The System Costs of Different Power Generation Technologies: A New Look at the Competitiveness of Nuclear Power

Ron Cameron and Jan-Horst Keppler

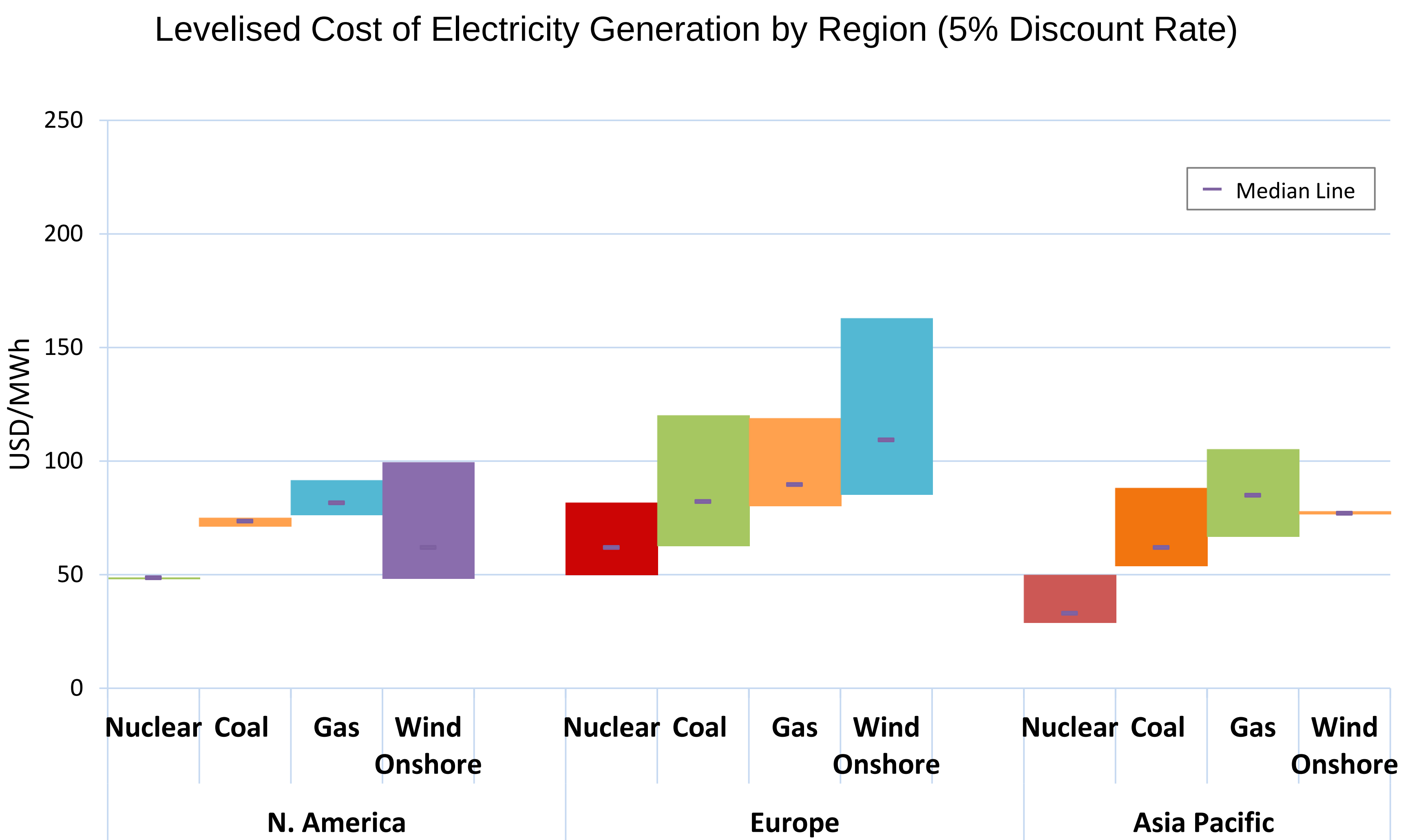
OECD Nuclear Energy Agency

European Nuclear Conference, Manchester 9-13 December

Competitiveness of Nuclear

1. Nuclear power has advantages in an energy mix because it contributes to security of supply, reduction of GHG and provides stability of electricity prices over long periods.
2. However, financing of nuclear power in a liberalised market is challenging because the lack of certainty in prices is a disincentive for investors
3. Without innovative financing schemes – cooperative models in Finland, BOO in Turkey, 'strike price' and CfD in the UK, new build would only be expected in regulated markets without government support.
4. LCOE calculations confirm the overall lifetime competitiveness of nuclear but discount rates and construction times have significant influence #
5. For the private investor, without carbon pricing and if prices were low, nuclear is less profitable than gas or coal. #
6. In addition, cheap gas and subsidised renewals make the environment even more challenging
7. But is this the true picture? #

