ORDEM DOS ENGENHEIROS

WORLD ENGINEERING DAY FOR SUSTAINABLE DEVELOPMENT

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Under the High Patronage of the
President of the Portuguese Republic

O Presidente da República

Lisbon

March 4th 2024

Engineering Solutions for a Sustainable World

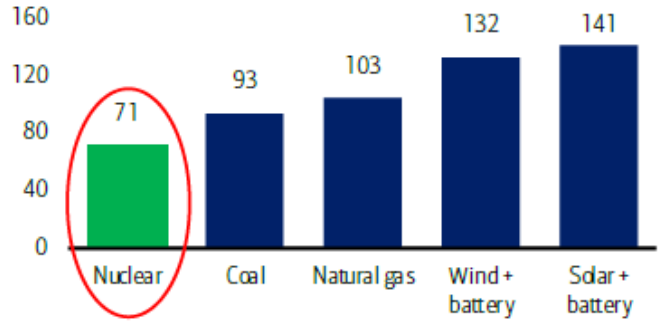
Ordem dos Engenheiros

The Future of Nuclear Energy in Europe

Pedro Sampaio Nunes

High costs for managing renewables intermitency…

Cost of generation, different sources ($/MWh)



Source: BofA Research Investment Committee, Lazard, Entler, et al. (2018). Note: nuclear, coal, and natural gas price estimates from Entler, et al. Wind and solar cost estimates are from Lazard's 2023 Levelized Cost of Energy+ report. Wind + battery and solar + battery use estimates from California's Independent System Operator (CAISO) and assume a 4-hour lithium-ion battery storage system to account for firming costs. All cost estimates show unsubsidized costs.

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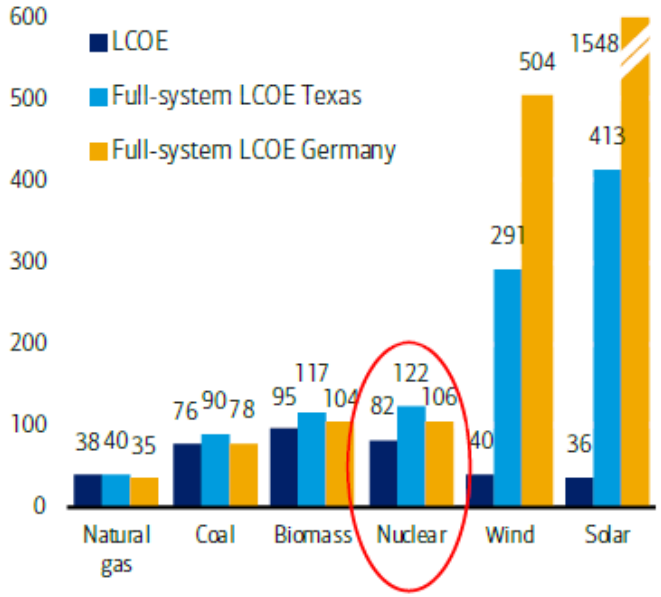
LCOE & LFSCOE calculations by energy source



Source: BofA Research Investment Committee, Idel 2022

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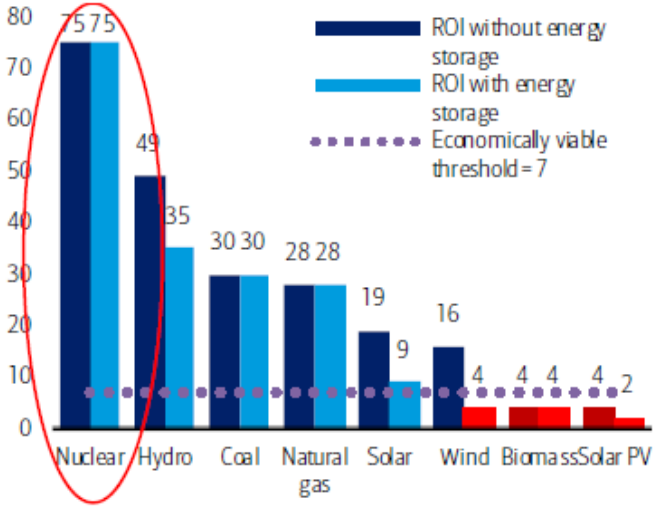
Energy returned on energy invested, by source



Source: BofA Research Investment Committee, D. Weißbach, G. Ruprecht, A. Huke, K. Czerski, S. Gottlie, A. Hussein; Red signals EROI below economically viable threshold

