International Energy Agency

NEA NUCLEAR ENERGY AGENCY

The 8th IEEJ Global Energy Webinar

Projected Costs of Generating Electricity: 2020 Edition

Jan Horst Keppler

Senior Economic Advisor
Division of Nuclear Technology Development and Economics
OECD Nuclear Energy Agency (NEA)

Stefan Lorenczik

Energy Analyst
Gas, Coal and Power Markets Division

International Energy Agency (IEA)

Projected Costs of Generating Electricity: 2020 Edition
Table of Contents

iea International Energy Agency

NEA NUCLEAR ENERGY AGENCY

Overview of Country Data

Table 1.1: Summary of responses by country and technology

Country	Natural gas	Coal	Nuclear	LTO	Solar PV	Solar thermal	Onshore wind	Offshore wind	Hydro	CHP	Storage	Other	TOTAL
Australia	3	4			1	1	1	1			1		12
Austria					1		1		1				3
Belgium	6				4		4	2					16
Canada	3				2		1				1		7
Denmark					4		1	2		7	2		16
Finland							1				1		2
France			1	1	3		1	1				3	10
Germany									1				1
Hungary					4								4
Italy	2				7		14		15	1	1	6	46
Japan	1	1	1		2		1	1	1				8
Korea	2	1	1		2		1	1					8
Mexico	3												3
Netherlands					3		1						4
Norway					1		1		2			1	5
Romania	1									2			3
Russia			1				2						3
Slovak Republic			1							2			3
Sweden				1			1						2
Switzerland				1									1
United States	2	8	1	1	15	3	10	14	8			2	64
Non-OECD countries													
Brazil	2	1			1		1		1			1	7
China	1	1	1		1		1	1					6
India		2	1		1		1		1		2	1	9
TOTAL	**26**	**18**	**8**	**4**	**52**	**4**	**44**	**23**	**30**	**12**	**8**	**14**	**243**

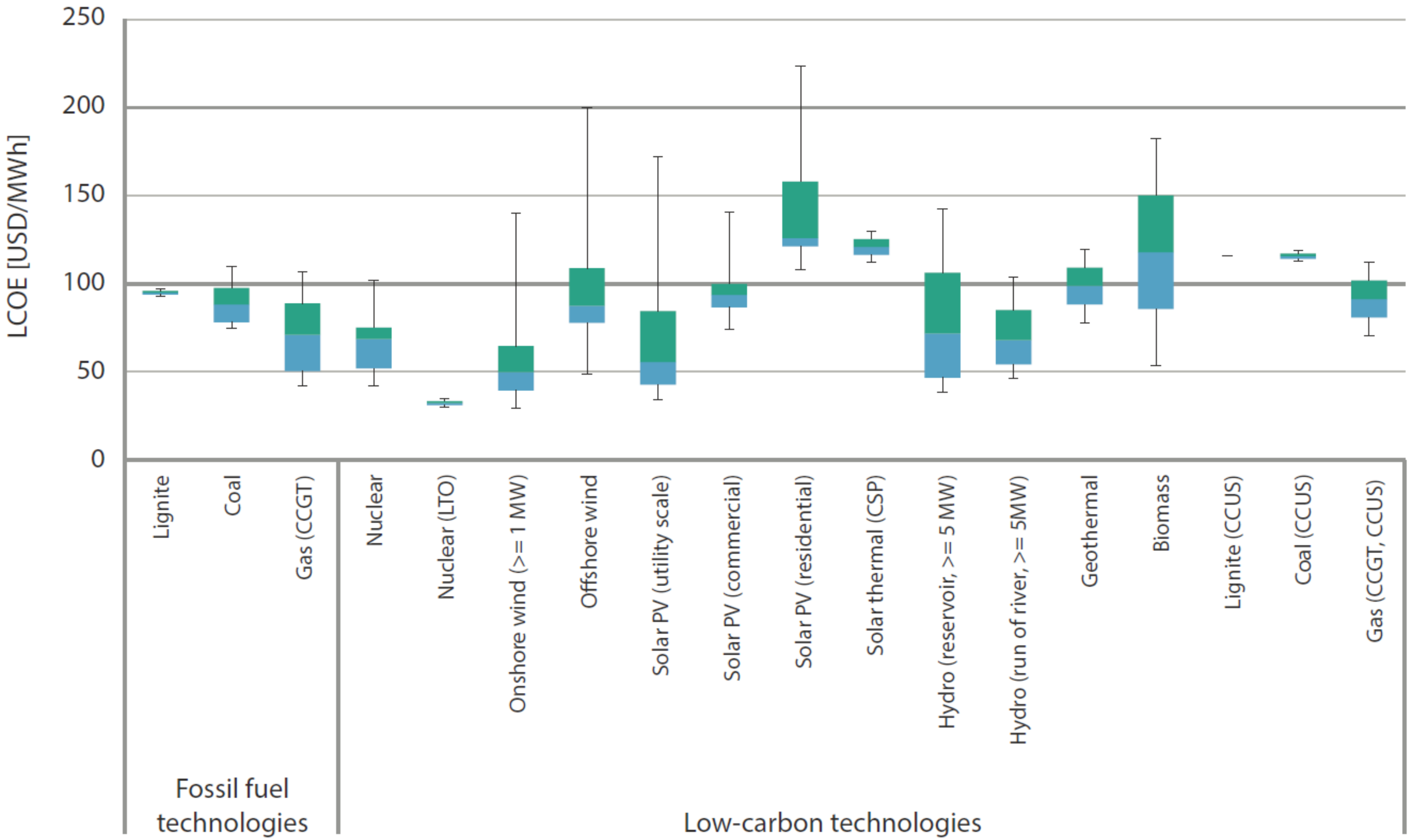
Key messages from *Projected Costs: 2020 Edition*

- Low carbon generation is becoming fully cost competitive in LCOE terms.
- Competitiveness depends on national and local conditions for all technologies (renewables, coal, gas or nuclear).
- Technologies have to fit into the market as system costs analysis is important to understand the full picture; storage is becoming more important.
- Costs of renewable energies, especially onshore wind, have continued to decrease and at USD 30/tCO2 their LCOE costs are now competitive with dispatchable fossil fuel-based electricity generation in most countries.
- The system value of variable renewables such as wind and solar however decreases as their share in the power supply increases.
- Nuclear remains the dispatchable low carbon technology with the lowest costs. Only large hydro reservoirs, where available, can provide a similar system contribution at comparable costs.
- Coal is no longer competitive at USD 30/tCO2. CCGTs are very dependent on the gas price. They are very competitive in North America, less so in Asia and Europe.
- Electricity produced from nuclear long-term operations (LTO) is highly competitive and remains the least cost option not only for low carbon generation but for all power generation across the board.
- Carbon capture technologies would only be competitive with unmitigated coal or gas at carbon prices higher than USD 30/tCO2.