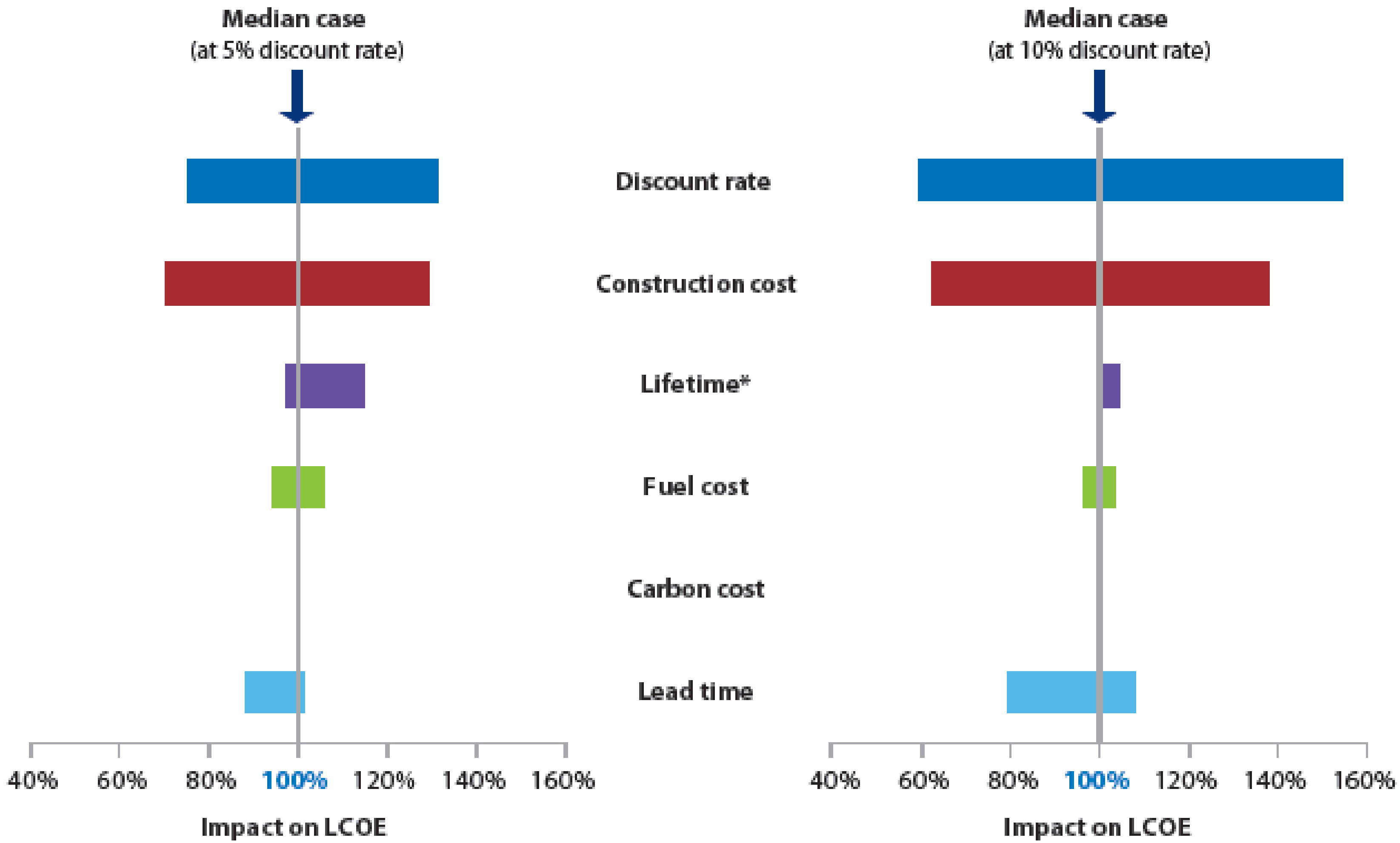
Is Nuclear Competitive? (1)



Nuclear is already a very cost competitive technology

Source: Projected Costs of Generating Electricity, IEA/NEA 2010

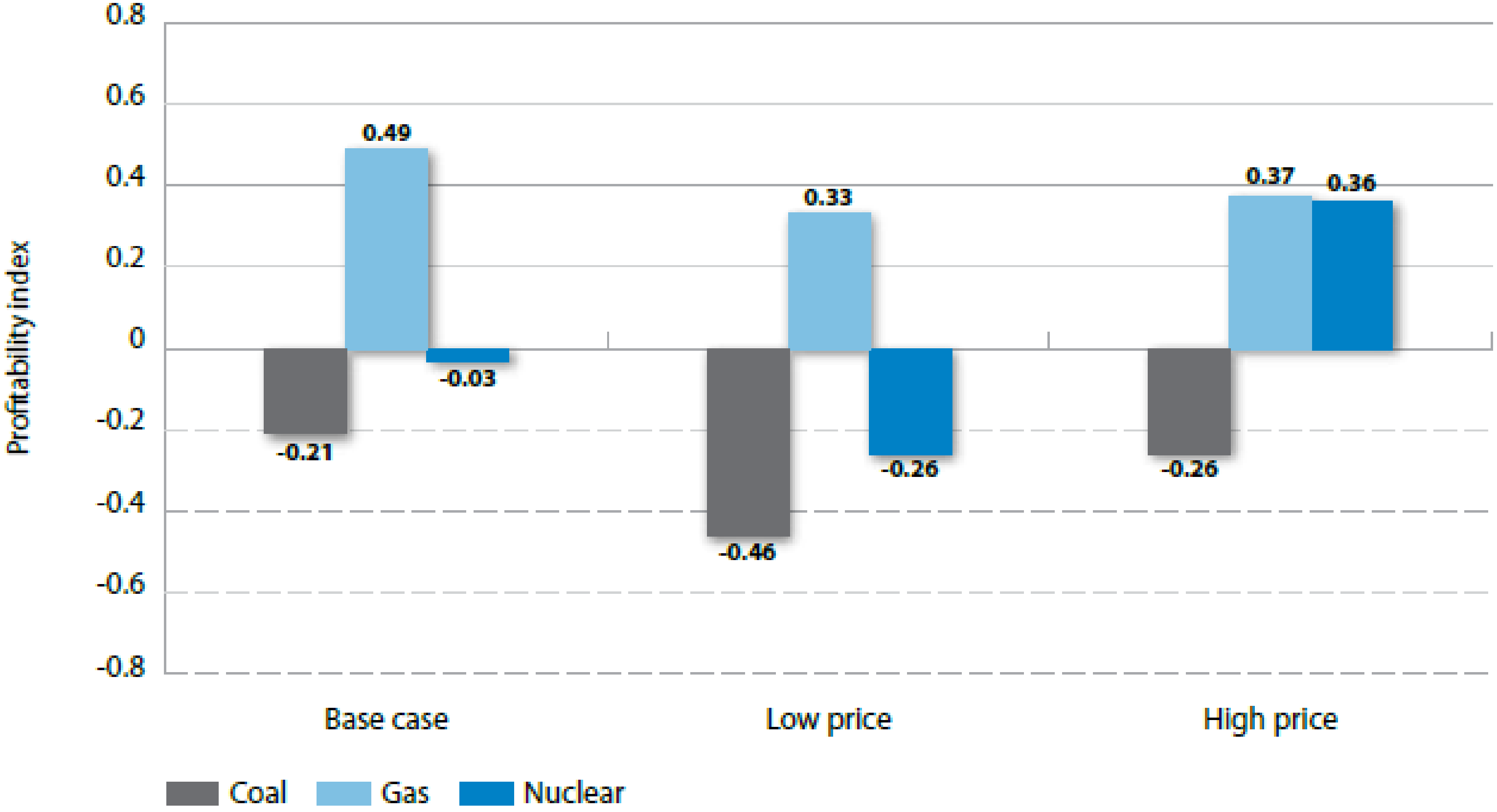
Tornado graph nuclear (+/- 50%)



