CLEAN ENERGY OF TOMORROW

Nuclear Energy's Role in the Clean Energy Transition

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Elektrárna Dukovany II, a. s.

CTU

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Elektrárna Dukovany II, a. s.

- Owner of locality Dukovany for NPP
- Member of ČEZ Group, ČEZ, a.s. is the sole shareholder of the subsidiary
- Investor into the new NPP project is Dukovany

Marek Adamec

- Head of Economic Model Department
- 12 years in nuclear projects development
- Doctoral degree from CTU, FEE

Jakub Zapletal

- Economic Model Department Specialist
- 1.5 years in nuclear projects development
- Master‘s degree from CTU, FEE

Project of NPP in Dukovany

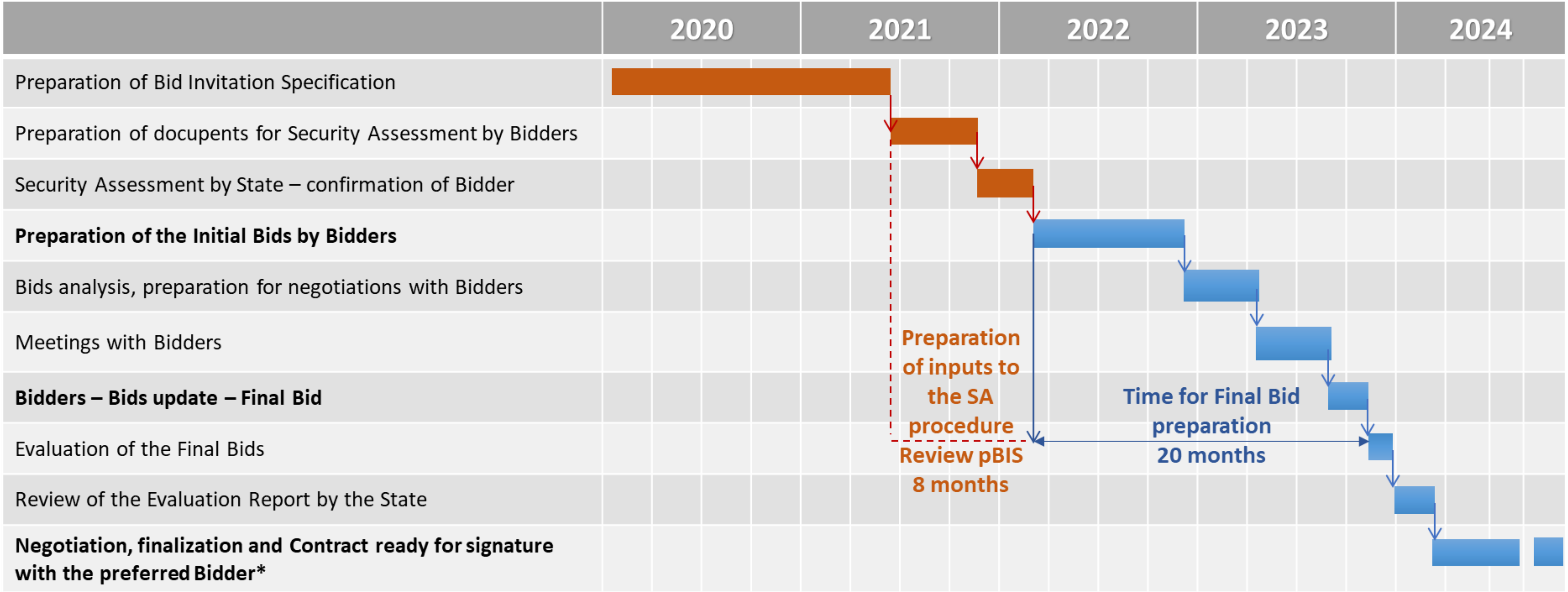
- Scope of the project:
  - preparation (investment, licensing and authorization),
  - construction,
  - commissioning,
  - operation and decommissioning,
  - its lifetime is planed for 60 years, some extensions seems to be technically possible.

- Output ca. 1 000 MW – 1 200 MW

- Selection of contractor in tender procedure

- Tender participants
- Strictly confidential

Tender Schedule



Agenda

1. History
2. Context
3. Current Situation of Nuclear Power
4. Comparison of Electricity Sources
5. Technical Aspects of Nuclear Power Plants
6. Economics of Nuclear Power Plants
7. Conclusion – Why Nuclear?

History of Nuclear Energy

Mainly use in the military industry, research	
1951	• First reactor in the US (*Experimental Breeder Reactor Idaho*)
1954	• First reactor in USSR (Обнинская атомная электростанция)
Commercial use	
1956	• First commercially used reactor in GB
1960	• Two commercial reactors in the US (Westinghouse a GE)
1962	• First commercial reactor in Canada
1964	• First commercial reactor in USSR
1973	• First high capacity (1000+ MW) reactors built in USSR
1980-2000	• Stagnation of the nuclear industry due to the absence of planning and research for new types of reactors
2000 – present	• 3rd generation of reactors

Context

- Sustainability and focus on low-carbon energy generation

- Global challenges
  - Import dependency
  - Increase of power consumption
    - Electromobility

- Incentives to target the abovementioned:
  - In EU – Green Deal
  - In DE – Energiewende

- Need to maintain competitiveness within the EU as well as the world

Nuclear Power – Current Situation

In the World…

USA

93 reactors

95 GWe (18%)

1 being built

France

56 reactors

61 GWe (68%)

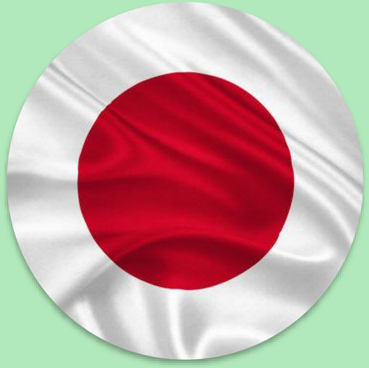
1 being built

China

54 reactors

52 GWe (5%)

21 being built



Japan

33 reactors

32 GWe (6%)

2 being built

Russia

37 reactors

28 GWe (20%)

6 being built

South Korea

25 reactors

24 GWe (30%)

3 being built

*data until year 2022

In Europe (EU)…

100
nuclear power plants in the EU covering a quarter of electricity generated in the EU

12
EU Member States

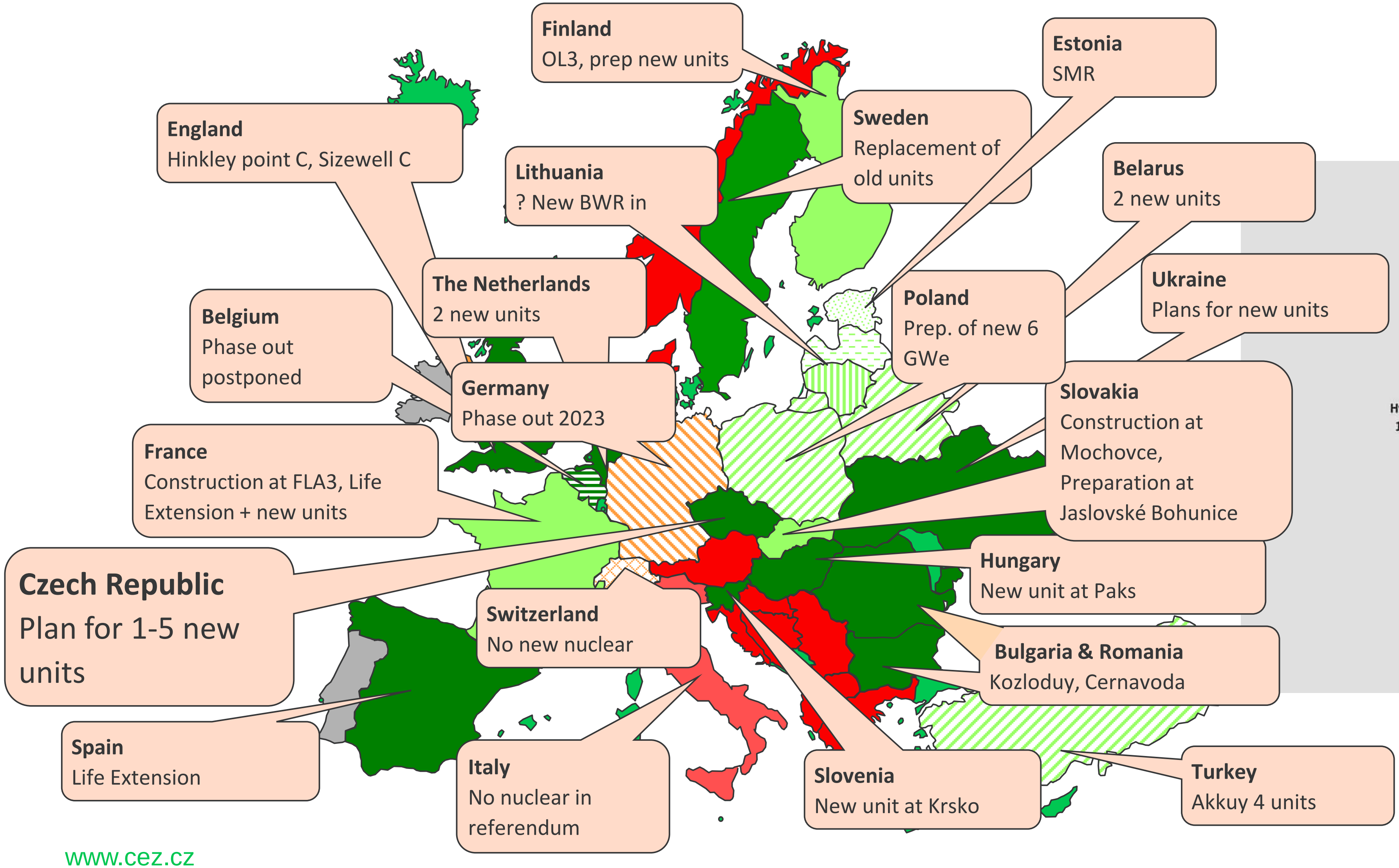
600 million
tons of CO2 kg per year avoided in the EU due to nuclear generation