International Energy Agency

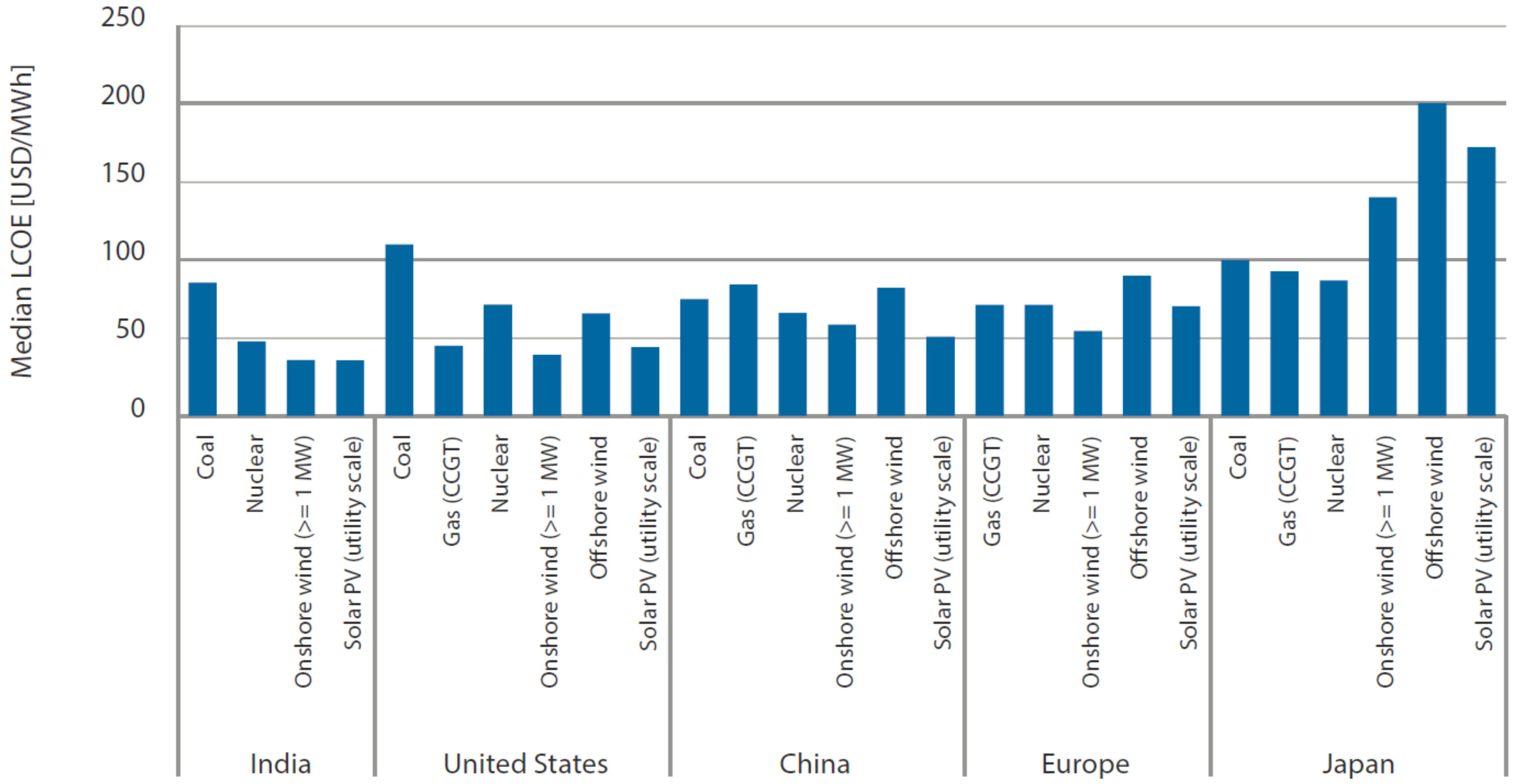
NEA NUCLEAR ENERGY AGENCY

LCOE ranges for different technology



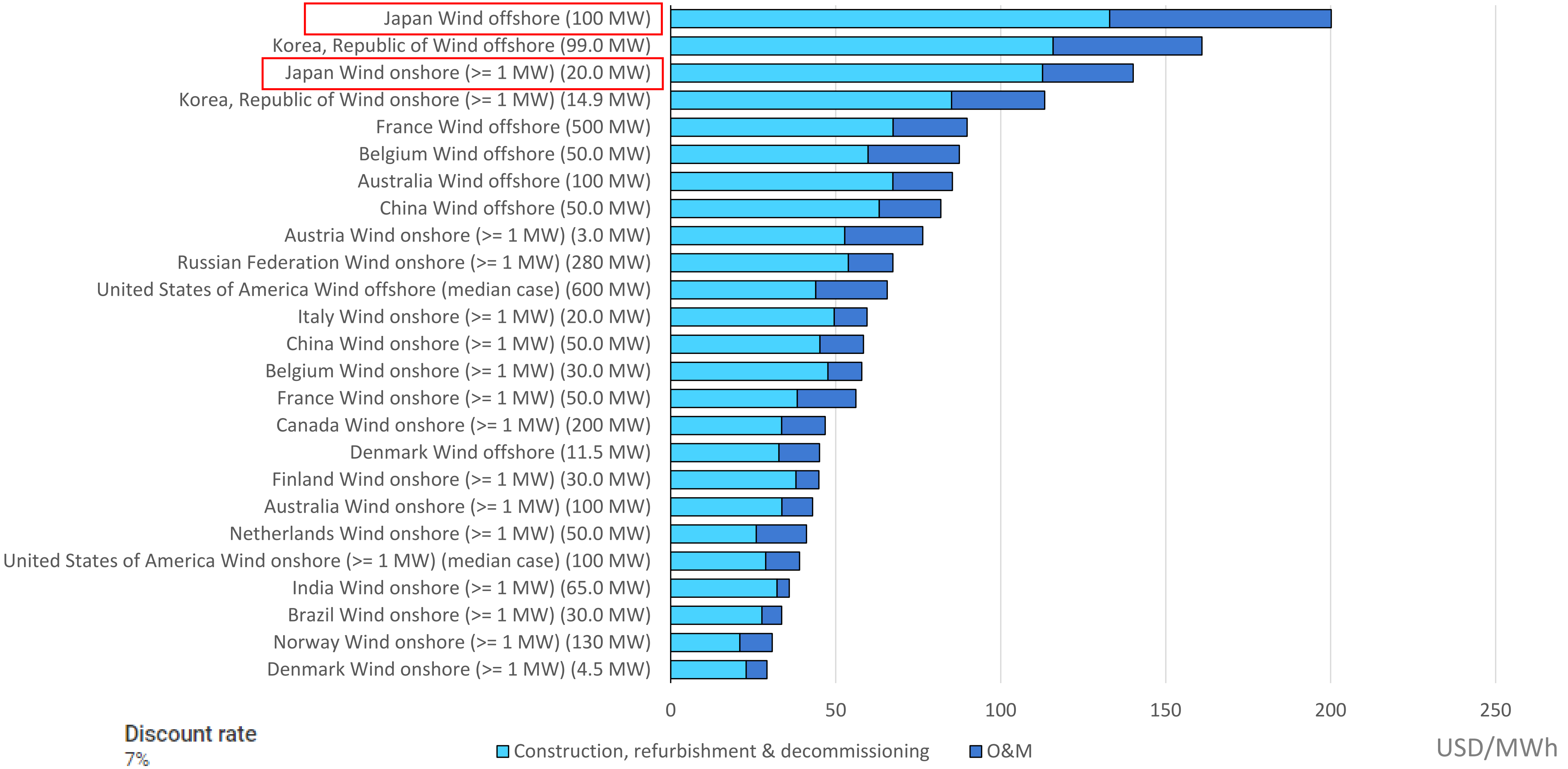
Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

Competiveness depends on national and local conditions: median technology costs by region