* Lifetime and LCOE are inversely related, as a lifetime extension results in total levelised cost reduction and a lifetime decrease leads to a generation cost increase.

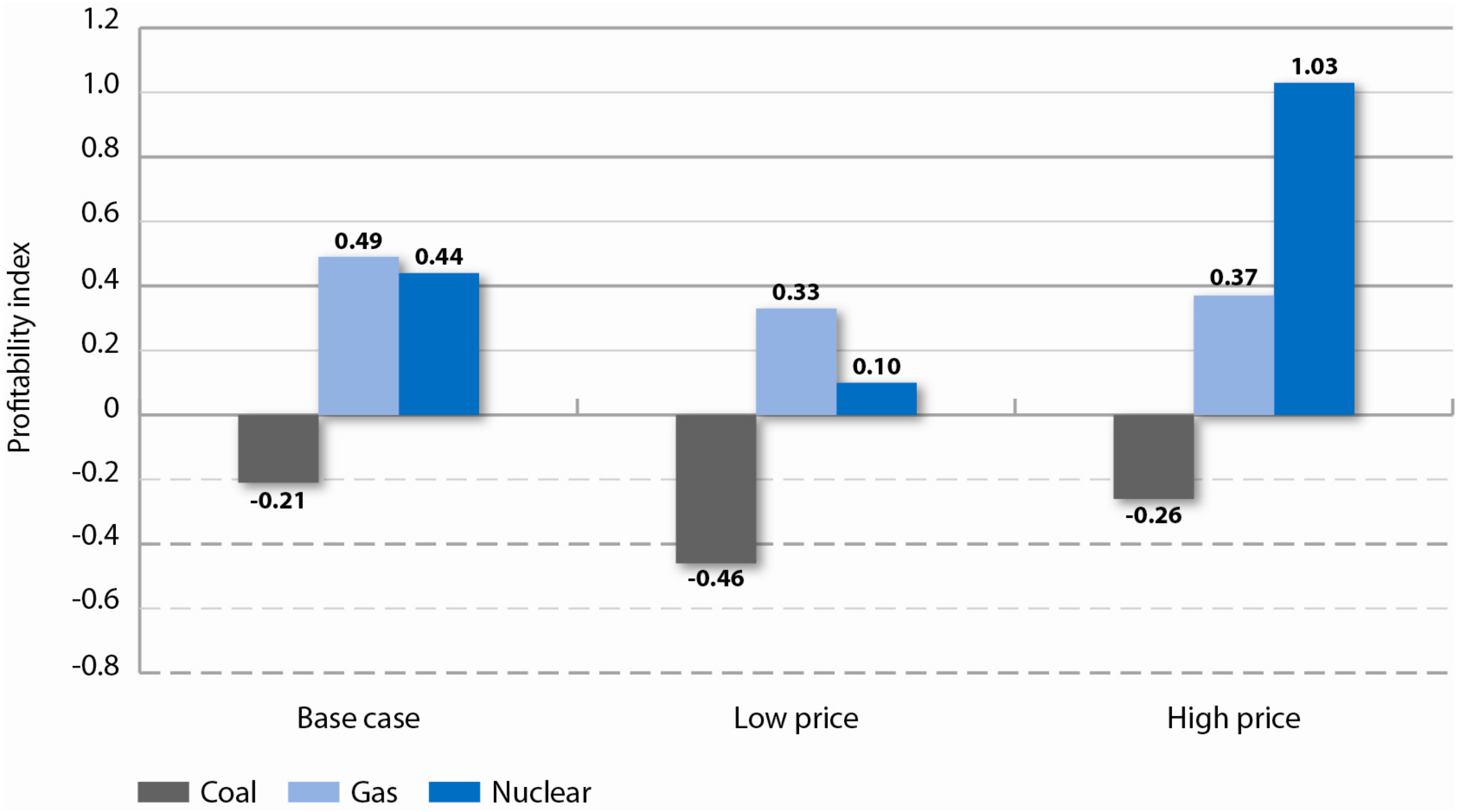
Investment Analysis I (PI, FOAK, 7%)

With First-of-a-kind capital costs nuclear struggles to be competitive even at high electricity prices (during a period when gas prices are moderate).