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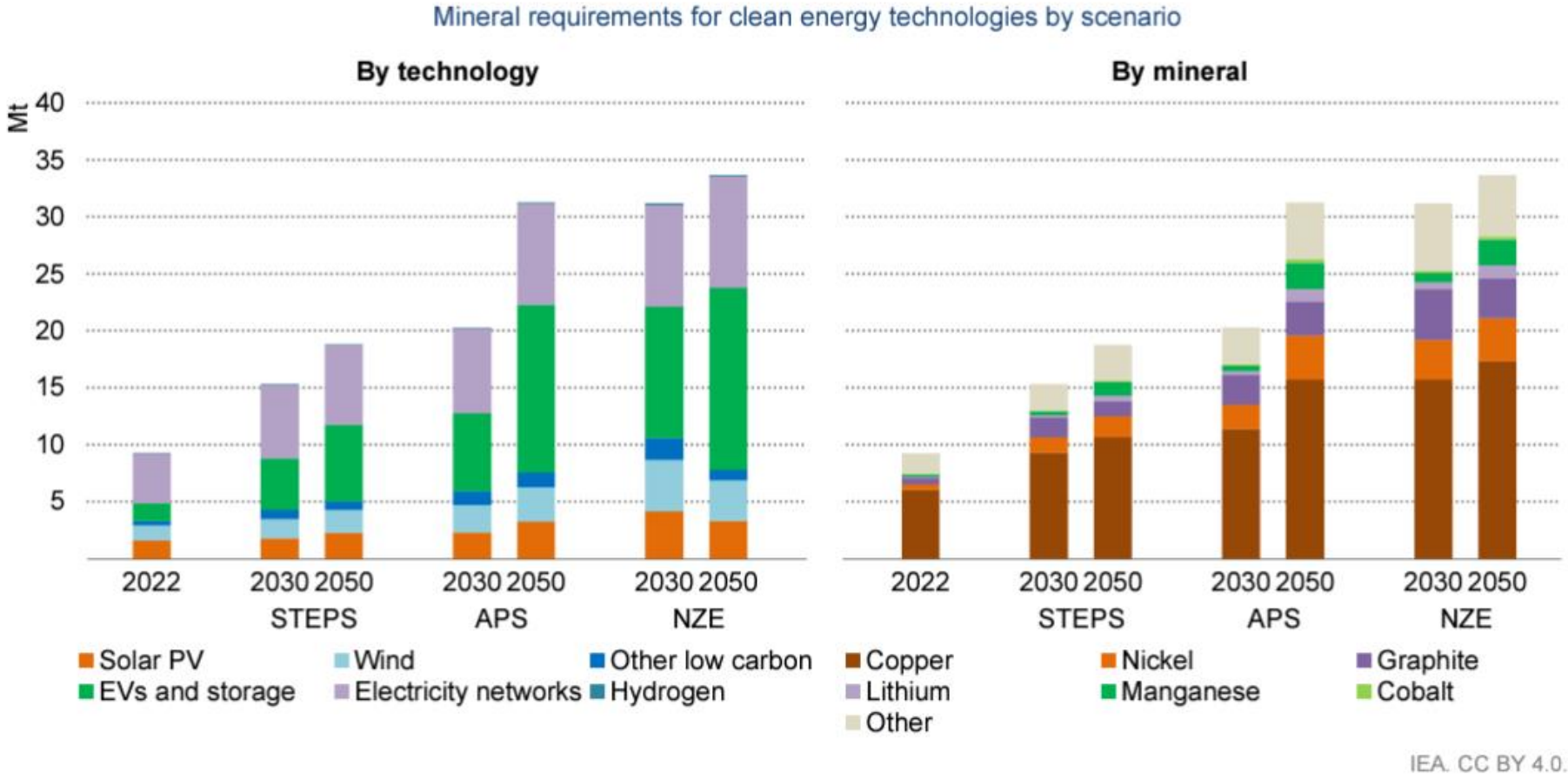
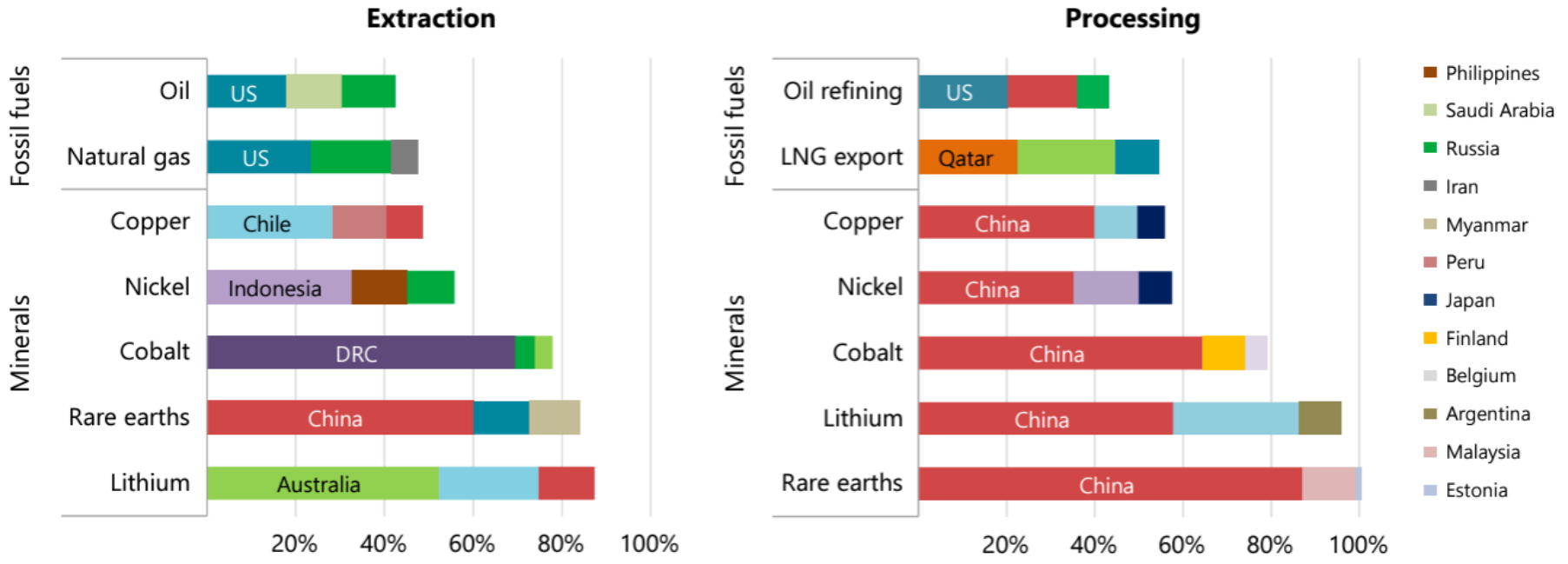
And huge mining needs due to low energy density of renewables…