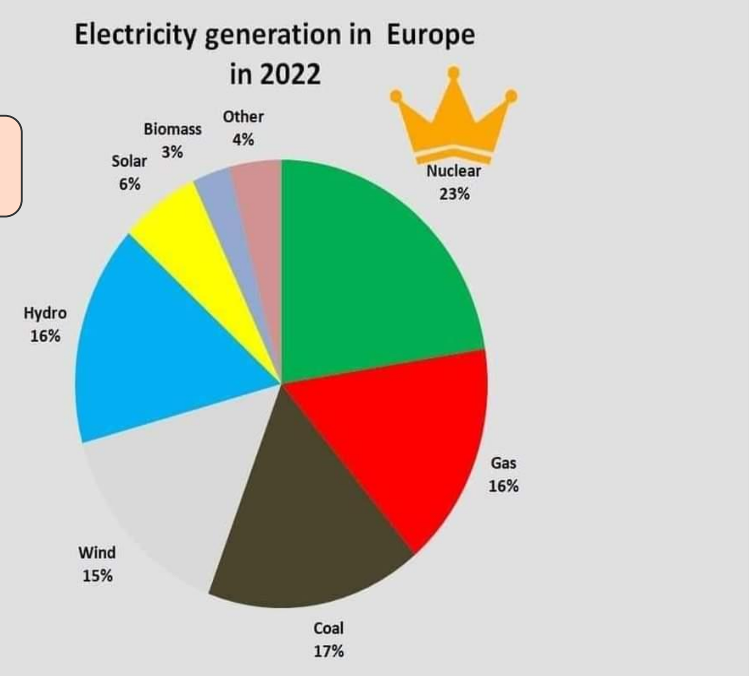
55%
of the EU's low-carbon electricity

Essentially available
24/7, 365 days/year

800 000
jobs supported by the nuclear industry in Europe

Europe – Current Development





In the Czech Republic…

NPP Dukovany

Operating since 1985
(all units 1987)

VVER 440

4 x 510 MWe

NPP Temelín

Operating since 2000

VVER 1000

2 x 1125 MWe

CTU Educational Reactors

VR-1 (since 1990)

VR-2 (since 2023)

UJV Řež Research Reactors

LR-0 (since 1983)

LVR-15 (since 1995, reconstruction of the reactor VVR-S which ran since 1957)

Czech Republic is a member of IAEA and WANO

Strategic goals of the energy sector of the Czech Republic

Secure Energy Supply

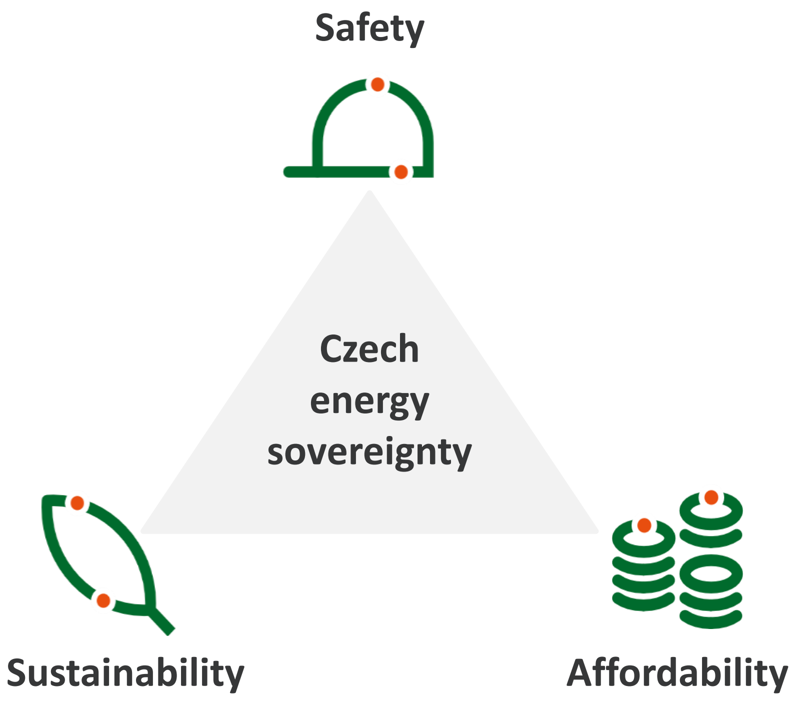
• Ensuring necessary energy supplies for consumers in normal operation even in the event outages in the supply of primary sources, price fluctuations on the markets, disturbances and attacks in the context of the EU.

Competitiveness

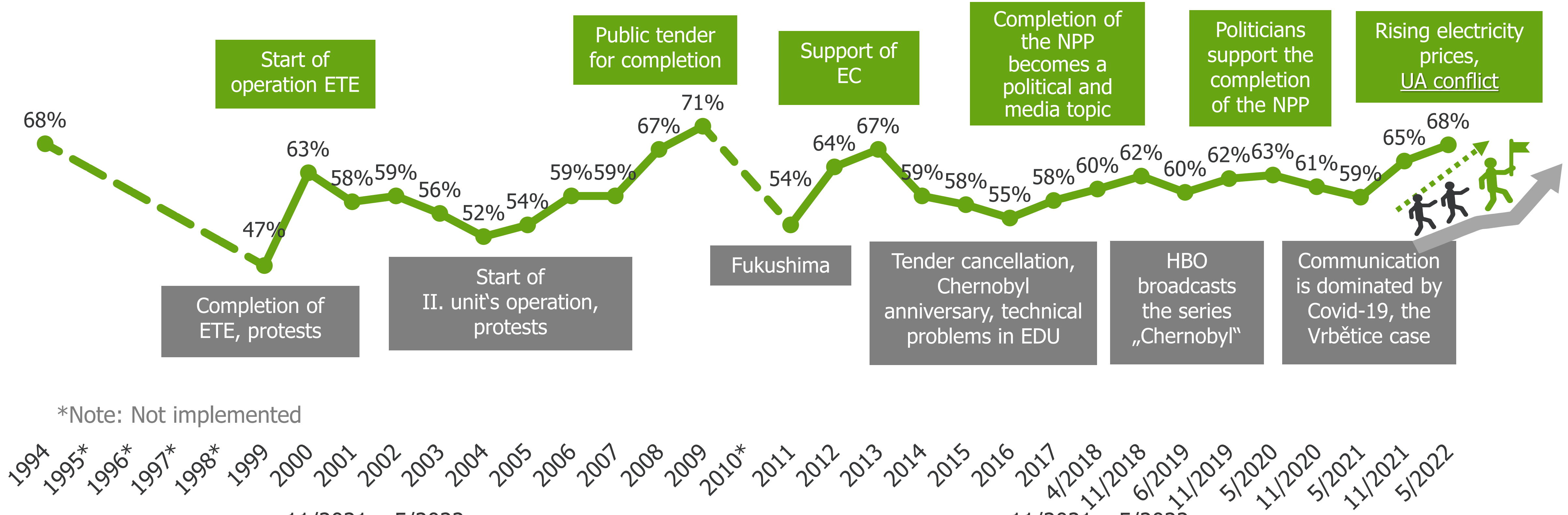
• Final electricity prices for industrial consumers and for households comparable to countries in the region and other direct competitors + energy companies capable of creating economic added value in the long term.

Sustainability

• A structure of the energy industry that is sustainable in the long term from the point of view of the environment, financial and economic, human resources and social impacts, and primary resources.