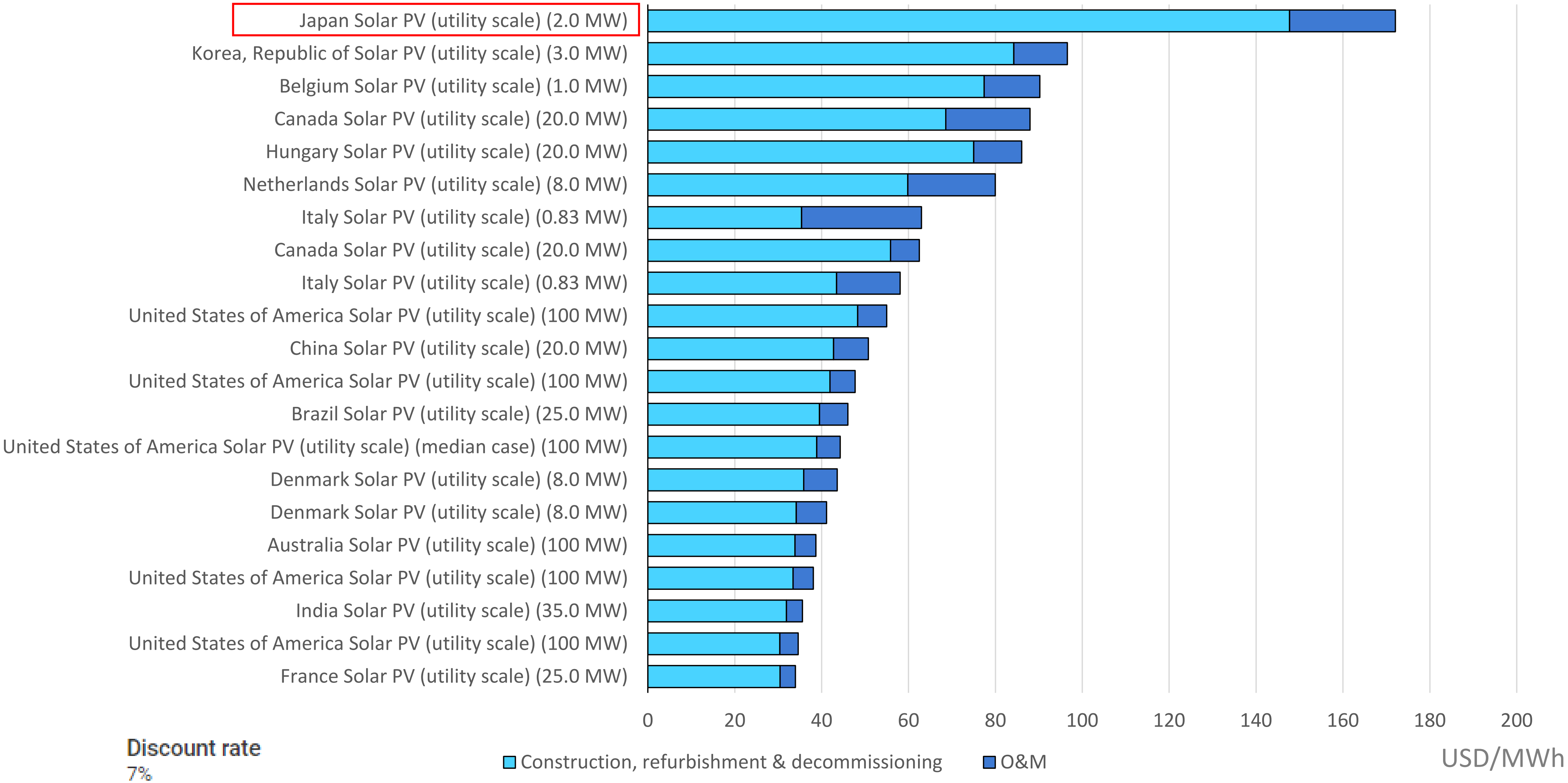


Note: Values at 7% discount rate.

In Japan, renewable energies continue to have high LCOEs

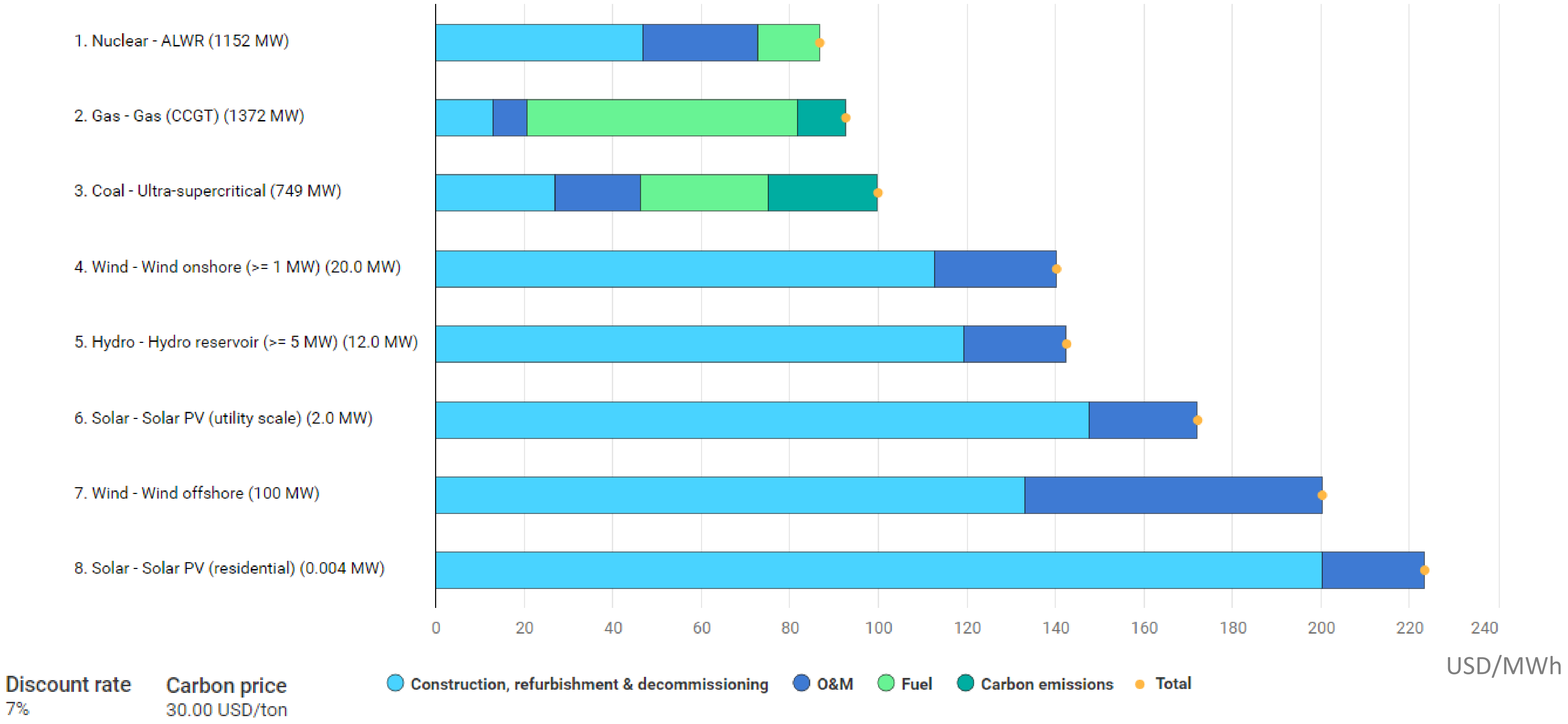


In Japan, renewable energies continue to have high LCOEs



Discount rate
7%

In Japan, renewable energies continue to have high LCOEs



International Energy Agency

System costs are important to show the full picture

NEA NUCLEAR ENERGY AGENCY

- LCOE is a well-known, relatively simple and transparent metric for comparing baseload technologies under a set of common assumptions.
- However, LCOE neglects the *system contribution* of different technologies, which depends on variability, dispatchability, response time, cost structure and place in the merit order, but also on system configuration and flexibility resources.
- In particular, increasing amounts of variable wind and solar PV capacity impact the load factors and LCOE of flexible technologies such as gas, coal or nuclear, which remain indispensable as dispatchable back-up.
- The system contribution of VRE declines with their share in the mix as shown by their average remuneration per MWh. This is due to the autocorrelation of generators with zero variable costs.
- Optimised least cost electricity systems thus require system-level analysis (IEA 2019, NEA 2019).
- To assess system contribution, the IEA has reported value adjusted LCOE (VALCOE) for existing brownfield systems in three regions.