Critical minerals demand for clean energy is set to grow by up to three-and-a-half times over the period to 2030 as the world moves through energy transitions



Currently largely dominated by China, in extraction, processing and end products …

Share of top three producing countries in production of selected minerals and fossil fuels, 2019



Production and processing of many minerals such as lithium, cobalt and some rare earth elements are geographically concentrated, with the top three producers accounting for more than 75% of supplies

Against a modest growth in mineral demand from nuclear power

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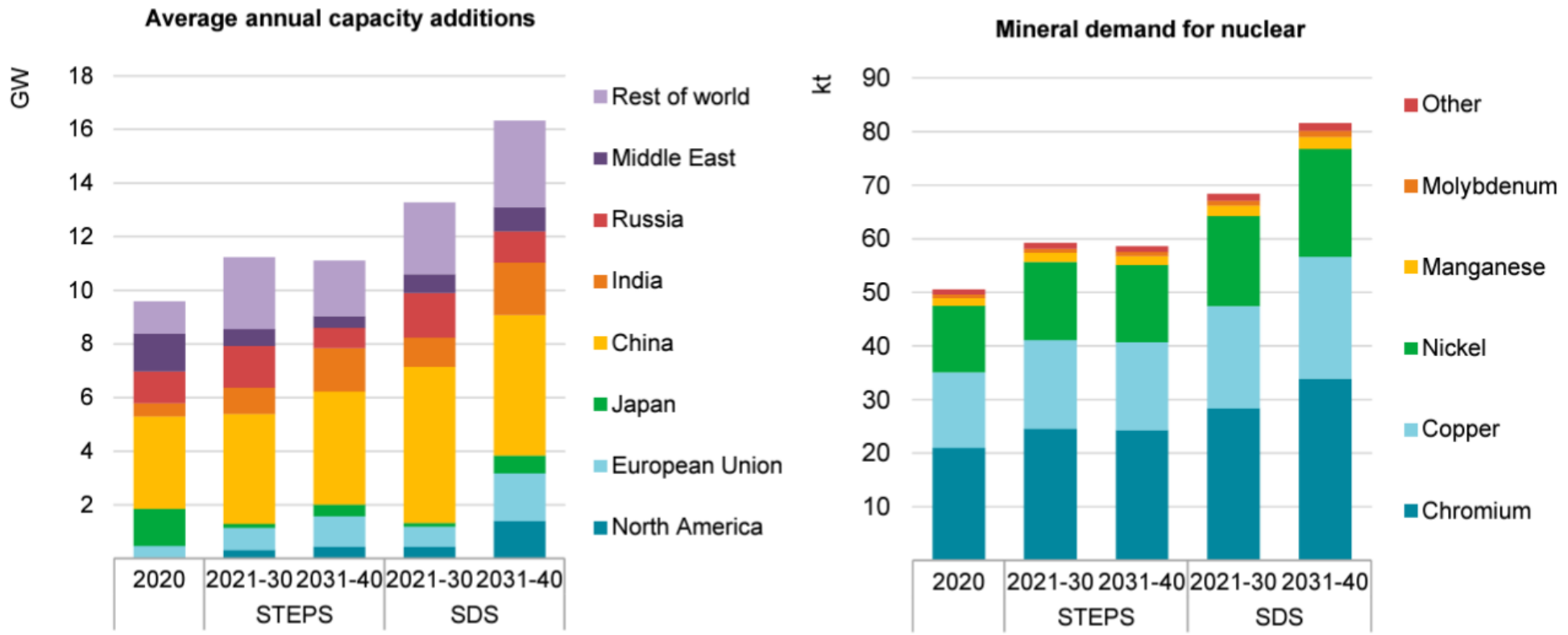
Average annual capacity additions and mineral demand from nuclear power



Note: Russia = Russian Federation.

