not necessarily the case in nuclear,
  b) Industrial assets are "specific", i.e. not commoditised ➡ Very much the case in nuclear.

- Model 1 and 2 can reduce uncertainties and provide clear interlocutor for customers and governments. Model 3 may have advantages in reducing costs.

More competitive, less vertically integrated, industry requires "commoditisation" through international standard-setting, such as harmonisation of RCC-M and ASME engineering codes.

Project management and cost increase: Is de-verticalisation increasing costs?



Source*: University of Chicago (2011), *"Analysis of GW-Scale Overnight Capital Costs"

Issues in Project Management (I)

On learning-by-doing and costs (economies of scale):

- Areva shows cost reductions in French reactor programme per series on average 16% between first and last unit;
- Taishan EPR benefits from reductions in key cost indicators of up to 50% compared to Flamanville (EDF) or Olkiluoto (Areva);
- Study by École des Mines says 12% cost reduction from first to second reactor in batch.

On Project Management

- No single model of project management, different customers want different things;
- Transfer of lessons learned needs to be consciously organised
- Completion of design, early contract involvement (EWI) and early work agreements (EWA) must precede final contract
- Plan for long-lead time between authorisation to proceed (ATP) and first concrete
- Promising new technologies (automatic welding, 4-season site shelters).

Modularisation, standardisation, benchmarking

- Modularisation holds promise but no panacea, requires up-front investment and scale
- Initiatives on quality standards (NQSA, NUPIC) under way but not yet global standard
- Benchmarking of best practice as in oil and gas might be logical next step.

The global harmonisation of design, engineering and quality codes (RCC-M, ASME, NSQ-100) is a necessary step towards a more competitive and better integrated supply chain.

Issues in Project Management (II)

- Recurring theme of soft issues: “trust”, “team spirit” , “shared vision”, “mutual understanding “ and “collaboration” (including with regulators), “leadership”.
  - ✓ Particularly important when dealing with unexpected problems and changes.
  - ✓ Appropriate incentives (e.g. lump-sum contracts) can provide motivations.
- Impact of shortages in expertise and skills, especially amongst subcontractors,
- Requirement for new competences amongst individuals and subcontractors,
- The requirement to “teach” aspects of nuclear quality and safety culture to subcontractors. Even companies familiar with working in other industries with high regulatory standards may find it difficult to adapt to the particular requirements of nuclear.
- Anticipating and absorbing the implications of the variation in regulatory practice across national boundaries,
- The importance of selecting manufacturers and subcontractors on the basis of quality rather than price.

Lessons Learnt and Conclusions

on Financing

1. Market design, technology choices and CO2 emissions are intrinsically linked. Electricity price risk introduces bias against high-capital-cost, low-carbon technologies such as nuclear.
2. Decarbonisation and NNB require in addition to carbon taxes **long-term electricity price arrangements:** the more stable are electricity prices, the more stable is NPV, the lower are interest rate and the more competitive is nuclear.
3. Even with high leverage, nuclear projects pose limited risks to bondholders. Equity holders face an higher risk.

on Project Management

a. Different models of project management offer different trade-offs between internal and external transaction costs.
b. Less vertically integrated projects (EPC contractor model) offer efficiency gains via competitive pressure, but may add financial costs by layering responsibility, without a dedicated entity to assume residual project risk
c. Advance the convergence and standardisation of engineering codes and quality standards in the global nuclear industry.
d. Design completion and long lead-times for preparation are required.
e. Importance of "Soft issues" such as leadership, team building, experience, incentives and trust.

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Financing new generation capacity under current market conditions

- Electricity wholesale prices are very low in Europe, well below long-term average generation cost for all technologies.
- Several power plants in Europe are unable to recup variable generation costs:
  - ✓ Peaking and mid-load plants (OCGT and CCGT).
  - ✓ More surprisingly also capital intensive plants (hydro plants in Switzerland).
- The financial situation of several utilities has strongly deteriorated, jeopardising their ability to take on new investments.
- Utilities are not perceived anymore as part of a low-risk business (low β, favourable ratings, low cost of capital).
- **Under these conditions, no Power Plant can be financed on a pure market basis. This is particularly challenging for large, capital intensive projects.**
- Still need to finance a large electricity infrastructure:
  - ✓ Generation infrastructure is ageing
  - ✓ Need to go toward a low-C generation mix
  - ✓ Transmission and Distribution

Current electricity markets and challenges ahead

Electricity markets in many OECD countries are based on **marginal cost pricing** :

- Successfully enhanced competition and effectiveness in the electricity sector.
- Effective in providing appropriate signals for short-term dispatch.
- Does not provide appropriate long-term investment signal (“missing money” and SoS) and implicitly favour carbon intensive fossil fuel technologies.