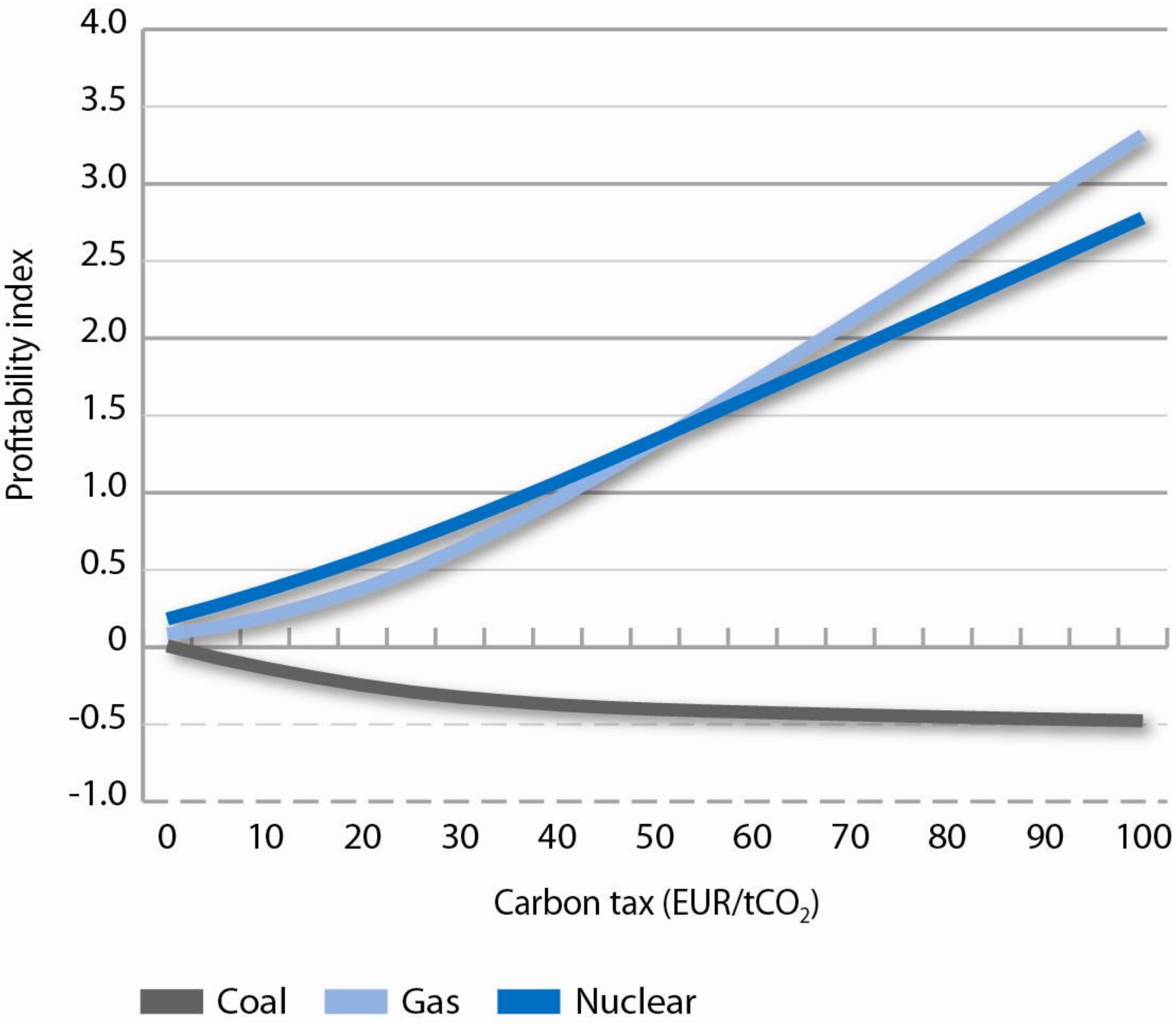


Investment Analysis II (PI, IM, 7%)

With the overnight costs of the Industrial Maturity case (IM), the situation improves



Liberalised markets & carbon tax analysis I (IM, 7%, € 10)



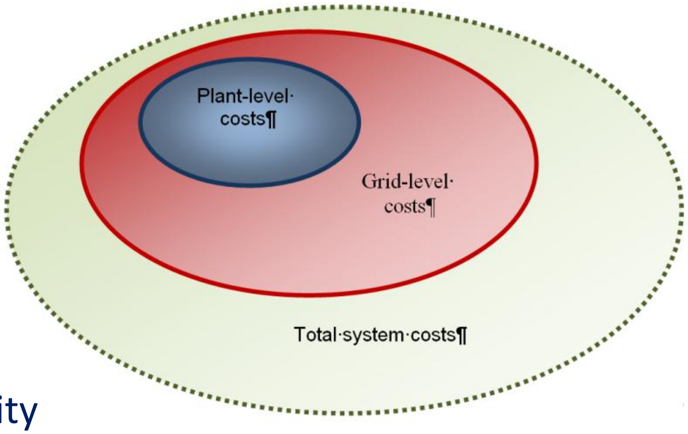
Scenario 2: Bringing down overnight costs in the Industrial Maturity (IM) case would make nuclear competitive even with € 10 profit margins and average gas prices, especially at carbon prices below € 50/tCO2.