And despite a huge investment in renewables, a disappoiting performance in emissions…

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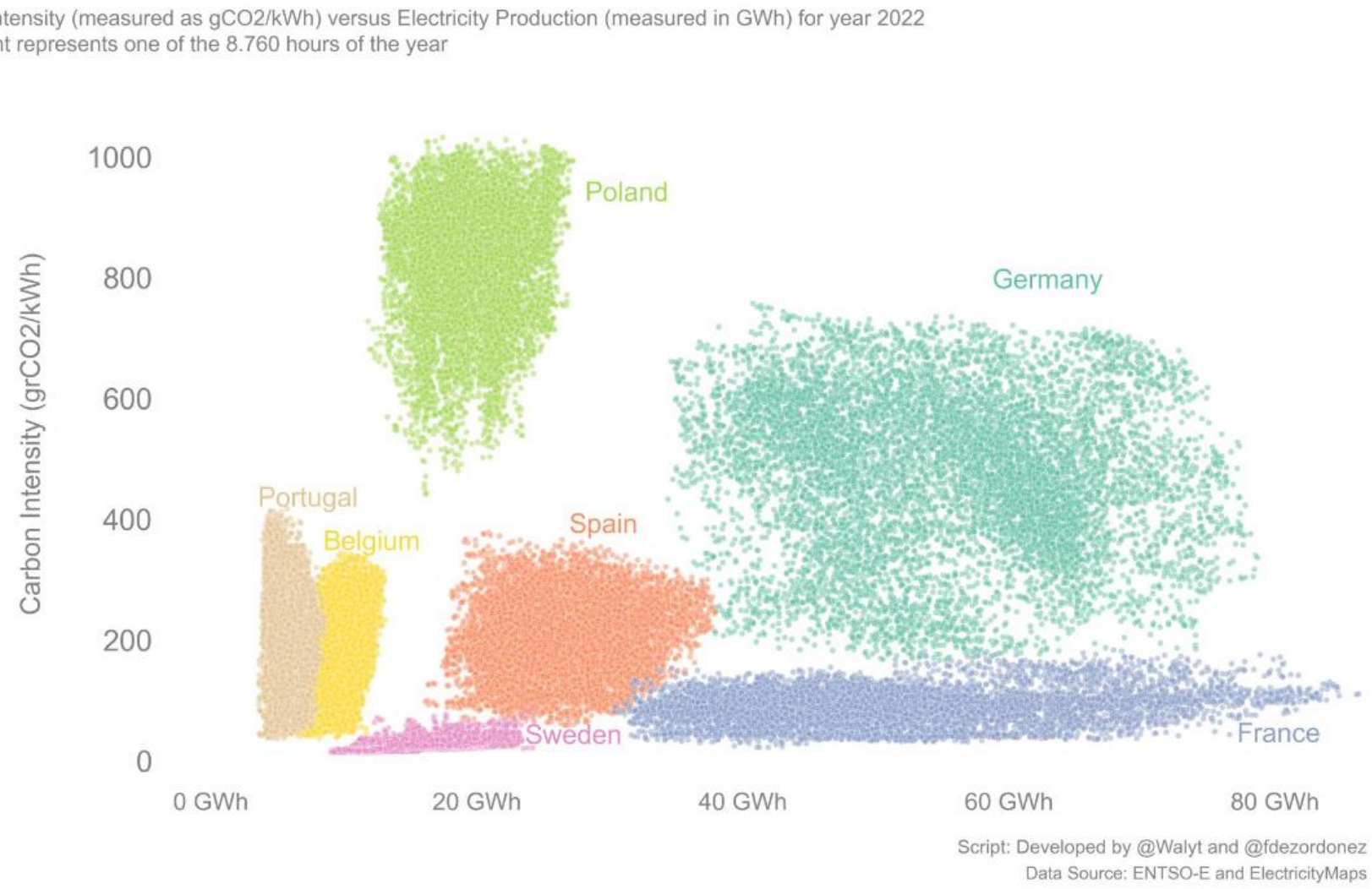

Recalling the effectiveness of the French nuclear program in reducing fossil fuels dependency …