Current market designs are not well suited for investments in capital intensive technologies and won’t deliver a low-C mix. Forcing low carbon technologies on a pure market basis would require very high CO_2 prices and entail some risk for SoS.

- A low-carbon mix with large quantity of VRE, will inevitably lead to high variability of electricity prices, with a high number of hours at VOLL and 1000s of hours at zero price, with a very skewed distribution of revenues for all generation capacities.
- Electricity price will be strongly dependent on annual weather conditions (high/low wind production, high/low hydro production), with large fluctuations for VRE and base-load.
- Electricity market risk (and political risk) will have an impact on the cost of capital.
- Decreasing value of VRE generation and increased market risk will make full market finance for solar and wind very challenging.

New Market design for low-C technologies

1. High levels of low-carbon investments will need new market arrangements and a **robust CO_2 price**.
2. Low-Carbon technologies need a **long-term price signal**: price stability can be provided through long-term power purchase agreements (PPAs), feed-in premiums (FIP) or feed-in-tariffs (FITs) / contracts-for-difference (CfDs).
   - This does not mean the end of competition. However, it means proceeding from competing on marginal costs to competing on average costs through competitive auctions.
   - Regulated markets have their own challenges but provide the price and revenue stability that low carbon technologies require.
3. **Flexibility provision** through demand response, storage and improved interconnections are part of the new market design.
4. The **system costs** of all technologies must be allocated fairly and transparently:
   - Back-up power and increased "profile costs"
   - Balancing needs
   - Connection and reinforcement of transport and distribution costs

Key points and takeaway messages

- **Decarbonising the energy sector is an immense challenge for all OECD countries.**

- **Achievement of climate targets inevitably requires the full-decarbonisation of electricity sector by 2040/2050.**
  - ✓ Electrification of transport.
  - ✓ Complete reconfiguration of the generation mix, with the coexistence of all available low-C sources.
  - ✓ Massive investments are needed on generation, transmission and distribution.
  - ✓ Future low-C generation mix is characterised by the dominance of capital costs and by high fixed and low/very low marginal costs.

- **New market design are needed to achieve this transition at the lowest cost.**
  - ✓ Introducing a robust carbon price is the most effective solution.
  - ✓ Some sort of financial security for capital intensive technologies is needed.
  - ✓ System effects are significant, should be taken into account and internalised.
  - ✓ Need to maintain the price signal (*value of production*)