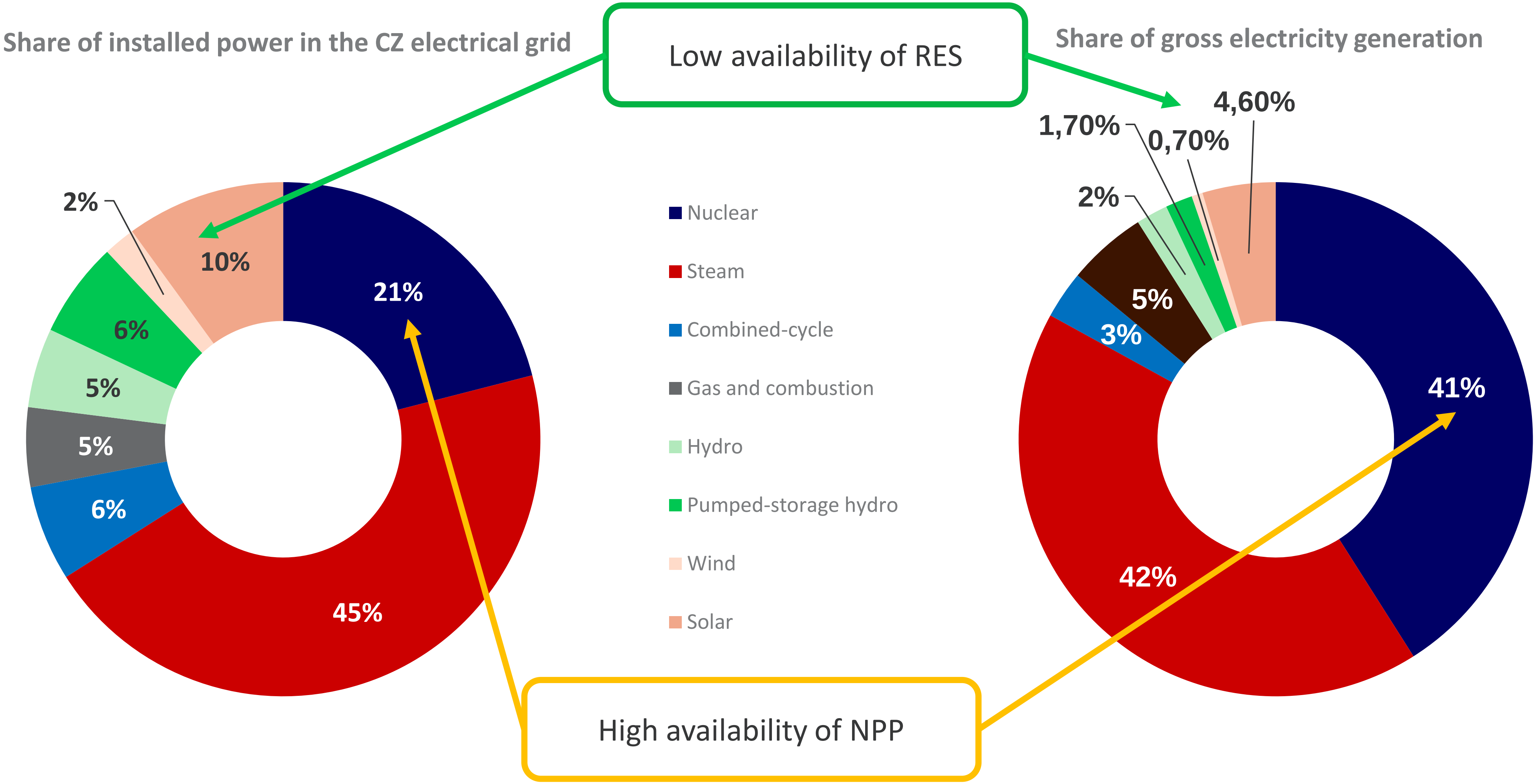
Due to the UA conflict, the support of nuclear power continues to grow significantly – support is now near an all-time high



	11/2021	5/2022
In favour	52%	54%
Neutral	12%	12%
Against	36%	34%

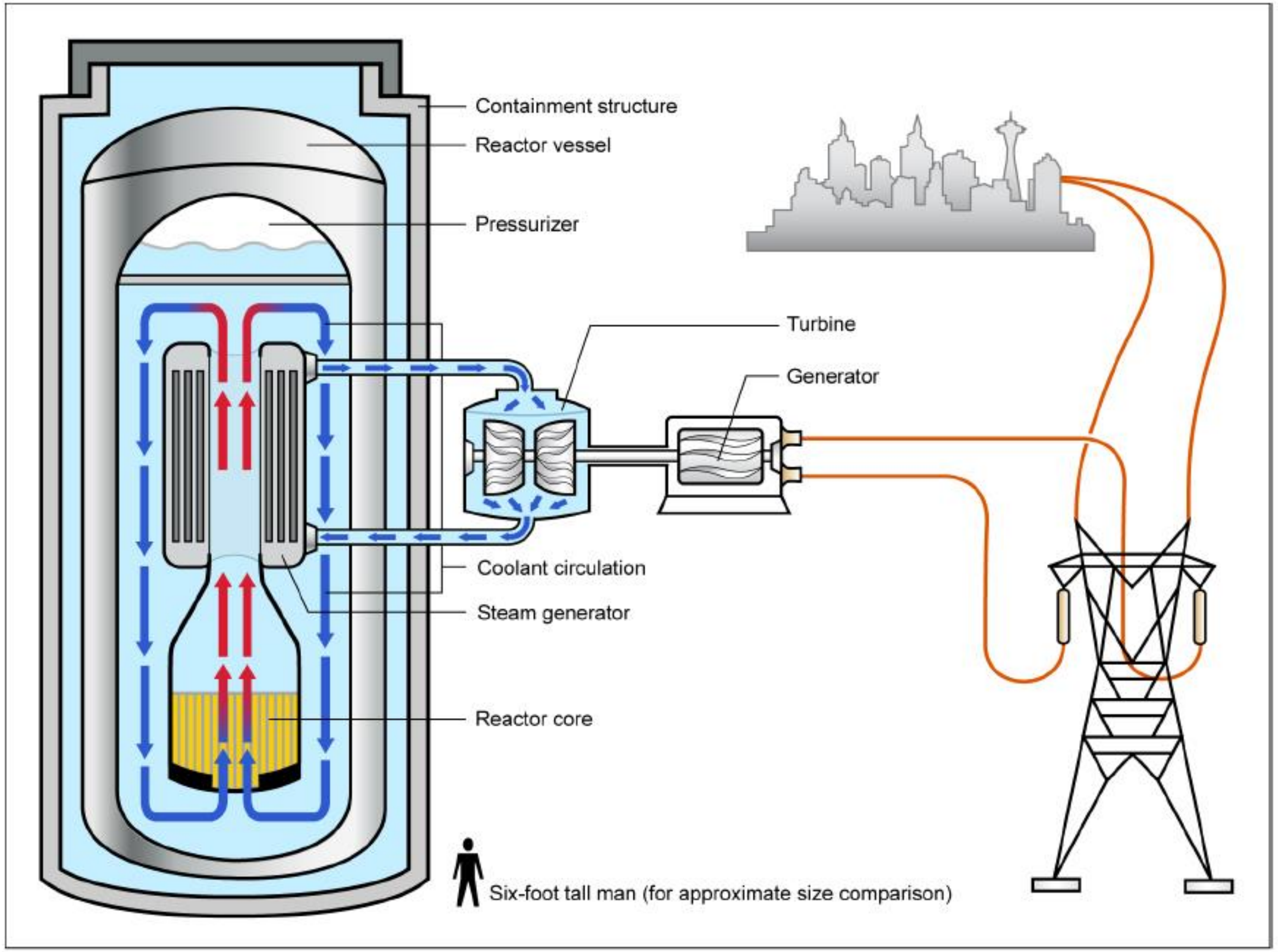
Q4) Are you personally in favour of the development of nuclear energy in our country?
(all respondents N=500 answer / statistical error: max. 3.7%)

In 2022, the share of nuclear power plants in production was 41%



Small Modular Reactor (SMR)

- Most designs have 50 – 300 MWe output
- Technology comes from 1950s, until now used mainly by military
- Most designs are PWR
- Passive safety
- Build off-site, shipped on-site
- Not only for electricity generation, but also for heating
- Legislative changes
- Economies of scale
- FOAKs in late 2020s / early 2030s



Source: GAO, based on Department of Energy documentation. | GAO-15-652

LRW SMR UNDER CONSIDERATION

(In an alphabetical order of the design)

AP 300 (USA, 300/900 MWe/MWt), PWR
Westinghouse

BWRX-300 (USA, 300/870 MWe/MWt), BWR
GE Hitachi

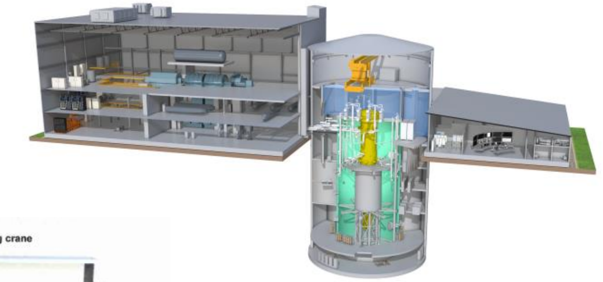
NuScale (USA, 12 modules – 924 MWe), PWR
NuScale Power

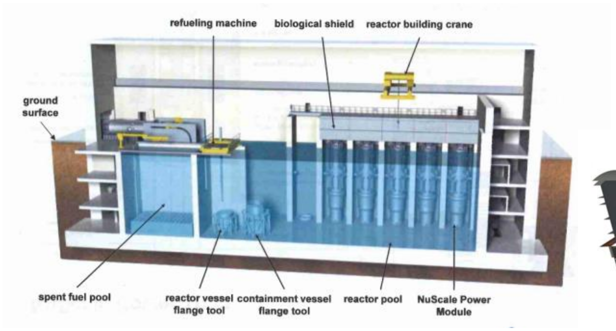
Nuward (France, 2 x 170/2 x 540 MWe/MWt), PWR
EDF