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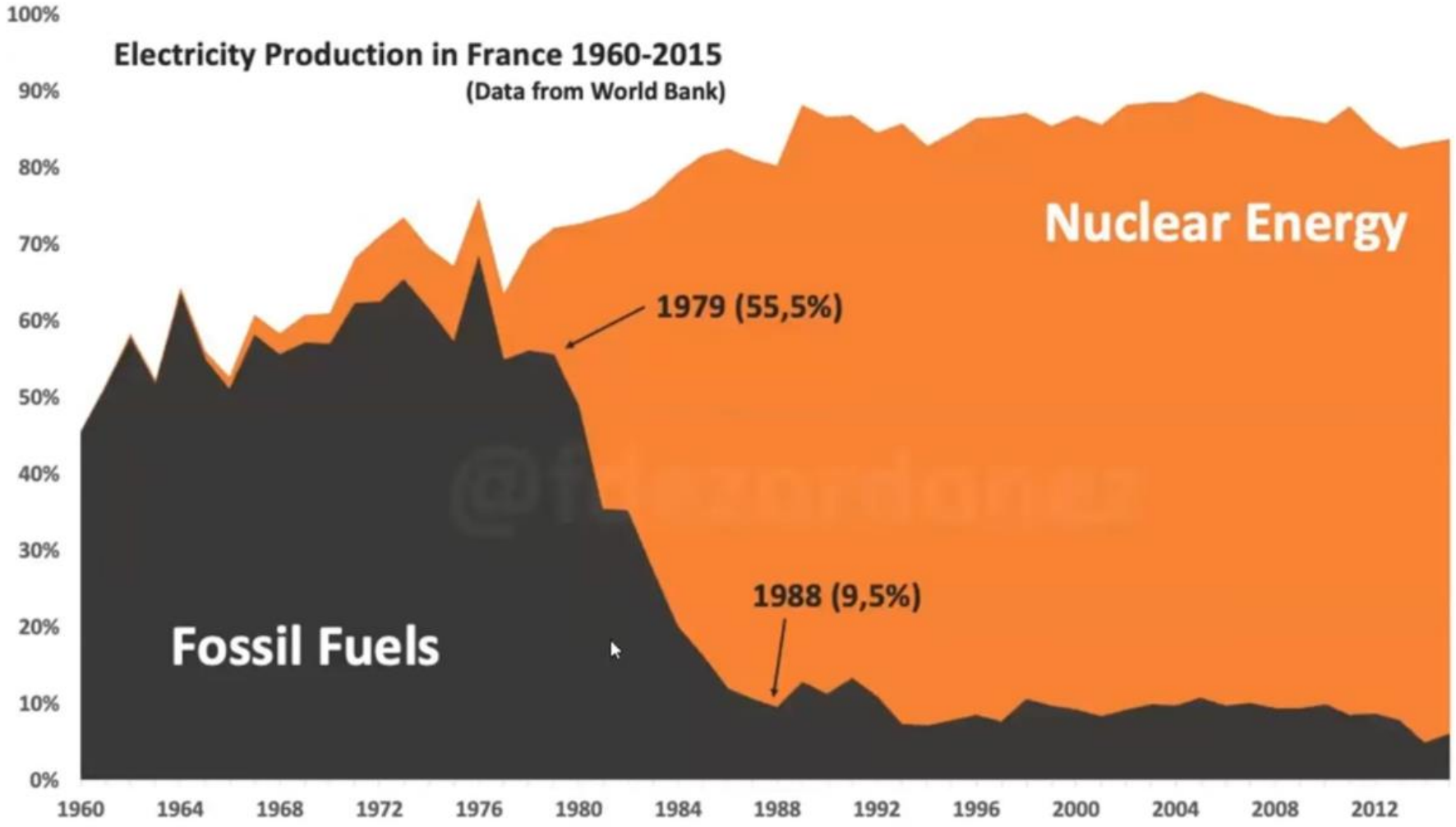

Are changing the nuclear landscape in Europe and in the World

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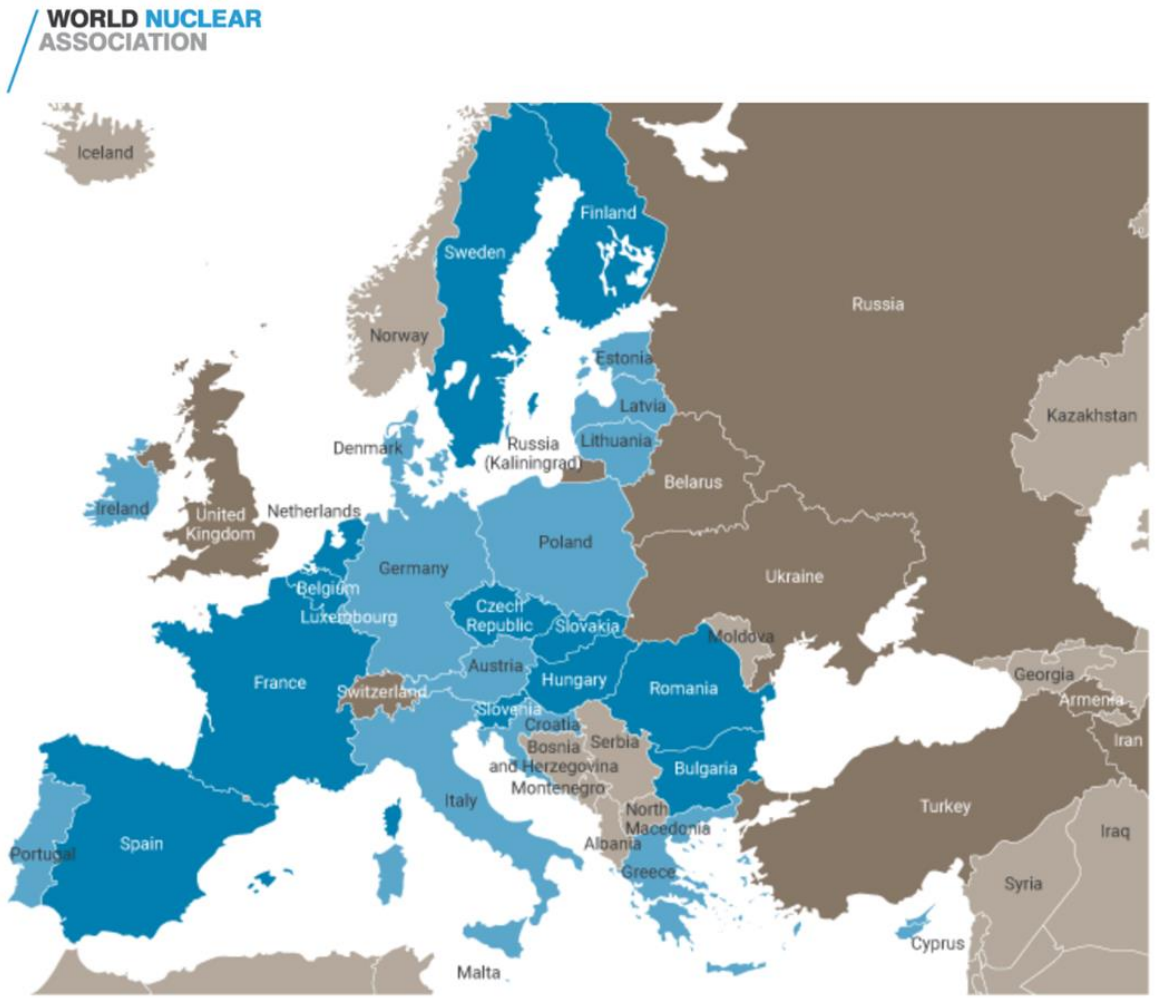