#

System Effects Study

"System costs are the total costs above plant-level costs to supply electricity at a given load and given level of security of supply."

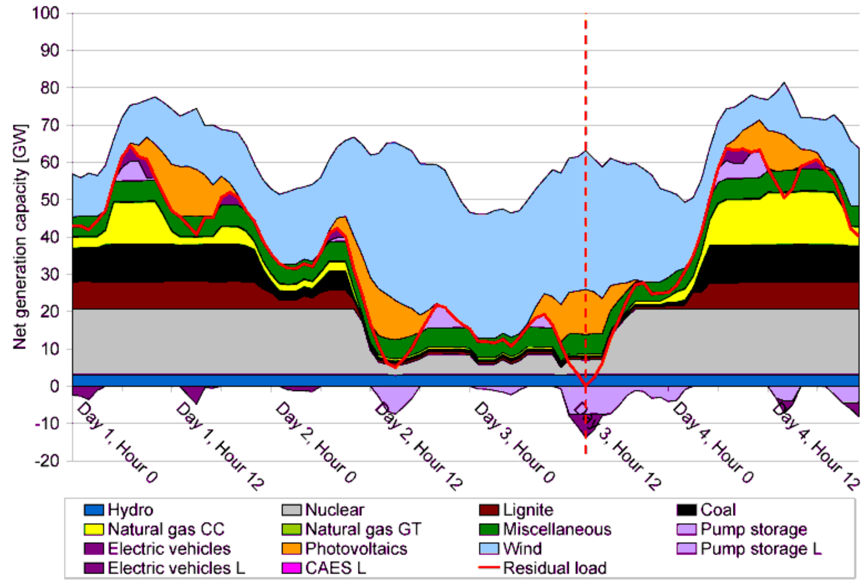
- *Plant-level costs*
- *Grid-level system effects (technical externalities)*
    - Grid connection
    - Grid-extension and reinforcement
    - Short-term balancing costs
    - Long-term costs for maintaining adequate back-up capacity



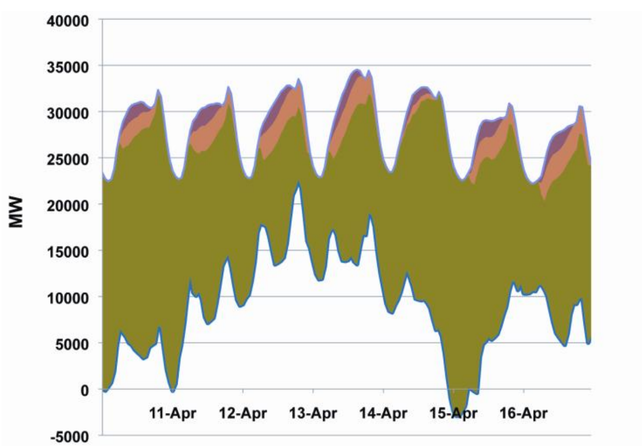
- *Total system costs*
    - Take into account not only the costs but also the benefits of integrating new capacity (variable costs and fixed costs of new capacity that could be displaced)
    - Other externalities (environmental, security of supply, cost of accidents, …)
- *Dynamic effects (pecuniary externalities)*
    - Reduced prices and load factors of conventional plants in the short-run
    - Re-configuration of the electricity system in the long-run

System Effects – Interaction with renewables

1. Interaction between nuclear power and the electricity system
   - System effects of NPPs (additional requirements on grid size, location, safety)
   - Ability of NPPs to deal with system effects (load following and fleet management provide flexibility)



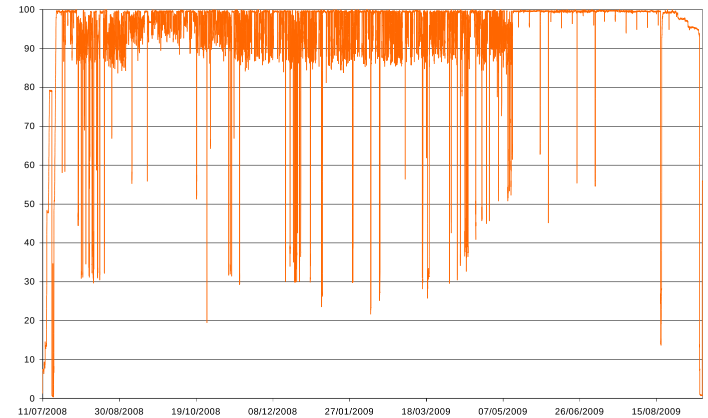
2. Quantitative estimation of system effects of different generating technologies
   - Costs imposed on the electricity system above plant-level costs
   - Total system-costs in the long-run
   - Impact of intermittent renewables on nuclear energy and other generation sources



3. Institutional frameworks, regulation and policy conclusions to enhance the sustainability, flexibility and security of supply of power generation and enable coexistence of renewables and nuclear power in decarbonising electricity systems

The Ability of Nuclear Power to Deal with System Effects (Flexibility Provision)

- In some countries (France, Germany, Belgium) significant flexibility is required of NPPs:
  - Primary and secondary frequency control
  - Daily and weekly load-following;



- Good load-following characteristics
  - No proven impacts on fuel failures and major components
  - Availability factor reduction due to extended maintenance (1.2 – 1.8%)
  - Economical consequences of load-following mainly due to reduction in load factors