Storage

- Increasing shares of variable renewables in the energy mix increase the volatility of electricity prices and therefore trigger demand for flexibility and balancing options.
- Falling investment costs, for example for battery units, are already making short-term storage an economically attractive option in some niche applications (e.g., ancillary services markets).
- In markets with shares of VRE and thus more volatile electricity prices, storage could become an attractive alternative to peaking units such as open cycle gas turbines.
- Long-term storage, such as seasonal storage remains elusive. Here dispatchable low carbon generators such as hydropower or nuclear energy are required.
- Future low carbon systems will work with a mix of flexibility options such as storage, demand response and dispatchable low carbon generation.
- *Projected Costs of Generating Electricity: 2020 Edition* for the first time includes the levelised cost of storage (LCOS) as well as an in-depth methodological discussion in Chapter 6.

iea International Energy Agency

Storage (continued)

NEA NUCLEAR ENERGY AGENCY

Table 3.18: Levelised cost of electricity for storage technologies

Country	Technology	Net capacity (MWe)	Storage capacity**** (h)	Capacity factor (%)	Investment (USD/MWh)			Decommissioning (USD/MWh)			Charging Costs (USD/MWh)	O&M (USD/MWh)	LCOS (RAOP*) (USD/MWh)			Country
					3%	7%	10%	3%	7%	10%			3%	7%	10%	
Australia	Pumped storage	200	na	15%	22.59	47.98	68.27	0.10	0.01	0.00	0	3.41	**26.11**	**51.40**	**71.68**	**Australia**
Canada	ACAES***	250	4	15%	51.65	100.17	143.55	2.51	1.99	1.70	0	12.71	**66.88**	**114.87**	**157.96**	**Canada**
Denmark	Lithium-ion battery	19	0.33	15%	43.19	52.46	59.96	1.54	1.21	1.00	0	2.73	**47.46**	**56.39**	**63.70**	**Denmark**
	Pumped storage	1 000	na	15%	111.54	236.86	337.03	0.50	0.05	0.01	0	8.08	**120.13**	**245.00**	**345.12**	
Finland	Lithium-ion battery	1.14	5.26	15%	175.52	213.17	243.66	6.25	4.90	4.08	0	19.03	**200.79**	**237.09**	**266.76**	**Finland**
Italy	Lithium-ion battery	2	0.5	15%	40.34	48.99	56.00	1.44	1.13	0.94	0	6.85	**48.62**	**56.97**	**63.79**	**Italy**
Non-OECD countries																**Non-OECD countries**
India	Lithium-ion battery	1	na	15%	73.70	89.51	102.31	1.80	1.41	1.17	0	12.57	**88.07**	**103.49**	**116.06**	**India**
	Pumped storage	175	4	15%	14.18	30.12	42.86	0.03	0.00	0.00	0	10.71	**24.93**	**40.83**	**53.57**	

* The required average operational profit (RAOP) is the required total operational profit (OP**) on a per unit of discharged energy basis.
** The total required operational profit (OP) is the total required revenue from discharging electricity minus the total cost from charging electricity.
*** Adiabatic Compressed Air Energy storage.
**** Without specific data available, the storage capacity was set at 4 hours by default.

iea International Energy Agency

Nuclear power

NEA NUCLEAR ENERGY AGENCY

Table 3.13a: Levelised cost of electricity for nuclear plants at 85% capacity factor – New build

Country	Technology	Net capacity (MWe)	Electrical conversion efficiency (%)	Investment (USD/MWh)			Decommissioning (USD/MWh)			Fuel (USD/MWh)	O&M (USD/MWh)	LCOE (USD/MWh)			Country
				3%	7%	10%	3%	7%	10%			3%	7%	10%	
France	EPR	1 650	33%	21.32	47.46	73.29	0.36	0.05	0.01	9.33	14.26	45.27	71.10	96.89	France
Japan	ALWR	1 152	33%	21.05	46.87	72.37	0.36	0.05	0.01	13.92	25.84	61.16	86.67	112.13	Japan
Korea	ALWR	1 377	36%	11.46	25.51	39.39	0.20	0.03	0.01	9.33	18.44	39.42	53.30	67.16	Korea
Russia	VVER	1 122	38%	12.06	26.86	41.47	0.21	0.03	0.01	4.99	10.15	27.41	42.02	56.61	Russia
Slovak Republic	Other nuclear	1 004	32%	36.76	81.84	126.37	1.80	0.96	0.64	9.33	9.72	57.61	101.84	146.06	Slovak Republic
United States	LWR	1 100	33%	22.58	50.26	77.61	0.39	0.05	0.01	9.33	11.60	43.90	71.25	98.56	United States
Non-OECD countries															**Non-OECD countries**
China	LWR	950	33%	13.28	29.57	45.65	0.22	0.03	0.01	10.00	26.42	49.92	66.01	82.08	China
India	LWR	950	33%	14.76	32.85	50.73	0.25	0.03	0.01	9.33	23.84	48.17	66.06	83.91	India

Table 3.13b1: Levelised cost of electricity for nuclear plants at 85% capacity factor – Long-Term Operation (LTO), 10 years

Country	Technology	Net capacity (MWe)	Electrical conversion efficiency (%)	Investment (USD/MWh)			Decommissioning* (USD/MWh)			Fuel (USD/MWh)	O&M (USD/MWh)	LCOE (USD/MWh)			Country
				3%	7%	10%	3%	7%	10%			3%	7%	10%	
Switzerland	LTO	1 000	33%	8.79	10.88	12.62	0.71	0.40	0.27	9.33	12.92	31.74	33.53	35.13	Switzerland
France	LTO	1 000	33%	10.05	12.45	14.44	0.81	0.46	0.30	9.33	12.92	33.11	35.15	36.98	France
Sweden	LTO	1 000	33%	7.10	8.79	10.19	0.57	0.32	0.21	9.33	12.92	29.91	31.35	32.65	Sweden
United States	LTO	1 000	33%	6.25	7.74	8.97	0.51	0.28	0.19	9.33	18.69	34.78	36.04	37.18	United States

Table 3.13b2: Levelised cost of electricity for nuclear plants at 85% capacity factor – Long-Term Operation (LTO), 20 years

Country	Technology	Net capacity (MWe)	Electrical conversion efficiency (%)	Investment (USD/MWh)			Decommissioning* (USD/MWh)			Fuel (USD/MWh)	O&M (USD/MWh)	LCOE (USD/MWh)			Country
				3%	7%	10%	3%	7%	10%			3%	7%	10%	
Switzerland	LTO	1 000	33%	5.04	7.22	9.11	0.29	0.13	0.07	9.33	12.92	27.57	29.59	31.43	Switzerland
France	LTO	1 000	33%	5.76	8.25	10.42	0.34	0.15	0.08	9.33	12.92	28.35	30.65	32.74	France
Sweden	LTO	1 000	33%	4.07	5.83	7.35	0.23	0.10	0.06	9.33	12.92	26.54	28.17	29.66	Sweden
United States	LTO	1 000	33%	3.58	5.13	6.48	0.21	0.09	0.05	9.33	18.69	31.81	33.24	34.55	United States