- EU member states with operating and / or under construction nuclear power plants (as of July 2022)
- EU member states without nuclear power plants
- Non-EU countries with operating and / or under construction nuclear power plants
- Non-EU countries without nuclear power plants

Nuclear Alliance: Belgium, Bulgaria, Croatia, Czech Republic, Estonia, Finland, France, Hungary, Netherlands, Poland, Romania, Slovenia, Slovakia, Sweden, United Kingdom as invitee and Italy as observer

The European Industrial Alliance on Small Modular Reactors (SMRs) aims to facilitate and accelerate the development, demonstration, and deployment of SMRs in Europe by the early 2030s.

Construction time: First concrete to commercial operation of last reactors

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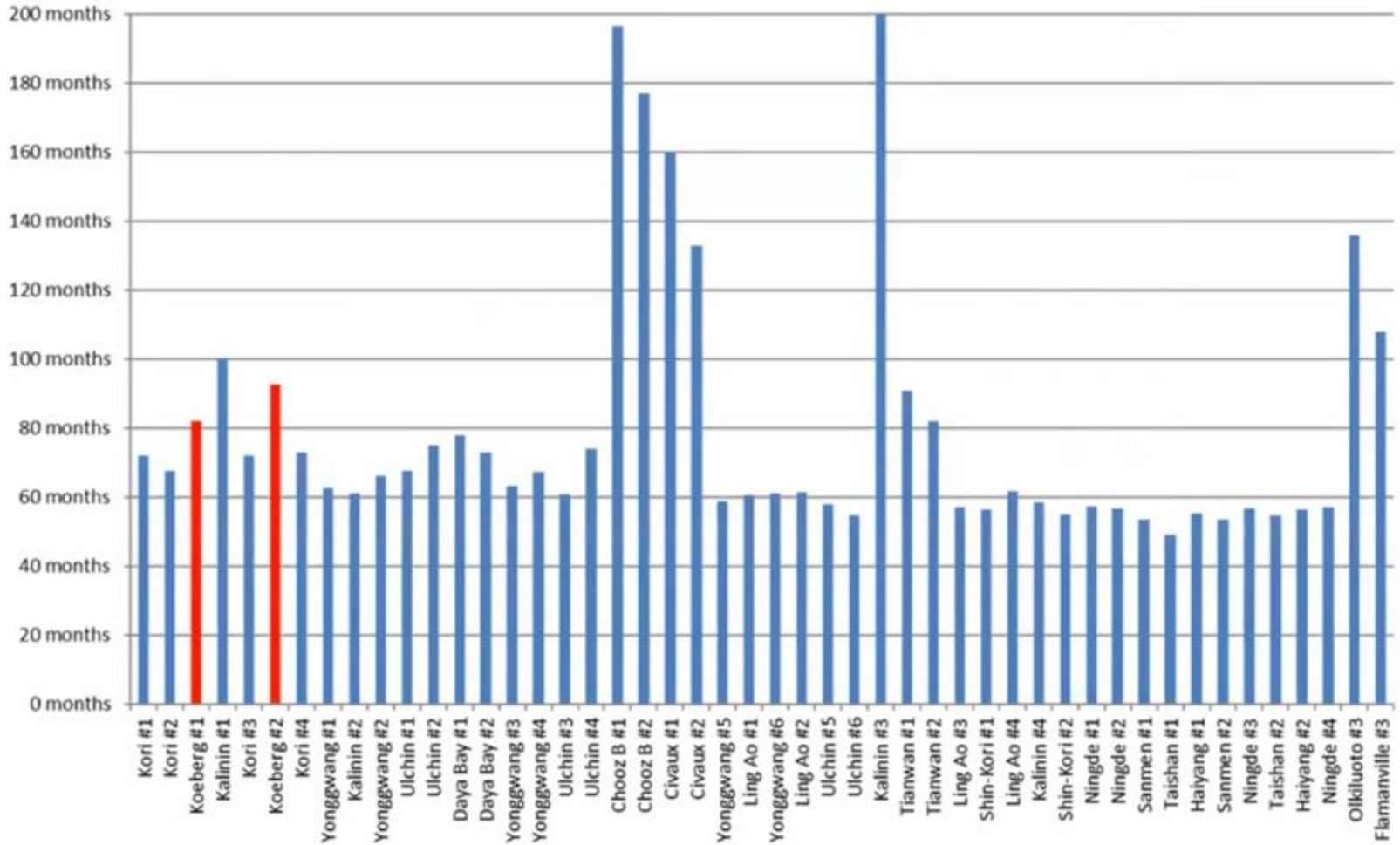

Cost of Nuclear: CAPEX from the last export contracts.