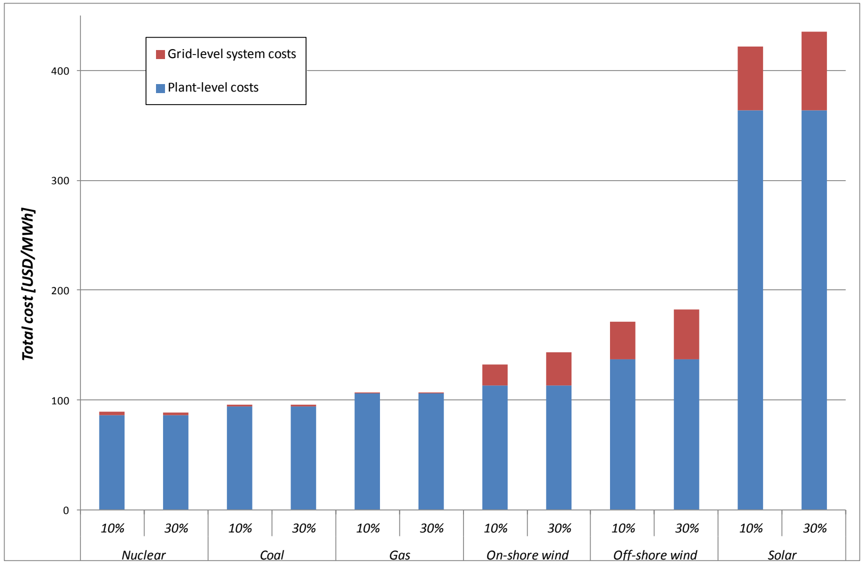
	Start-up Time	*Maximal change in 30 sec*	*Maximum ramp rate (%/min)*
Open cycle gas turbine (OGT)	10-20 min	20-30 %	20 %/min
Combined cycle gas turbine (CCGT)	30-60 min	10-20 %	5-10 %/min
Coal plant	1-10 hours	5-10 %	1-5 %/min
Nuclear power plant	2 hours - 2 days	up to 5%	1-5 %/min

- Nuclear fleet management
  - Performing outages when electricity is less valuable minimises private and social losses
  - Also reduces the residual demand balance and the need for additional capacity

System Effects of Different Technologies: Estimating Grid-level Costs

System Costs at the Grid Level (average of 6 countries - USD/MWh)												
Technology	Nuclear		Coal		Gas		On-shore wind		Off-shore wind		Solar	
Penetration level	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up Costs (Adequacy)	0.00	0.00	0.04	0.05	0.01	0.00	5.09	7.30	6.39	6.87	17.03	16.30
Balancing Costs	0.61	0.36	0.02	0.00	0.00	0.00	3.86	7.84	4.69	7.84	4.69	7.84
Grid Connection	1.73	1.71	1.03	0.94	0.59	0.51	5.24	6.24	17.23	18.68	14.58	13.71
Grid Reinforcement and Extension	0.00	0.00	0.00	0.00	0.00	0.00	1.86	6.28	1.68	3.82	4.19	13.55
Total Grid-Level System Costs	**2.34**	**2.06**	**1.09**	**0.99**	**0.60**	**0.51**	**16.06**	**27.65**	**29.99**	**37.21**	**40.49**	**51.40**

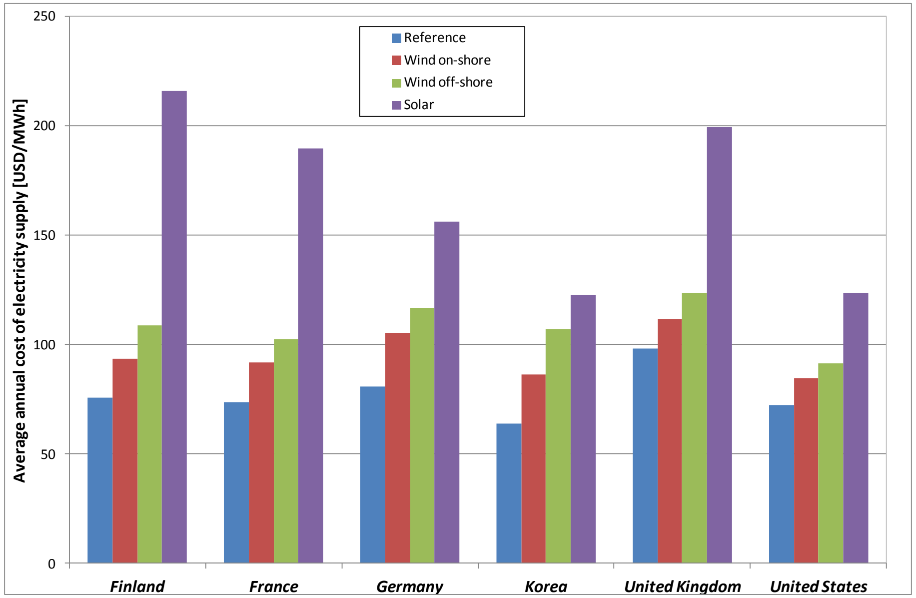
- Six countries, Finland, France, Germany, Korea, United Kingdom and USA analyzed
- Grid-level costs for variable renewables at least one level of magnitude higher than for dispatchable technologies
  - Grid-level costs depend strongly on country, context and penetration level
  - Grid-level costs are in the range of 15-80 USD/MWh for renewables (wind-on shore lowest, solar highest)
  - Average grid-level costs in Europe about 50% of plant-level costs of base-load technology (33% in USA)
  - Nuclear grid-level costs 1-3 USD/MWh
  - Coal and gas 0.5-1.5 USD/MWh.