International Energy Agency

Nuclear power (continued)

NEA NUCLEAR ENERGY AGENCY

Table 3.22a: Levelised cost of electricity for nuclear technologies at 50% capacity factor – New Build

Country	Technology	Net capacity (MWe)	Electrical conversion efficiency (%)	Investment (USD/MWh)			Decommissioning (USD/MWh)			Fuel (USD/MWh)	O&M (USD/MWh)	LCOE (USD/MWh)			Country
				3%	7%	10%	3%	7%	10%			3%	7%	10%	
France	EPR	1 650	33%	36.24	80.69	124.6	0.62	0.08	0.02	9.33	15.12	61.31	105.22	149.06	France
Japan	ALWR	1 152	33%	35.79	79.67	123	0.61	0.08	0.02	13.92	43.92	94.24	137.6	180.9	Japan
Korea	ALWR	1 377	36%	19.48	43.37	66.97	0.33	0.05	0.01	9.33	30.48	59.63	83.23	106.8	Korea
Russia	VVER	1 122	38%	20.51	45.7	70.5	0.35	0.05	0.01	4.99	15.77	41.61	66	91.3	Russia
Slovak Republic	Other nuclear	1 004	32%	62.49	139.13	214.8	3.07	1.63	1.09	9.33	15.87	90.76	166.0	241.1	Slovak Republic
United States	LWR	1 100	33%	38.38	85.45	131.9	0.66	0.09	0.02	9.33	18.47	66.83	113.33	159.76	United States
Non-OECD countries															**Non-OECD countries**
China	LWR	950	33%	22.58	50.26	77.6	0.38	0.05	0.01	10.00	34.41	67.36	94.72	122.03	China
India	LWR	950	33%	25.08	55.85	86	0.42	0.06	0.01	9.33	31.83	66.67	97.1	127.4	India

Table 3.22b1: Levelised cost of electricity for nuclear technologies at 50% capacity factor – Long-Term Operation (LTO), 10 years

Country	Technology	Net capacity (MWe)	Electrical conversion efficiency (%)	Investment (USD/MWh)			Decommissioning* (USD/MWh)			Fuel (USD/MWh)	O&M (USD/MWh)	LCOE (USD/MWh)			Country
				3%	7%	10%	3%	7%	10%			3%	7%	10%	
Switzerland	LTO	1 000	33%	14.94	18.50	21.5	1.21	0.68	0.45	9.33	20.91	46.39	49.42	52.15	Switzerland
France	LTO	1 000	33%	17.09	21.16	25	1.38	0.78	0.52	9.33	20.91	48.71	52.18	55.29	France
Sweden	LTO	1 000	33%	12.06	14.94	17.3	0.98	0.55	0.36	9.33	20.91	43.27	45.73	47.92	Sweden
United States	LTO	1 000	33%	10.62	13.15	15	0.86	0.49	0.32	9.33	30.72	51.54	53.69	55.63	United States

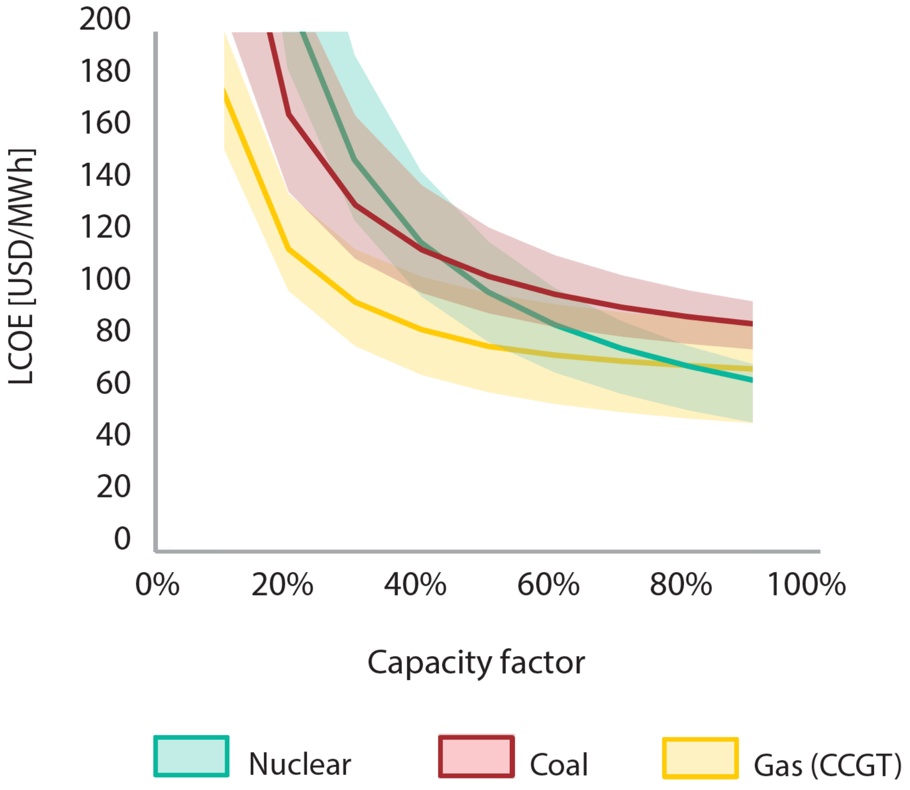
Table 3.22b2: Levelised cost of electricity for nuclear technologies at 50% capacity factor – Long-Term Operation (LTO), 20 years

Country	Technology	Net capacity (MWe)	Electrical conversion efficiency (%)	Investment (USD/MWh)			Decommissioning* (USD/MWh)			Fuel (USD/MWh)	O&M (USD/MWh)	LCOE (USD/MWh)			Country
				3%	7%	10%	3%	7%	10%			3%	7%	10%	
Switzerland	LTO	1 000	33%	8.57	12.27	15.5	0.49	0.22	0.12	9.33	20.91	39.29	42.72	45.84	Switzerland
France	LTO	1 000	33%	9.80	14.03	18	0.58	0.26	0.14	9.33	20.91	40.62	44.53	48.09	France
Sweden	LTO	1 000	33%	6.92	9.90	12.5	0.40	0.18	0.10	9.33	20.91	37.55	40.32	42.84	Sweden
United States	LTO	1 000	33%	6.09	8.72	11	0.35	0.16	0.09	9.33	30.72	46.50	48.93	51.15	United States