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Current Export Contracts

(public statements, various scope including fuel and O&M)

Country	Reactor	Capacity	Cost	$/kWe
Pakistan	HPR-1000 x 1	1 060MW	$3bn	$3 283/kW
India	VVER-1000 x 4	917MW	$12bn	$3 293/kW
China	VVER-1200 x 4	1 100MW	$18bn	$4 091/kW
UAE	APR-1400 x 4	1 337MW	$22bn	$4 114/kW
Belarus	VVER-1200 x 2	1 110MW	$10bn	$4 505/kW
Pakistan	HPR-1000 x 2	1 014MW	$10bn	$4 734/kW
Turkey	VVER-1200 x 4	1 114MW	$22bn	$4 937/kW
Bangladesh	VVER-1200 x 2	1 080MW	$13bn	$5 856/kW
Hungary	VVER-1200 x 2	1 100MW	$14bn	$6 364/kW
Egypt	VVER-1200 x 4	1 100MW	$29bn	$6 534/kW
UK	EPR x 2	1 650MW	$30bn	$9 061/kW

Financial Times - Opinion Inside Business 27 Jan 2019

"Nuclear is less costly than you think"

- Analysis for the Energy Technologies Institute (an organisation backed by the government and a number of energy companies) looked at 34 delivered nuclear projects round the world.

• First of a Class in USA/EU	$9,000-$12,000/kWe
• 15%	> $5,500/kWe
• 45%	$5,500-$3,500/kWe
• 40%	< $3,500/kWe

https://www.ft.com/content/1859ab32-2230-11e9-8ce6-5db4543da632?segmentid=acee4131-99c2-09d3-a635-873e61754ec6

Note that domestic projects in China, S Korea, Russia and India are quoted as below $3000/kW