The Total Costs of Electricity Supply for Different Renewables Scenarios

- Comparing total annual supply costs of a reference scenario with only dispatchable technologies with six renewable scenarios (wind ON, wind OFF, solar at 10% and 30%)
  - Takes into account also fixed and variable cost savings of displaced conventional PPs

		Total cost of electricity supply [USD/MWh]						
		Ref.	*10% penetration level*			*30% penetration level*		
		Conv. Mix	*Wind on-shore*	*Wind off-shore*	*Solar*	*Wind on-shore*	*Wind off-shore*	*Solar*
Germany	***Total cost of electricity supply***	80.7	86.6	91.3	101.2	105.5	116.9	156.2
	Increase in plant-level cost	-	3.9	7.8	16.9	11.6	23.3	50.6
	Grid-level system costs	-	1.9	2.8	3.6	13.2	12.9	24.9
	Cost increase	-	5.8	10.6	20.4	24.8	36.2	75.4
UK	***Total cost of electricity supply***	98.3	101.7	105.6	130.6	111.9	123.6	199.4
	Increase in plant-level cost	-	1.5	3.9	26.5	4.5	11.7	79.6
	Grid-level system costs	-	1.9	3.4	5.8	9.1	13.6	21.5
	Cost increase	-	3.4	7.3	32.3	13.6	25.3	101.1
USA	***Total cost of electricity supply***	72.4	76.1	78.0	88.2	84.6	91.5	123.7
	Increase in plant-level cost	-	2.1	4.2	14.3	6.2	12.5	42.8
	Grid-level system costs	-	1.6	1.4	1.5	6.0	6.5	8.5
	Cost increase	-	3.7	5.6	15.7	12.2	19.1	51.2



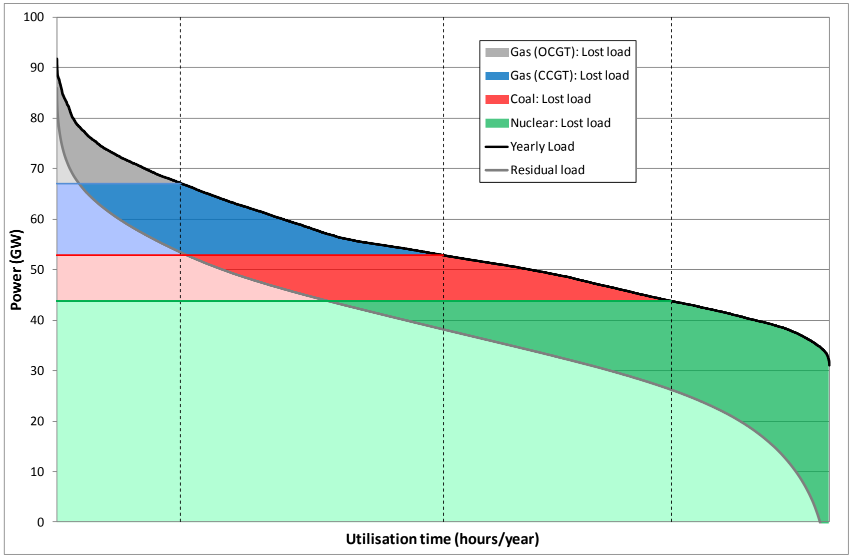
- Total costs of renewables scenarios are large, especially at 30% penetration levels:
  - Plant-level cost of renewables still significantly higher than that of dispatchable technologies.
  - Grid-level system costs alone are large, representing up to 67% of the increase in unit electricity costs.

Dynamic System Effects Beyond Grid-level Costs I

Short-run effects (impacts on load factors, average prices and profitability)

In the *short-run*, renewables with zero marginal costs replace technologies with higher marginal costs, including nuclear as well as gas and coal plants. This means:

- Reductions in electricity produced by dispatchable power plants (lower load factors, *compression effect*)
- Reduction in the average electricity price on wholesale power markets.



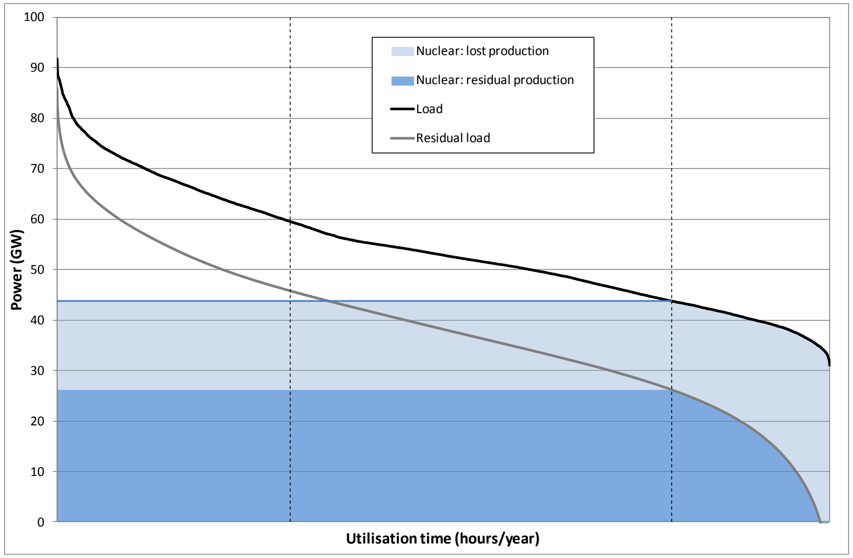
		10% Penetration level		30% Penetration level	
		Wind	Solar	Wind	Solar
Load losses	*Gas Turbine (OCGT)*	-54%	-40%	-87%	-51%
	Gas Turbine (CCGT)	-34%	-26%	-71%	-43%
	Coal	-27%	-28%	-62%	-44%
	Nuclear	-4%	-5%	-20%	-23%
Profitability losses	*Gas Turbine (OCGT)*	-54%	-40%	-87%	-51%
	Gas Turbine (CCGT)	-42%	-31%	-79%	-46%
	Coal	-35%	-30%	-69%	-46%
	Nuclear	-24%	-23%	-55%	-39%
Electricity price variation		-14%	-13%	-33%	-23%