International Energy Agency

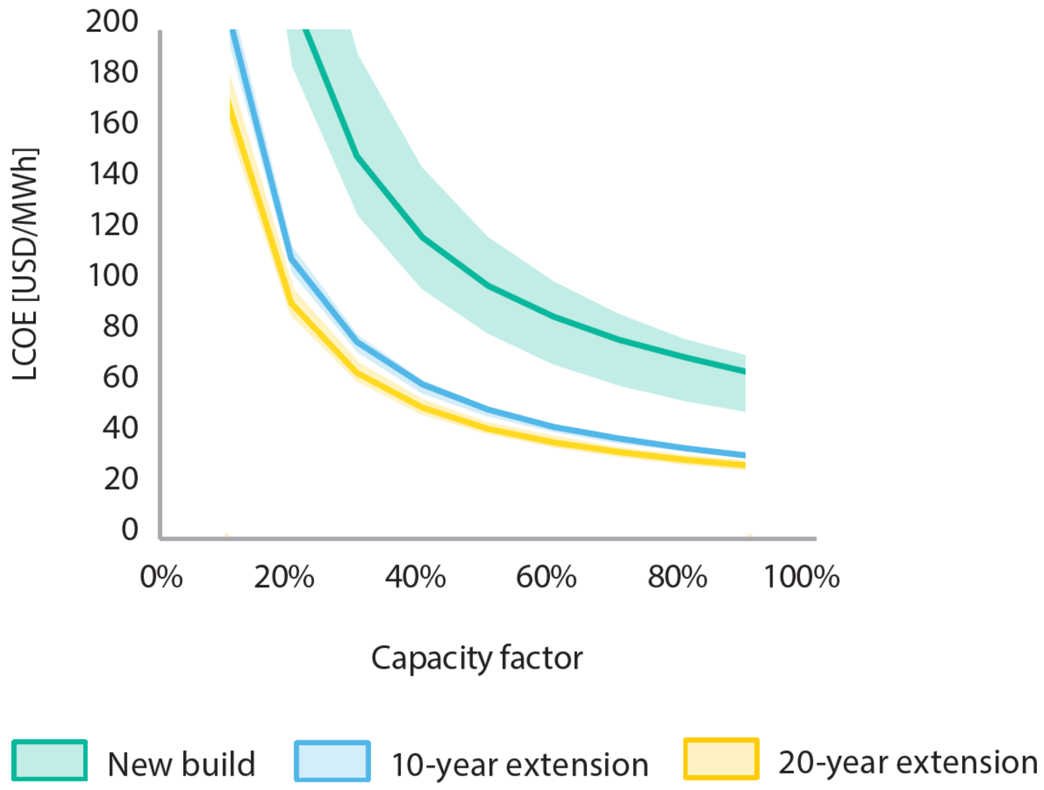
NUCLEAR ENERGY AGENCY

Generation costs critically depend on the capacity factor



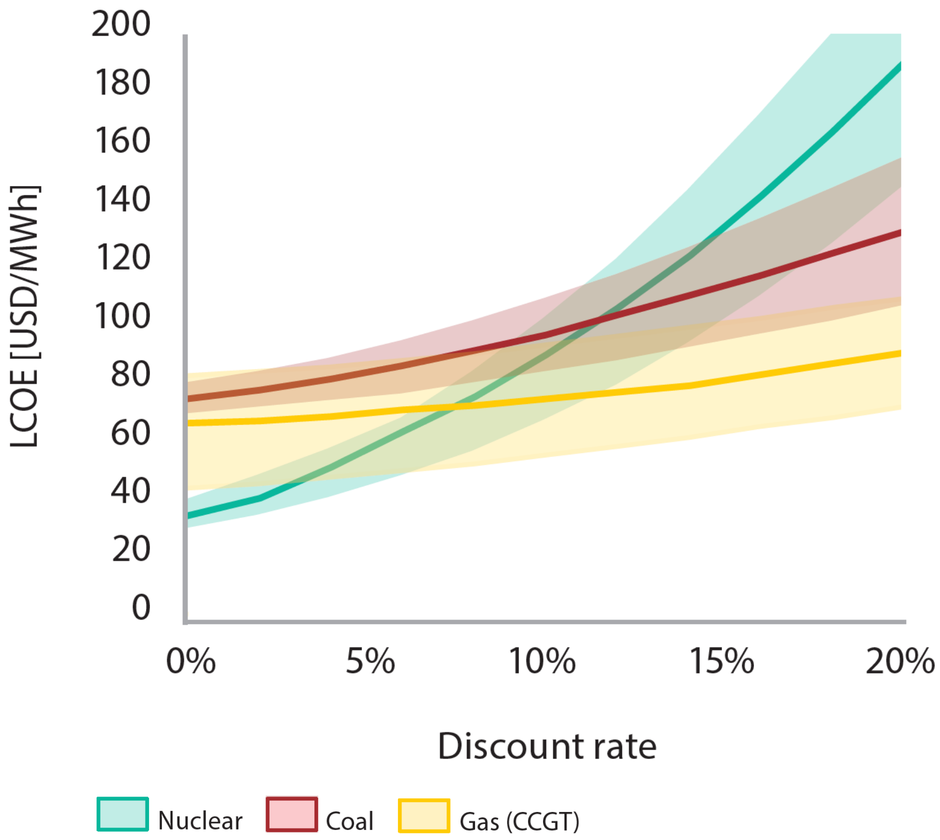
Note: Values at 7% discount rate. Lines indicate median values, areas the 50% central region.

Nuclear long-term operation (LTO) with low costs even with low capacity factors



Note: Values at 7% discount rate. Lines indicate median values, areas the 50% central region

Technologies to different extents exposed to financing costs



Note: Values at 7% discount rate. Lines indicate median values, areas the 50% central region

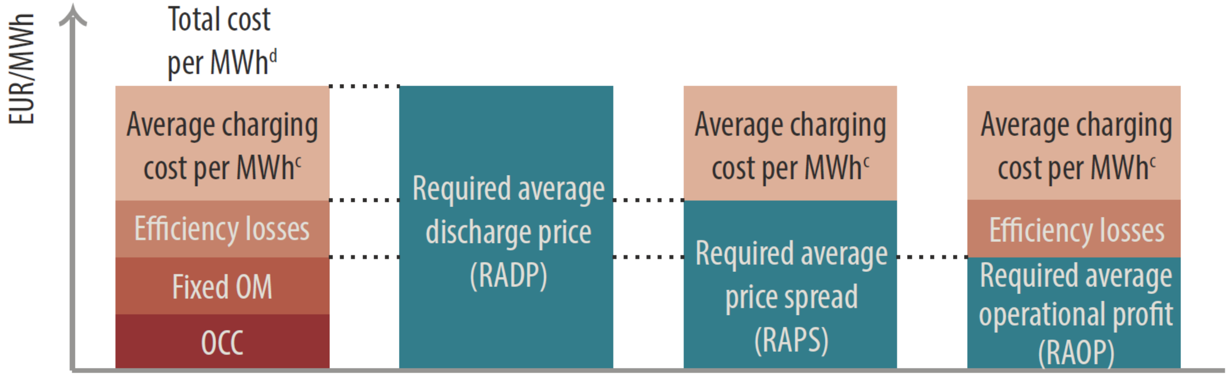
Chapter 6: The levelised costs of storage (LCOS)

In addition to a host of empirical information, Chapter 6 considers the following three storage cost metrics:

(1) The required average operational profit (RAOP), which is similar to traditional LCOE, *i.e.*, the constant price required to recuperate costs assuming that charging costs are zero and that there are no efficiency losses;