Thank you
For your attention

The "nuclear new built" study is available on-line

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

Contacts: Marco Cometto and Jan Horst Keppler

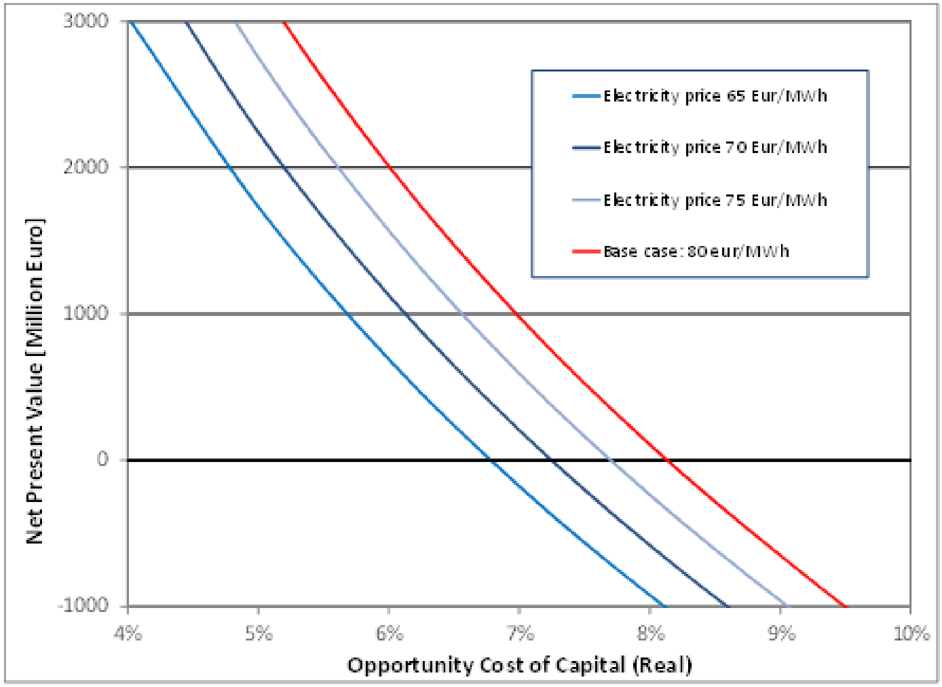
Marco.Cometto@oecd.org and Jan-Horst.Keppler@oecd.org

Reserve slides

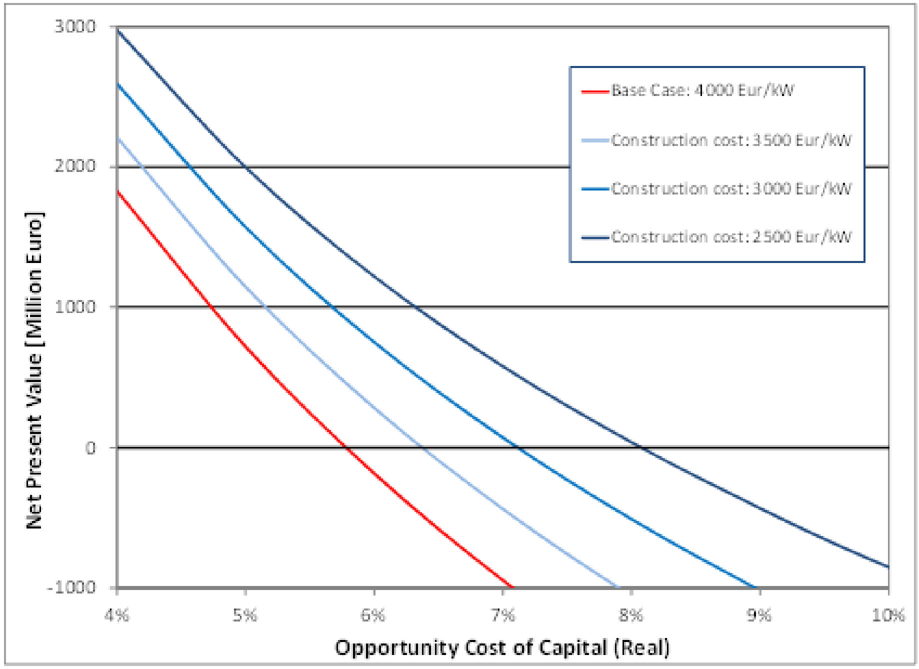
Financing NPP in continental Europe
Reduction in Overnight costs