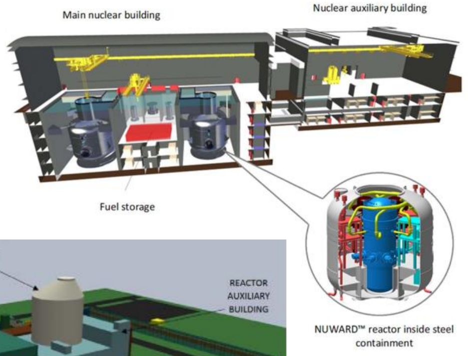
SMART100* (S. Korea, 2 x 107/2 x 365 MWe/MWt), PWR
KHNP

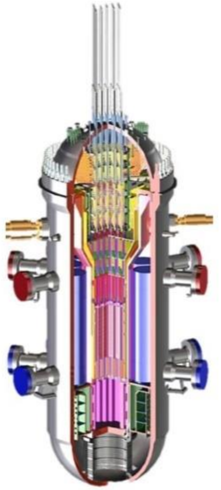
SMR-160** (USA, 160/525 MWe/MWt), PWR
Holtec

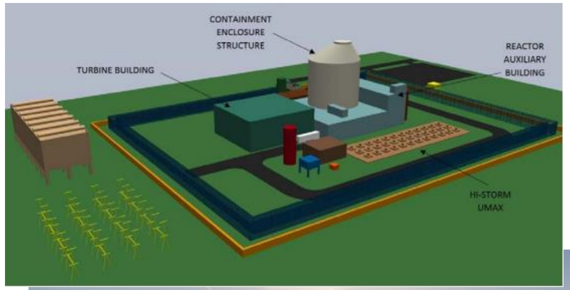
UK SMR (UK, 470/1276 MWe/MWt), PWR
Rolls Royce SMR





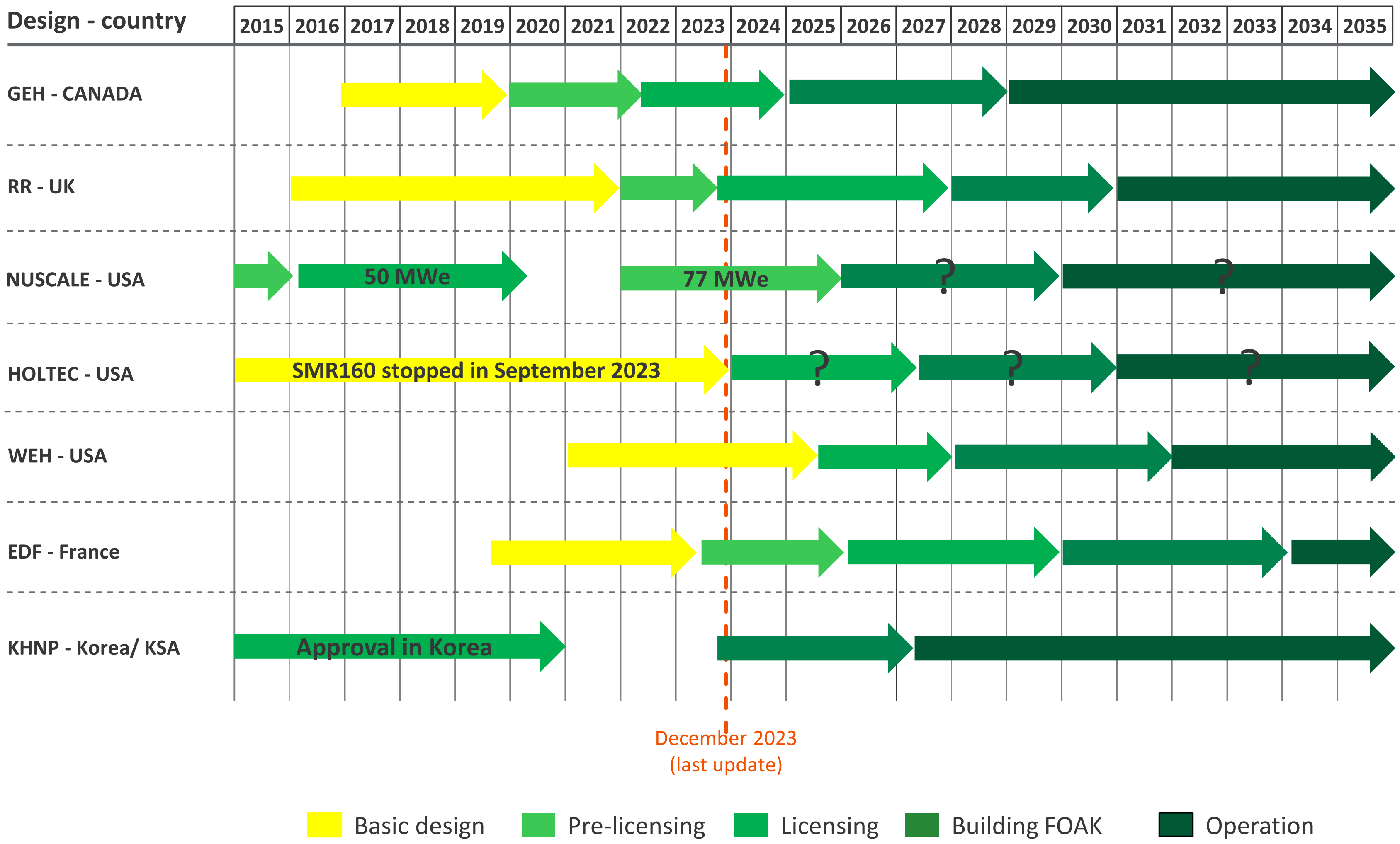






* iSMR under development since 2020 instead of SMART100 design
** Holtec changed its design to 300 MWe in 9/2023

CONSIDERED DESIGNS AND THEIR LICENCING PROGRESS – ROAD TO FOAK/OPERATION



Design - country	Current situation	FOAK by 2032?
GEH - CANADA	Vendor Design Review with CNSC. Darlington NPP in early stage of preparing site, FOAK operation 2028	✓
RR - UK	Expected GDA completion in 2026 and 2031 operation of FOAK	✓
NUSCALE - USA	In 11/2023 first site (Idaho) lost interest due to higher LCOE. Poland and Romania in progress	?
HOLTEC - USA	Expected delay due to change of design in 9/2023, uncertainty of design maturity	?
WEH - USA	Basic design phase - communication with NRC for faster licensing due to similarities with approved AP1000	✗
EDF - France	Pre-licensing since 7/2023, first concrete in 2030	✗
KHNP - Korea/ KSA	SMART100 design complete but shift towards iSMR in 2020, which is still in basic design phase. SMART100 in KSA – licensing progress unknown	✗

Comparison of Electricity Sources

Comparison – Characteristics of Different Electricity Sources





	Nuclear	Wind	Solar	Hydro	Natural Gas	Coal
Flexibility	Low	Very low	Very low	Very high	High	Medium
Firm/variable	Firm	Variable	Variable	Firm	Firm	Firm
Type of fuel	Nuclear	Renewable	Renewable	Renewable	Fossil	Fossil
Low Carbon	Yes	Yes	Yes	Yes	No*	No
Space needed per 1000MW	3.4 km2**	673-932km2	117-195km2	-	3.4 km2	3.4 km2

*The EU voted to keep some specific uses of natural gas in its taxonomy of sustainable sources of energy in some circumstances

** NPP Dukovany and NPP Temelín take up an area of ~ 1 - 1.5 km2 each

EU‘s Taxonomy

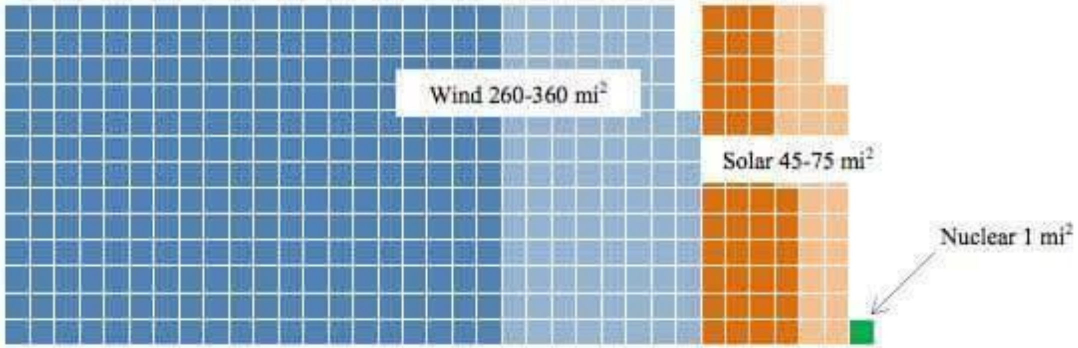
- Taxonomy ≠ Taxes
- EU‘s classification system of environmentally sustainable economic activities
- Aims to stop Greenwashing and direct investments towards environmentally sustainable projects
- In line with Green Deal and Net-zero by 2050 objectives
- Nuclear power and gas power proclaimed as low-carbon power sources with some conditions and limitations

- Restrictions for nuclear power:
    - For existing NPPs upgrades for LTO possible until 2040
    - For Gen III+ new build NPPs obtain construction permit before end of 2045
    - Gen IV technology must focus on safety and minimizing waste
    - All countries with NPPs must have Long-Term Storage by 2050