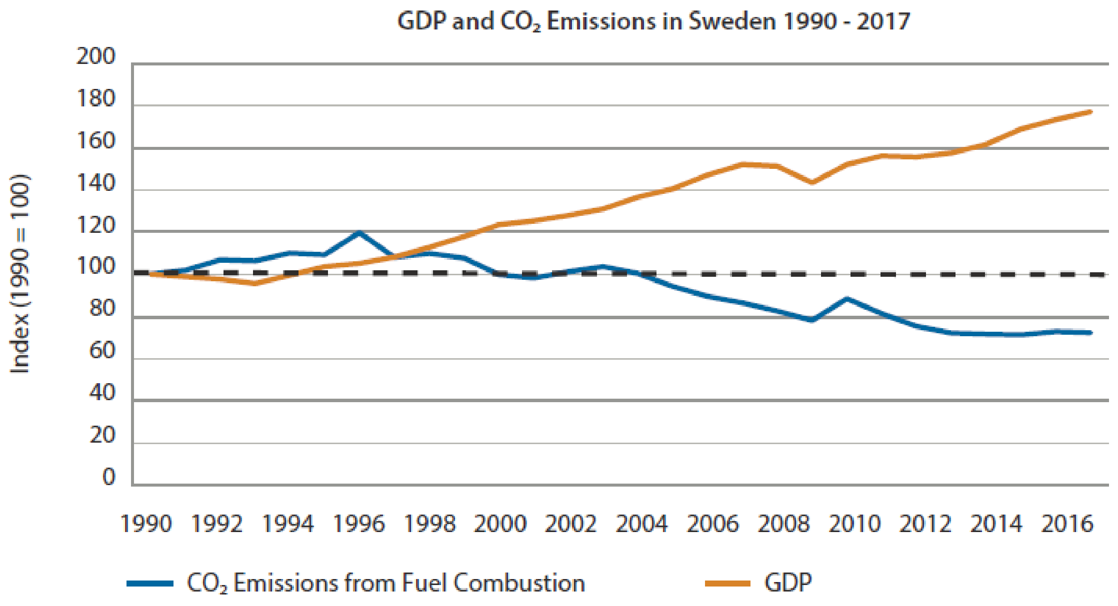
(2) The required average price spread (RAPS) is similar to the RAOP but includes also the round-trip efficiency losses when charging and discharging; and

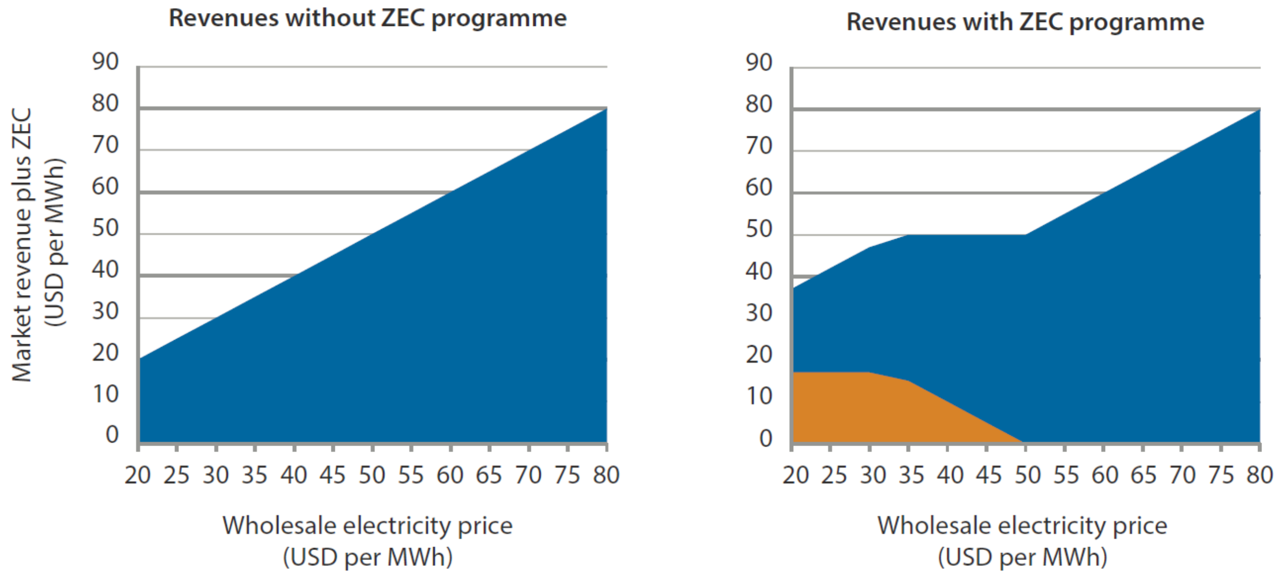
(3) The required average discharge price (RADP) includes charging costs and thus corresponds to the difference required to break even between the average price obtained for discharged electricity and the average cost of electricity used for charging.



Chapter 7: Carbon pricing and zero emission credits

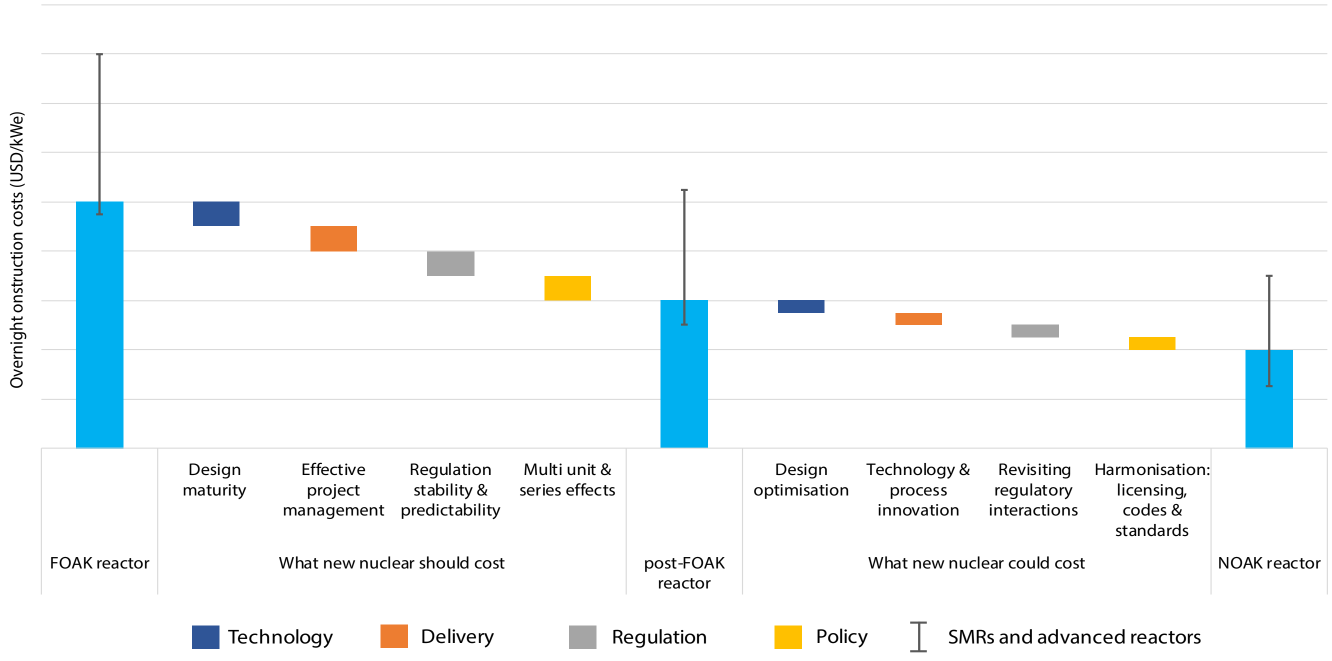
- Shows how different forms of carbon pricing (taxes, emissions trading, fixed or sliding feed-in premia etc.) serve to render explicit the differences in the full cost of different generation technologies.
- Considers Swedish experience of decoupling GDP from CO2 emissions following the introduction of a carbon tax in 1991.
- Includes case study of US experience of remunerating low carbon generation with zero emission credits (ZECs).
- Provides evidence of impact of emission trading under the EU ETS on the inframarginal rents of low carbon and fossil generators on Germany and France under both grandfathering and auctioning.