Net Present Value of a NPP investment

Sensitivity to Electricity Price



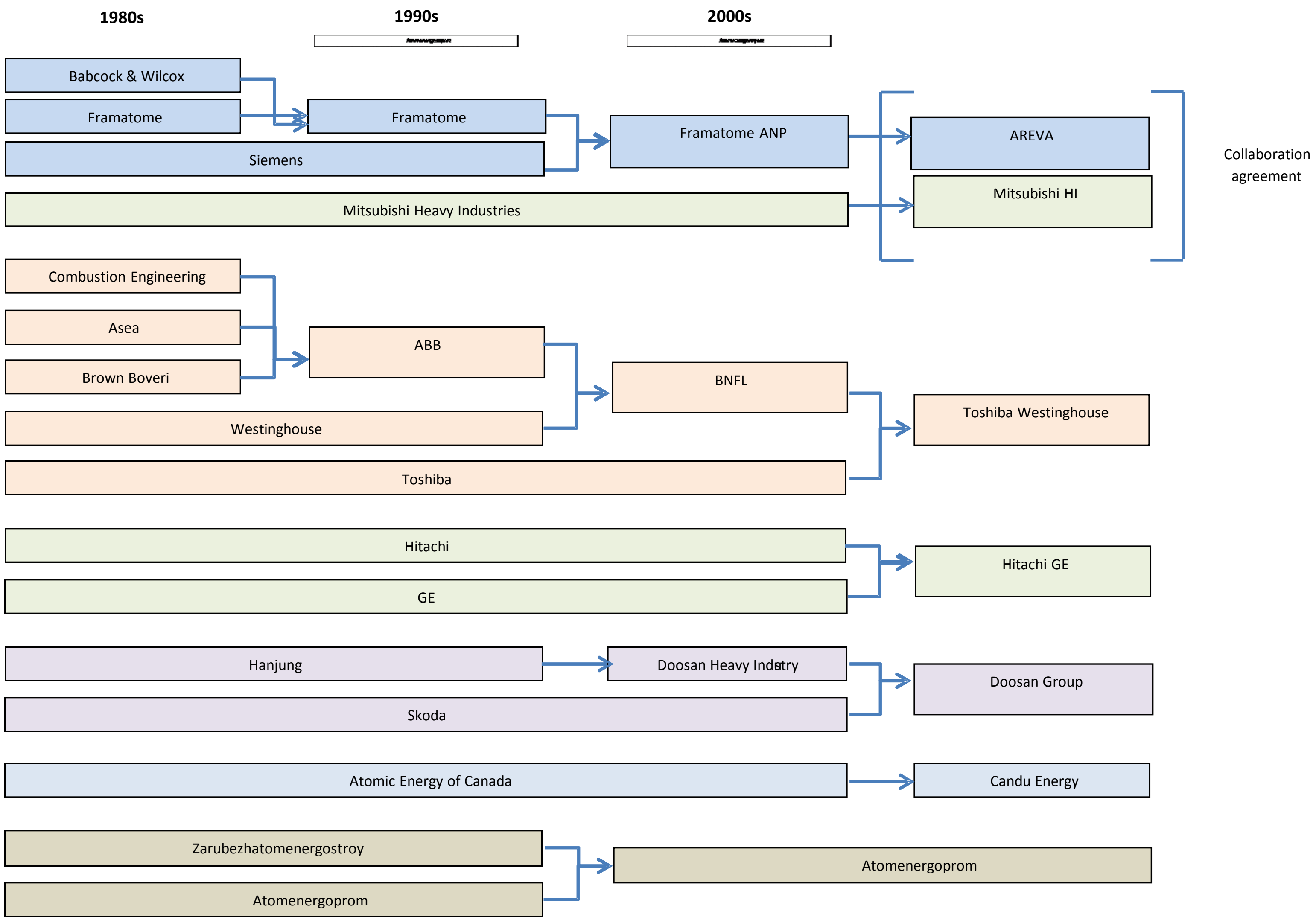
Sensitivity to Overnight Costs



- With current wholesale electricity prices (and prevailing construction costs) it is unlikely that a new NPP could be financed without governmental support.
- A combination of increase in electricity prices and reduction of construction costs is needed to make a NPP project viable in Continental Europe.

Part II: The Evolving Structure of the Nuclear Supply Chain II

Consolidation in Nuclear Reactor Manufacture



Part II - Project Management: Vertical Integration vs. Competition II

Which form of cooperation in different aspects of nuclear power plant construction following the structure provided by Williamson?

FREQUENCY \ ASSET SPECIFICITY	Low	Medium	High
Low	Spot market provision (Building services)	LT Outsourcing/Tender (Construction of headquarters)	Joint venture (Building of power plant in specific country)
Medium	Spot market provision (IT Supplies)	LT Outsourcing/Tender (NPP Maintenance)	LT Outsourcing/Tender (Provision of specialised valves and pumps)
High	LT Outsourcing/Tender (Payroll management)	Vertical Integration (Human resource management)	Vertical Integration (Fabrication of reactor vessel)