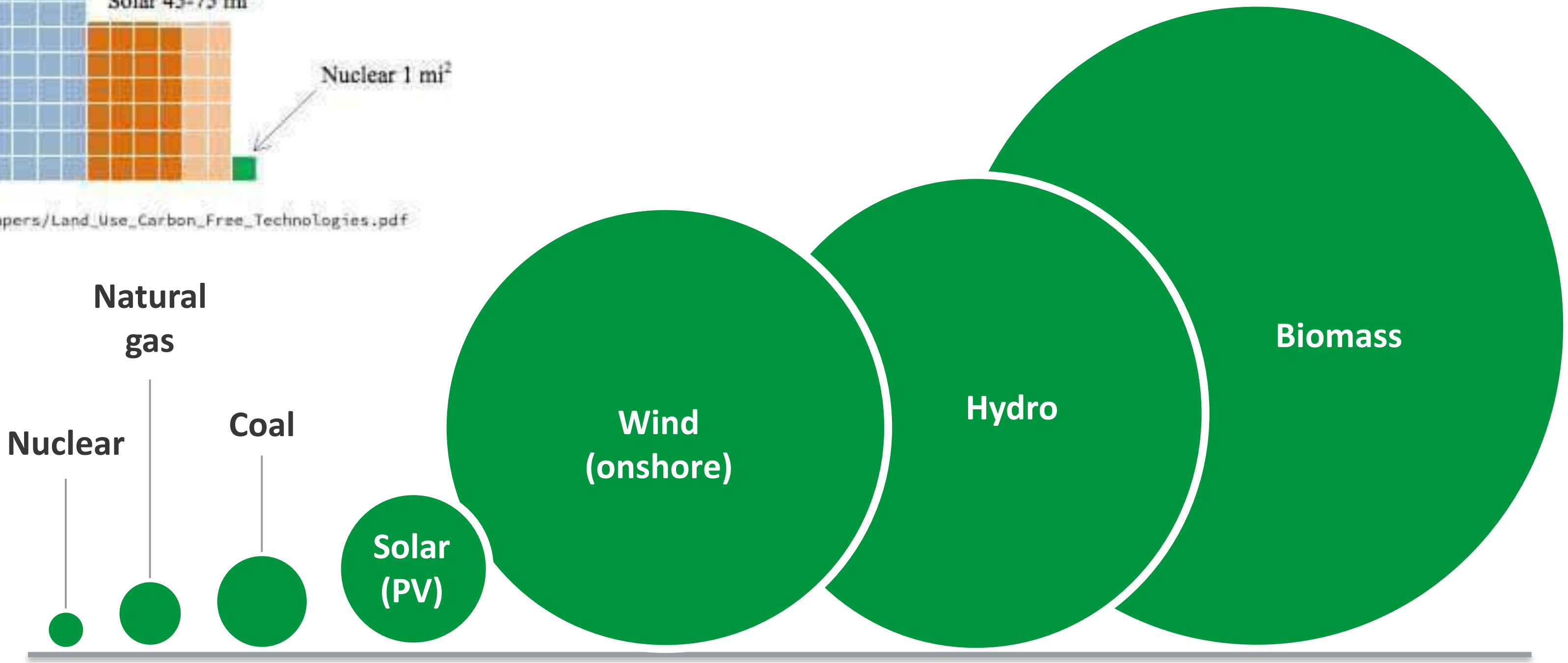
Land Use

Technology	Capacity Factor, %	Square Miles Needed for 1,000 MW
Wind	32-47	260-360
Solar	17-28	45-75
Nuclear	90	1.3

The table summarizes the approximate land required by wind and solar technologies to match the electricity produced annually by a 1,000-MW nuclear power plant.



source: http://www.nei.org/CorporateSite/media/filefolder/Policy/Papers/Land_Use_Carbon_Free_Technologies.pdf



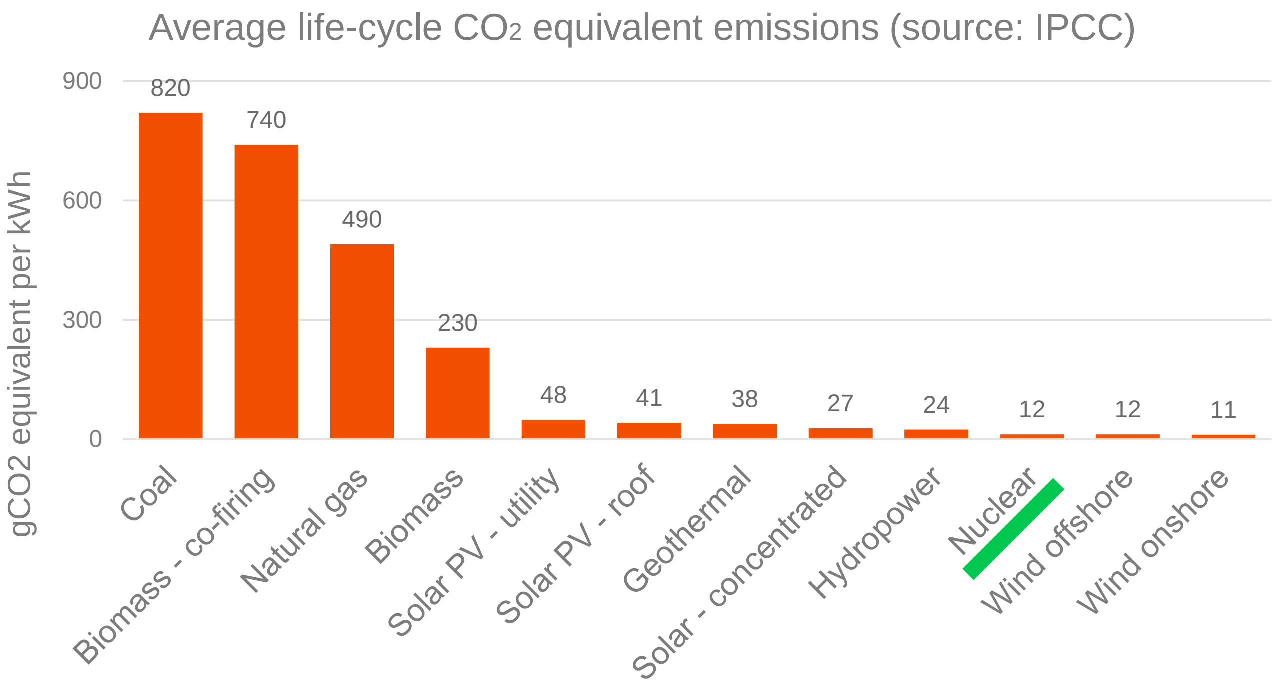
Relative land use (fuel mining and generating footprint) of electricity generation options per unit of electricity (source: Brook & Bradshaw, 2015)

Increase of Emissions Due to Nuclear Phase-out in Germany

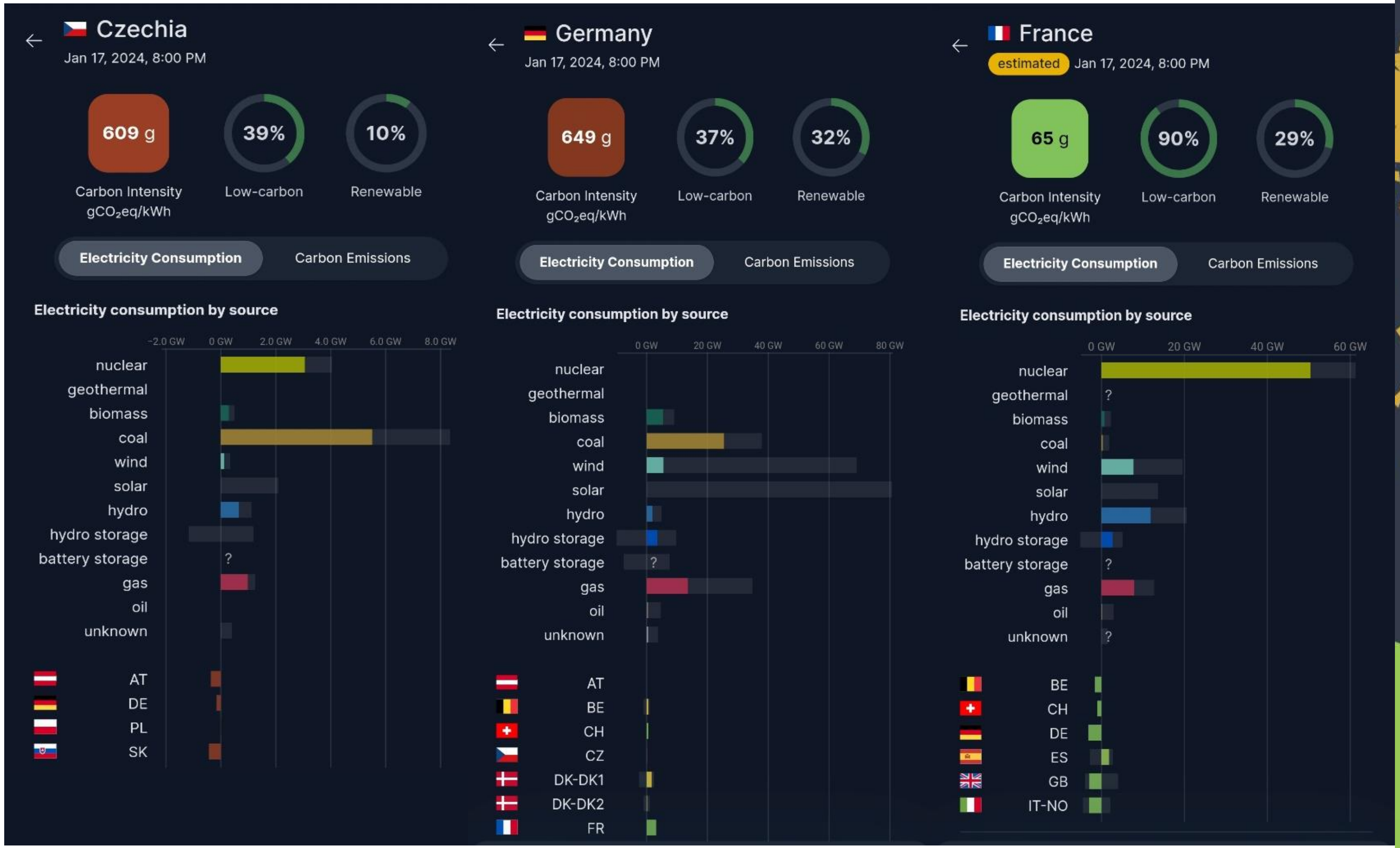
Estimated CO2 emissions caused by the exit from nuclear power