- Together this means declining profitability especially for gas (nuclear is less affected);
- Security of supply risks as fossil plants close;
- Some reductions in CO_2 emissions depending on existing mix.

Dynamic System Effects Beyond Grid-level Costs II

Long-run effects (Declining share of nuclear and potentially higher CO2 emissions)

In the *long-run*, and in the absence of countervailing measures such as carbon taxes, the reduction in load factors will lead to reduced investment and declining shares of high-fixed cost base-load technologies such as nuclear :



- New investment in the presence of renewable production will change generation structure;
- Renewables will displace base-load on more than a one-to-one basis, especially at high penetration levels, as reduced load hours will mean higher share of gas in total capacity;
- Costs for residual dispatchable load will rise as more expensive technologies are used;
- No changes in wholesale electricity market prices at penetration levels < 25%;
- Depending on the base-load technology displaced (nuclear or coal) CO_2 emissions can rise:
  - If there was no nuclear in the original generating mix, renewables will reduce CO_2 emissions;
  - If nuclear was part of the original generating mix, CO_2 emissions will increase.

New Markets for New Challenges

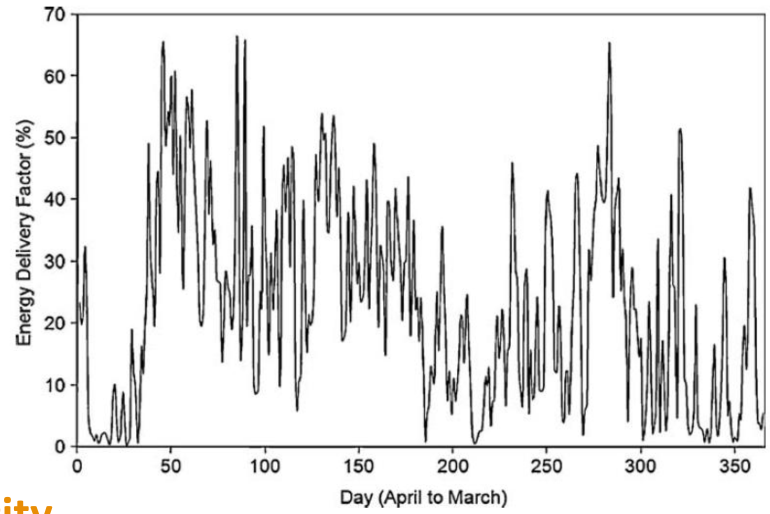
The integration of large amounts of variable generation and the dislocation it creates in electricity markets requires institutional and regulatory responses in at least three areas:

A. Markets for short-term flexibility provision

For greater flexibility to guarantee continuous matching of demand and supply exist in principle four options that should compete on cost:

1. Dispatchable back-up capacity and load-following
2. Electricity storage
3. Interconnections and market integration
4. Demand side management

So far dispatchable back-up remains cheapest.



B. Mechanisms for the long-term provision of capacity

There will always be moments when the wind does not blow or the sun does not shine. Capacity mechanisms (payments to dispatchable producers or markets with supply obligations for all providers) can assure profitability even with reduced load factors and lower prices.

C. A Review of Support Mechanisms for Renewable Energies

Subsidising output through feed-in tariffs (FITs) in Europe or production tax credits (PTCs) in the United States incentivises production when electricity is not needed (including *negative prices).* Feed-in premiums, capacity support or best a substantial carbon tax would be preferable.

Lessons Learnt and Policy Conclusions

Lessons Learnt

The integration of large shares of intermittent renewable electricity is an important challenge for the electricity systems of OECD countries and for dispatchable generators such as nuclear.

- Grid-level system costs for variable renewables are large (15-80 USD/MWh) but depend on country, context and technology (Wind ON < Wind OFF < Solar PV)
- Grid-level and total system cost increase *over-proportionally* with the share of variable renewables
- System effects of nuclear power exist but are modest compared to those of variable renewables
- Lower load factors and lower prices affect the economics of dispatchable generators: difficulties in financing capacity to provide short-term flexibility and long-term adequacy need to be addressed.

Policy Conclusions

1. **Account for system costs and ensure transparency of power generation costs.**
2. **New regulatory frameworks are needed to minimize and internalize system effects.**
   (1) Capacity payments or markets with capacity obligations, (2) Oblige operators to feed stable hourly bands of capacity into the grid, (3) Allocate costs of grid connection and extension to generators, (4) Offer long-term contracts (contracts for difference, feed-in-tariffs) to dispatchable base-load capacity.
3. **Recognize the role of dispatchable low-carbon technologies such as nuclear in long term stability and security of supply**
4. **Develop flexibility resources to enable the co-existence of nuclear and variable renewables in low carbon electricity systems.**