Chapter 8: A perspective on the costs of existing and new nuclear power plants

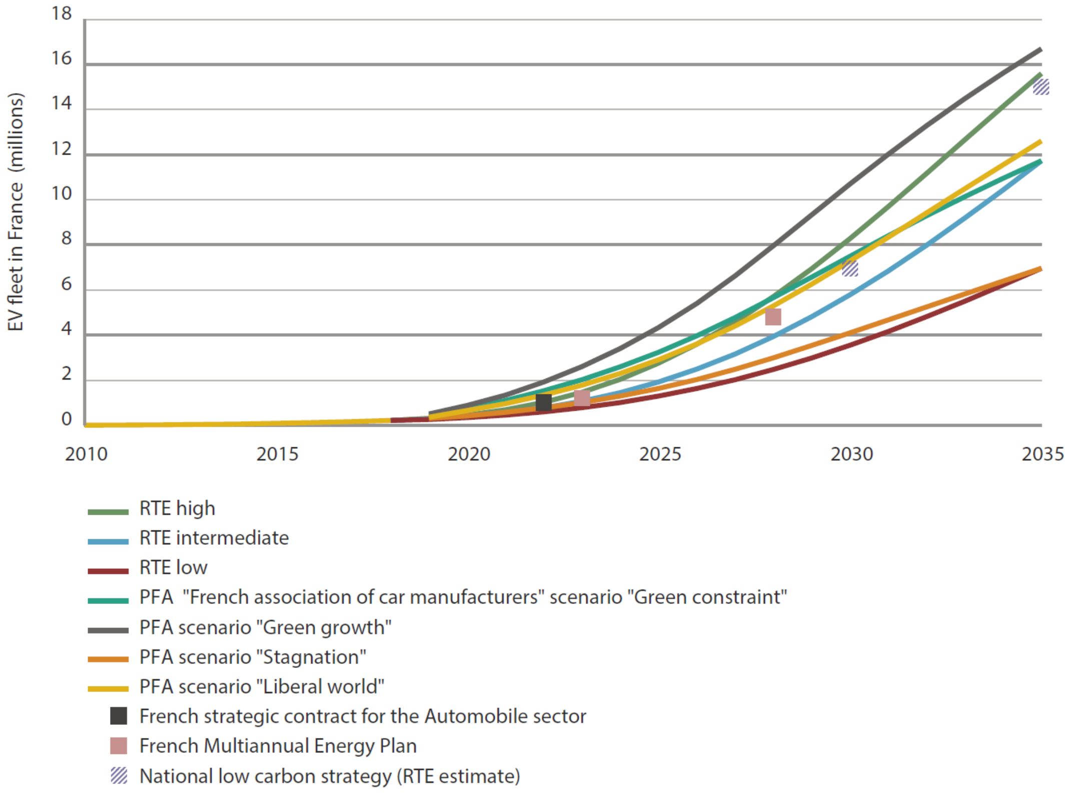
- Long-term operation (LTO) of existing nuclear power plants: today the most cost-effective solution for low carbon generation but the pool of projects is limited (see NEA, forthcoming 2021).
- Construction of new nuclear power plants (Gen-III reactors): cost reductions are realized as projects move past FOAK (see NEA (2020) *Unlocking Reductions in the Construction Costs of Nuclear* and figure below on drivers of cost reductions).
- Technology innovation through SMRs: new technical features promise cost reduction. However, challenges need to be overcome to reach commercial viability.



Chapter 9: Sector coupling and electrification – Understanding how the electricity sector can drive decarbonisation of the overall economy

- Overview of recent advances in analysing and understanding the impacts, benefits and constraints of sector coupling, contributed by the French transmission system operator RTE, followed by study results regarding
  - Electric mobility
  - Power-to-hydrogen
  - Heating in buildings

Projected changes in the numbers of light-duty electric vehicles in France

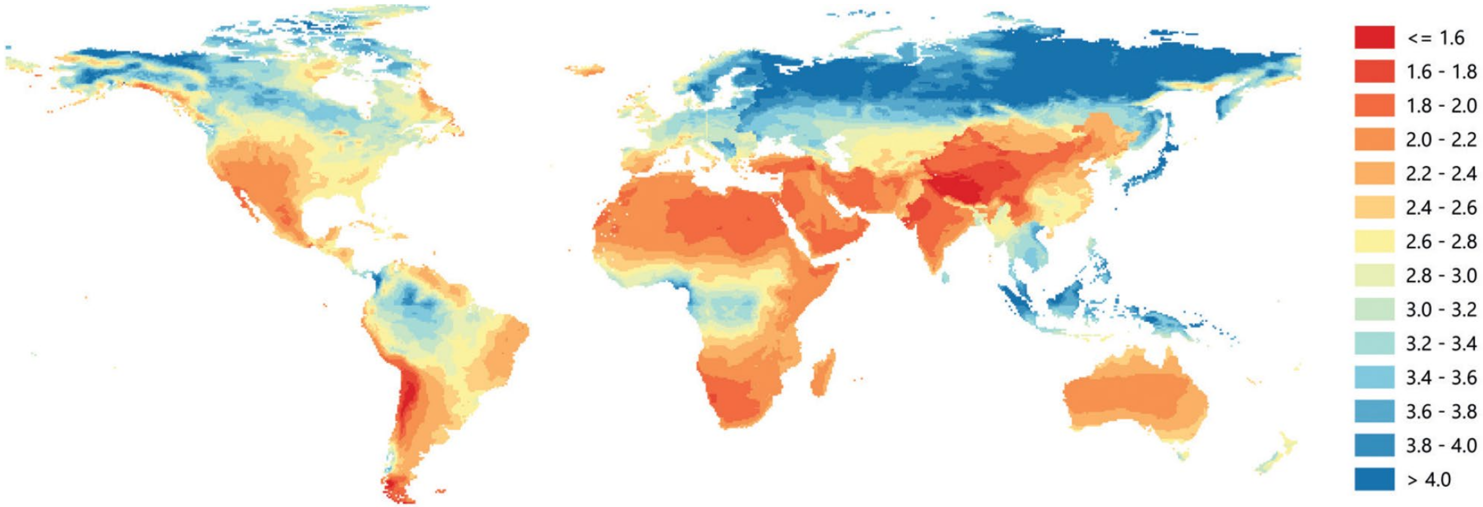


Chapter 10: Hydrogen – An opportunity for the power sector

➢Based on the 2019 IEA report *The Future of Hydrogen: Seizing Today's Opportunities*

- Hydrogen demand today and potential for the future: Industry, road transport and domestic heat
- Hydrogen production technologies and costs today and in the future: Using gas, coal and electricity
- Linkages to the electricity system: Integration of variable renewables, long-term storage and hydrogen as a fuel for electricity generation.

Hydrogen costs from hybrid solar PV-onshore wind systems in the long term (USD/kg H2)



Summary: Key points of *Projected Costs of Generating Electricity: 2020 Edition*

- Low carbon generation now fully cost competitive
  1) Holds for variable renewables such as wind and solar PV as well as for dispatchable low carbon generators hydro and nuclear
  2) LTO lowest cost option not only for low carbon but all power generation
  3) At modest carbon price of USD 30 per tonne of CO_2, unmitigated coal is no longer competitive.
  4) CCUS would require considerably higher carbon prices to become competitive.
- Regional differences remain important
- Largest overall number of submissions for *Projected Cost series*
- Includes for the first time
  1) Costs data on storage, fuel cells and nuclear LTO
  2) System approach
- Conceptual boundary chapters on LCOS (new methodology) and carbon pricing (new policies)
- Thematic boundary chapters on new nuclear, sector coupling and hydrogen.

Download the report

www.oecd-nea.org/egc-2020

or

www.iea.org/reports/projected-costs-of-generating-electricity-2020

LCOE calculators

www.iea.org/articles/levelised-cost-of-electricity-calculator

or

www.oecd-nea.org/lcoe

Thank you!

Contact: report@tky.ieej.or.jp