Year		2011-2012*	2013-2020*	2020
Electricity generation to be replaced (TWh)		86	468	53
Average emission factor for the replacement electricity generation (tCO2 per MWh)	Coal scenario	0.88	0.84	0.80
	Gas scenario	0.88	0.63	0.40
	Renewables & gas scenario	0.88	0.53	0.20
Additional emissions (MtCO2)	**Coal scenario**	**76**	**392**	**42**
	Gas scenario	**76**	**296**	**21**
	Renewables & gas scenario	**76**	**248**	**10**

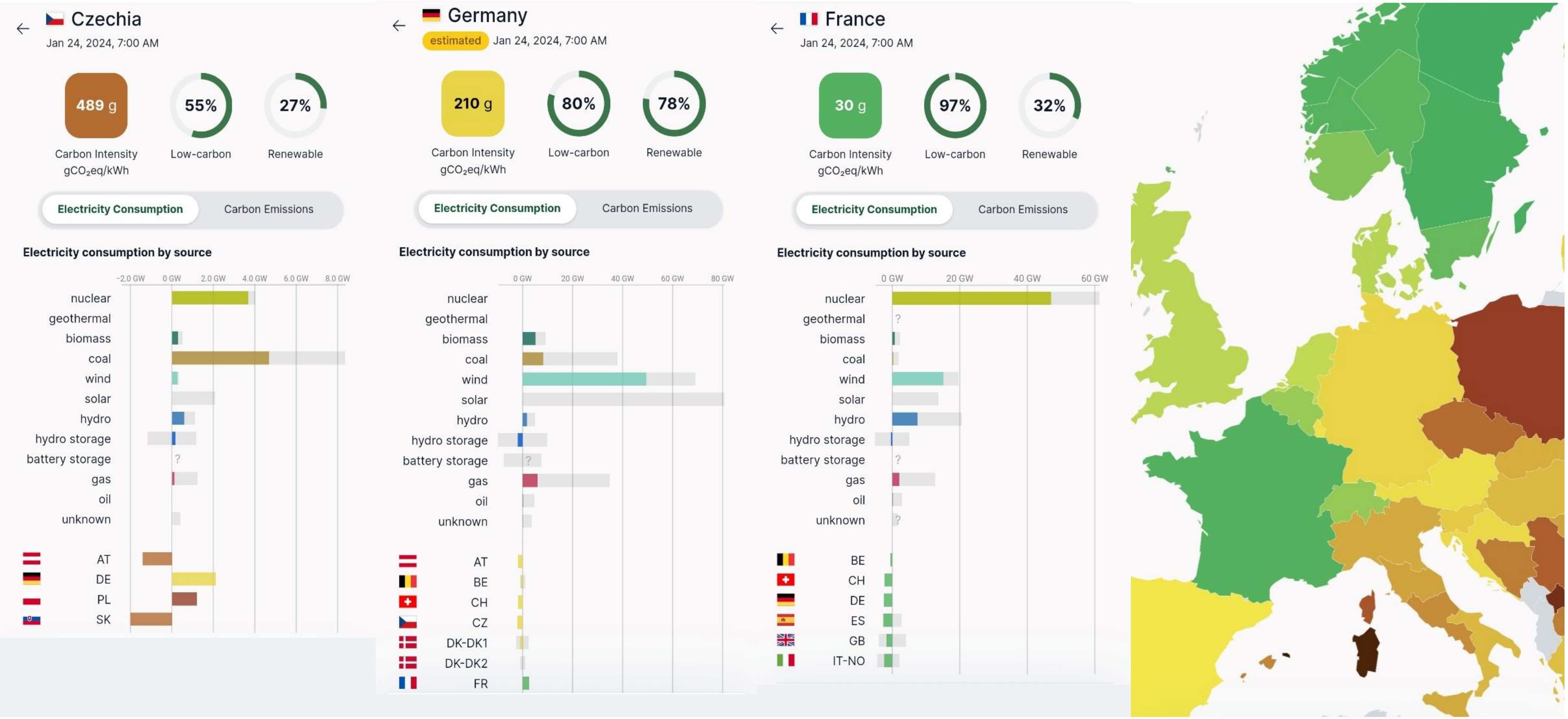
- Germany's position in the international electricity market will brobably switched from a net exporter to the rest of Europe to the net importer