Leading to the following levelized costs versus different net discount rates

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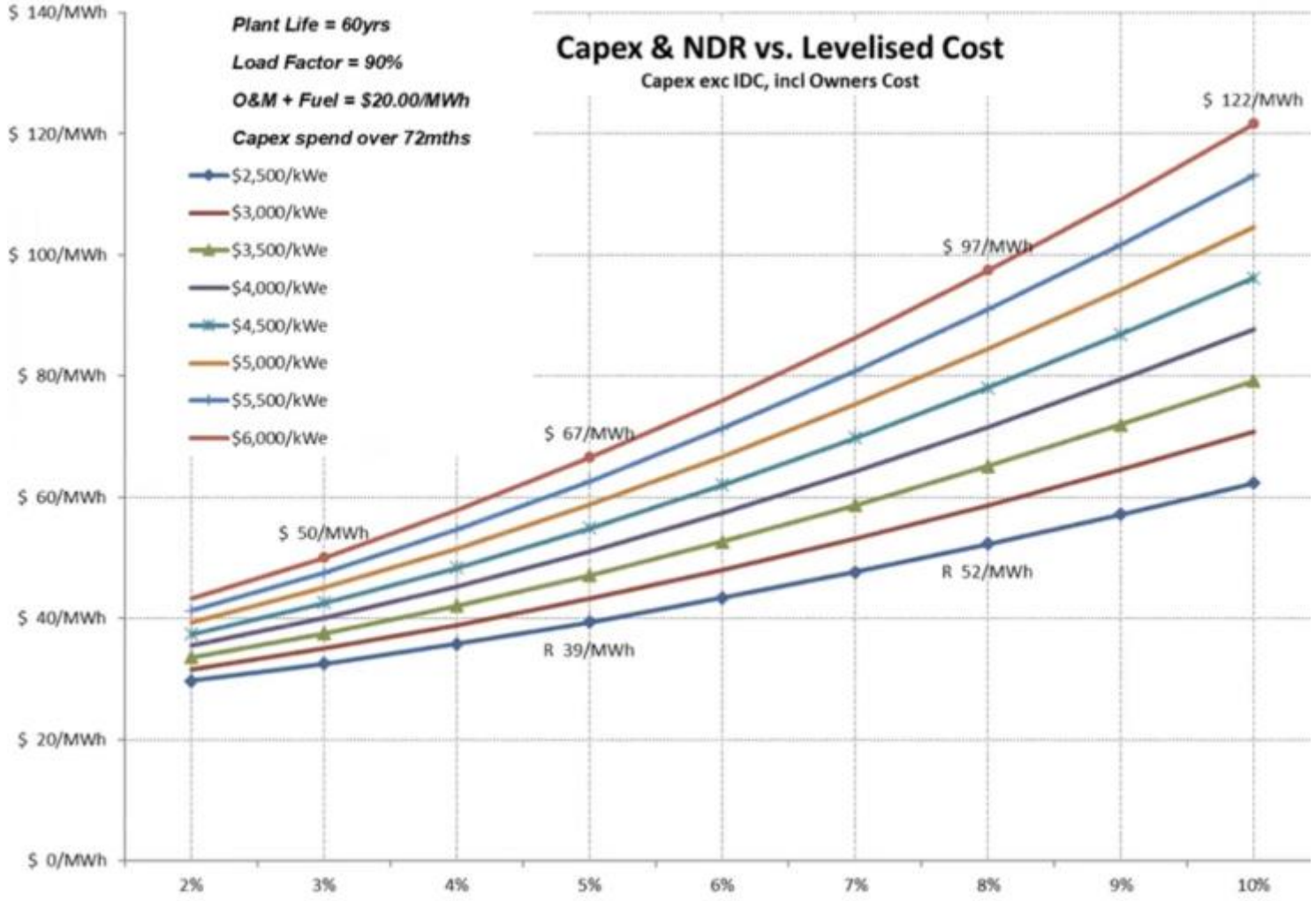
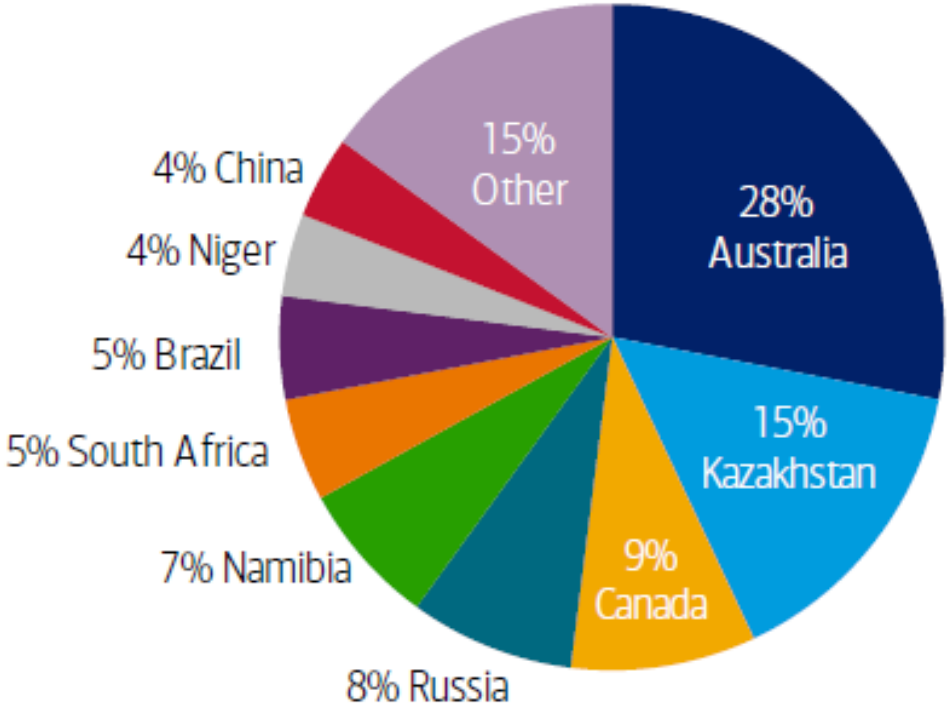


Today more than 50% of uranium comes from highly reliable sources



Source: BofA Research Investment Committee, World Nuclear Association

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Pressure from the Nuclear Alliance led to nuclear being included in Netzero technologies

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Proposal for a

REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act)

Article 3a

List of net-zero technologies

1. The net-zero technologies within the scope of this Regulation shall be:

(a) Solar technologies, including: solar photovoltaic, solar thermal electric and solar thermal technologies;

(b) onshore wind and offshore renewable technologies;

(c) battery and energy storage technologies;

(d) heat pumps and geothermal energy technologies;

(e) hydrogen technologies, including electrolysers and fuel cells

(f) sustainable biogas and biomethane technologies

(g) carbon capture and storage technologies

(h) electricity grid technologies, including electric charging technologies for transportation and technologies to digitalise the grid

(i) nuclear fission energy technologies, including nuclear fuel cycle technologies;

(j) sustainable alternative fuels technologies

(k) hydropower technologies;

(l) renewable energy technologies, not covered under the previous categories;

Conclusions

- The recent decisions of the European Union will be a strong lever to advance nuclear programs, both for conventional reactors and for fast breeders and SMRs. In almost all European countries the debate on nuclear energy has been lively and conclusive, with growing support from public opinion. Even in Denmark and Norway, the debate on nuclear power is ongoing.

- Countries without nuclear power now have plans to install it, such as Poland and Italy. Countries that had decided to stop or freeze nuclear power have decided to increase their use of this energy source, such as Sweden, France, the Netherlands, Belgium and the United Kingdom.

- Countries where the current governments resist and intend to maintain the current policy of all renewables, such as Germany and Spain, will see their policies change when the opposition takes office. Only countries like Austria, Portugal and Luxembourg maintain a taboo on the subject. In Portugal, for the first time, some parties have included in their electoral programs the need to study this option.

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