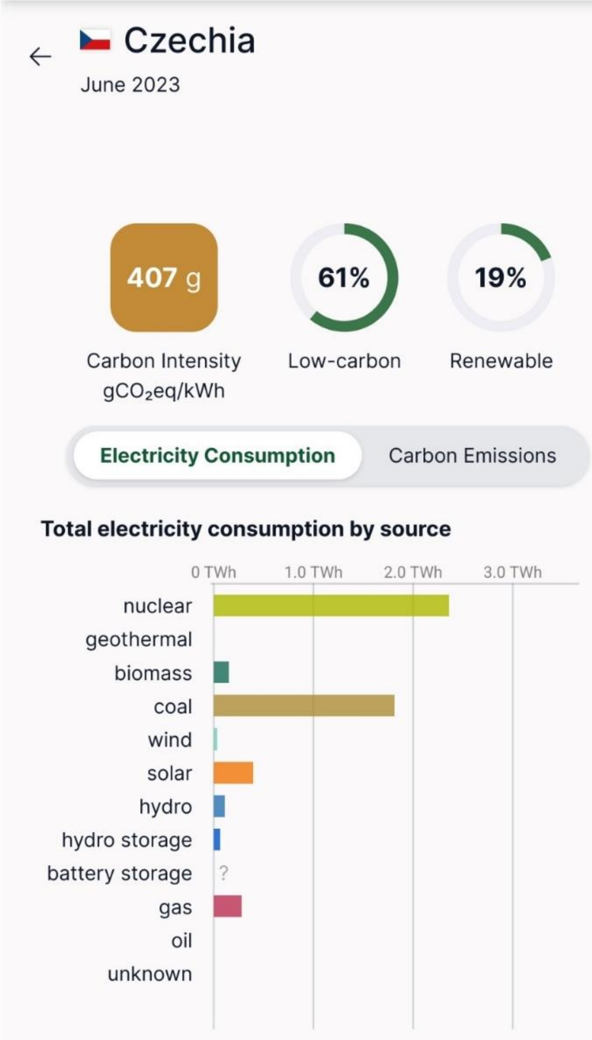
Electricity Map - Night

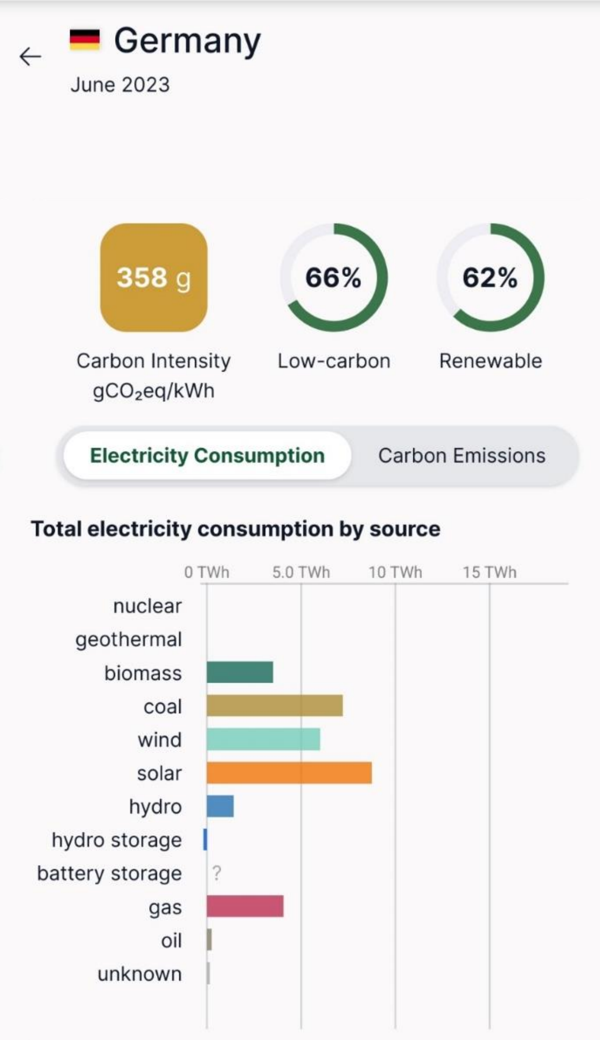


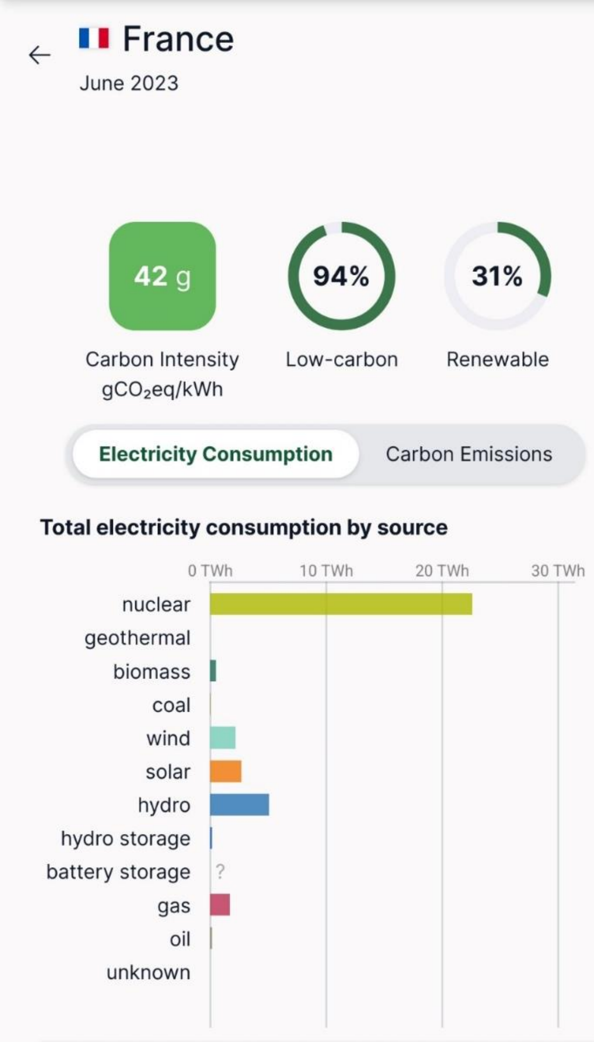
Electricity Map – Day

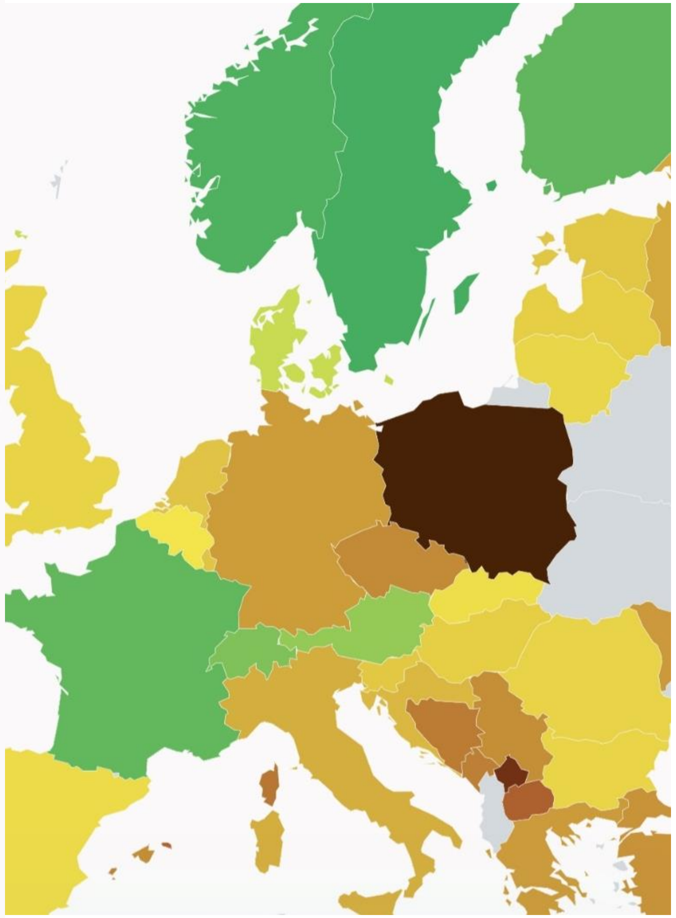


Electricity Map – Average



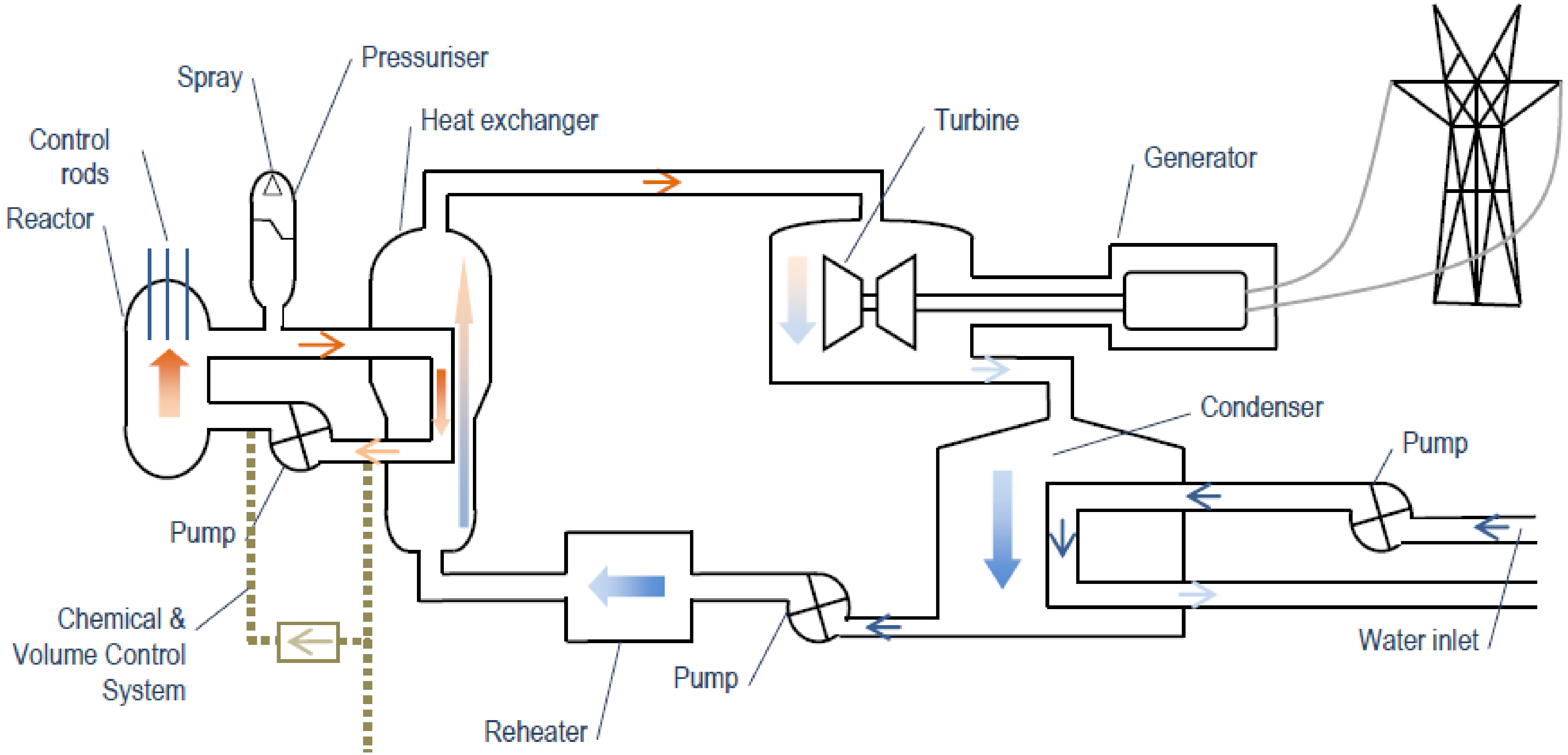






Technical Aspects of Nuclear Power Plants

General Scheme of Nuclear Power Plants - PWR

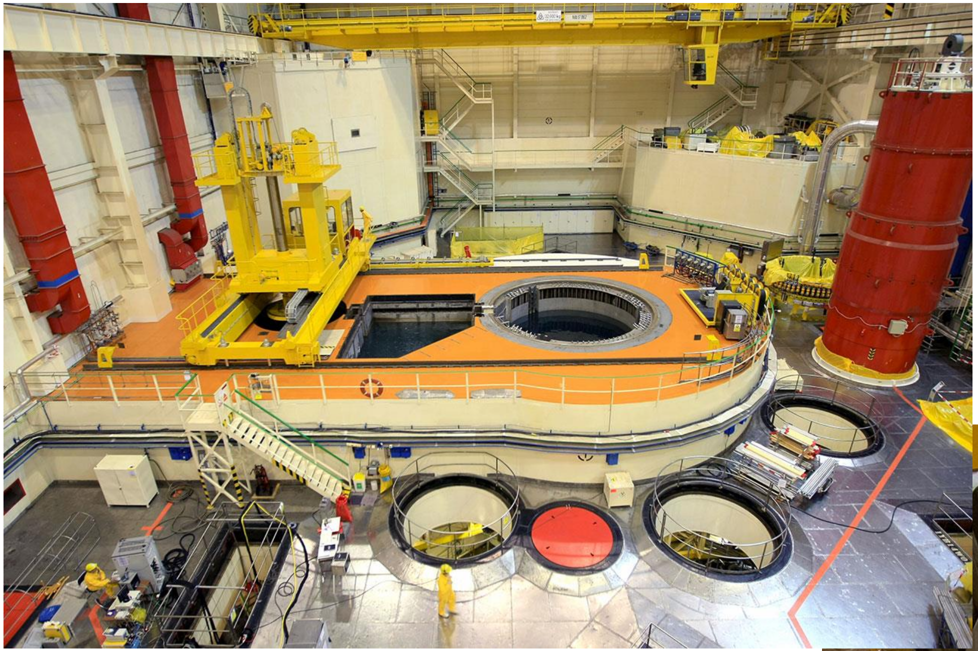


Source:

AEN NEA

NUCLEAR ENERGY AGENCY

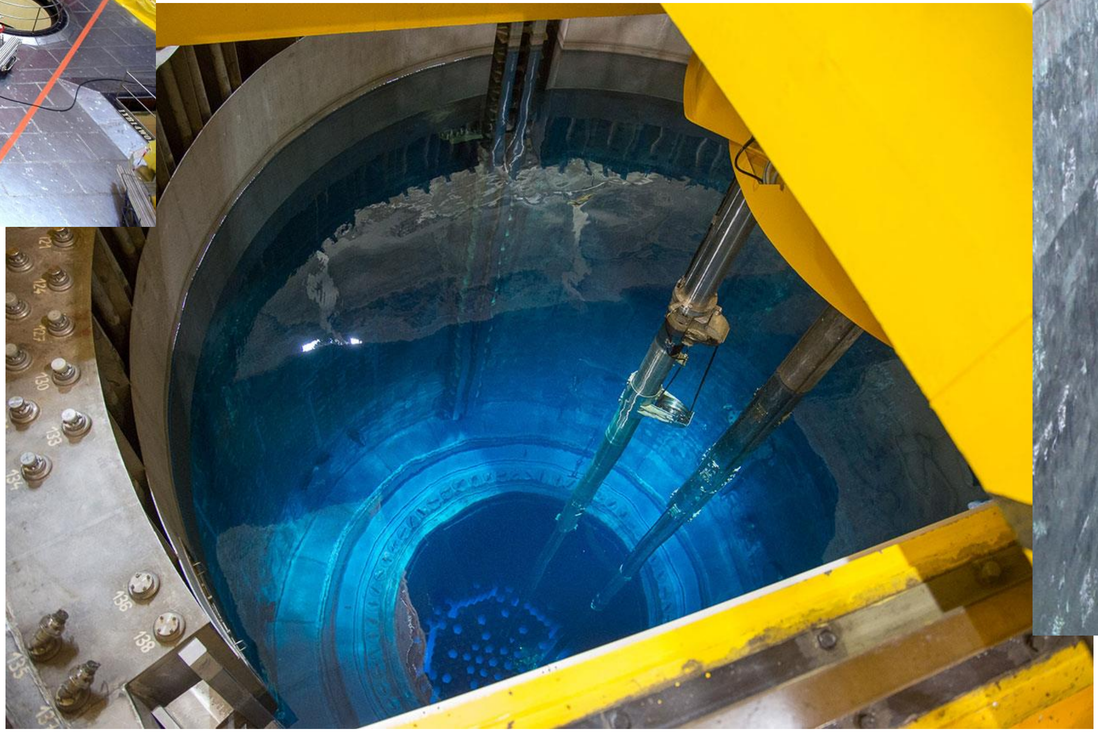
Nuclear Island



View of the open reactor and storage pool of the Dukovany power plant during shutdown for fuel replacement

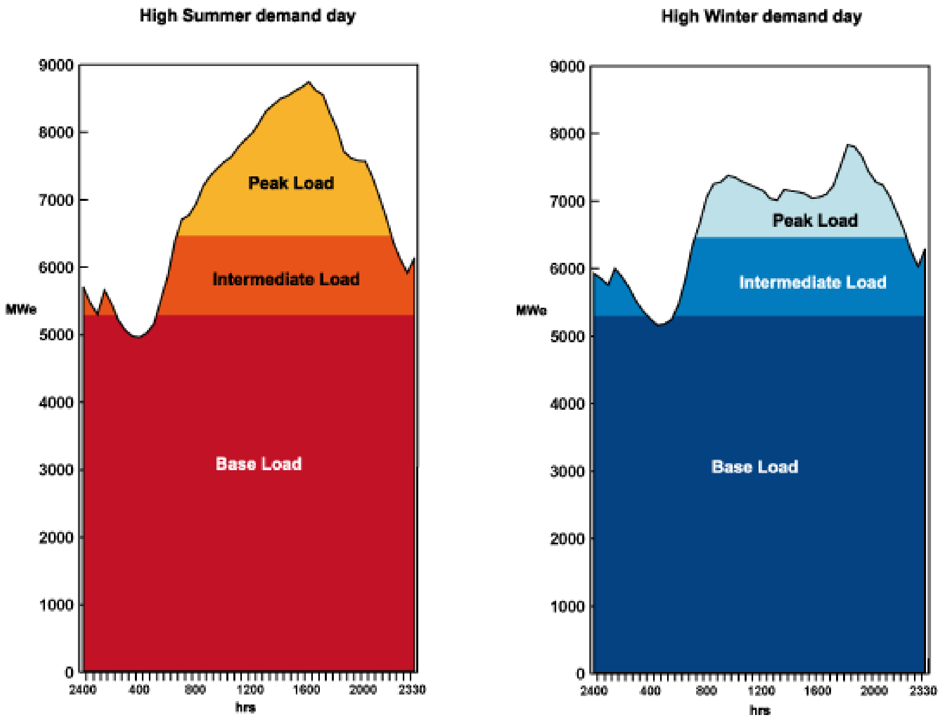
The body of the pressure vessel with a height of 11 meters is a complex and precise steel colossus, with a stainless-steel coating on the inside

The arm of the loading machine moves fuel cartridges from the reactor to the storage pool / NPP Dukovany during shutdown

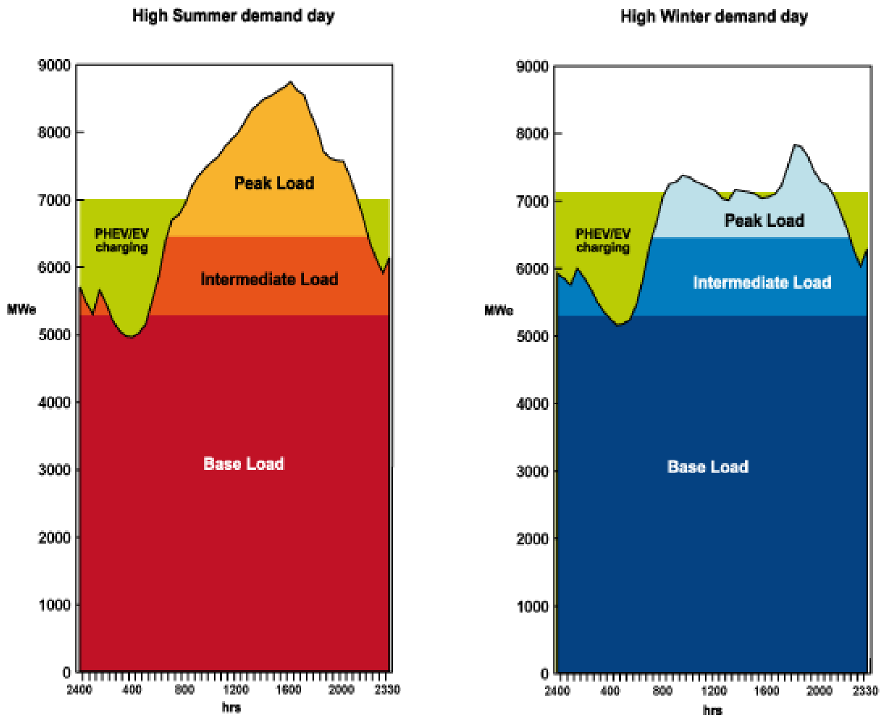


Nuclear Plants and Their Potential in Load Curves

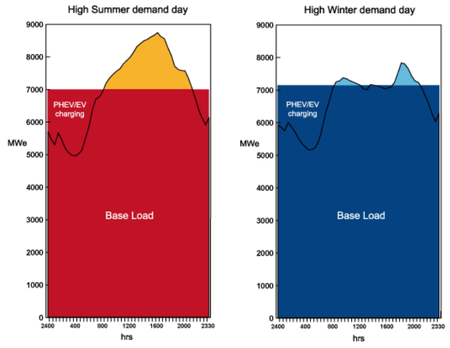
Load curves for Typical electricity grid



Load curves for Typical electricity grid



Load Curves For Typical Electricity Grid



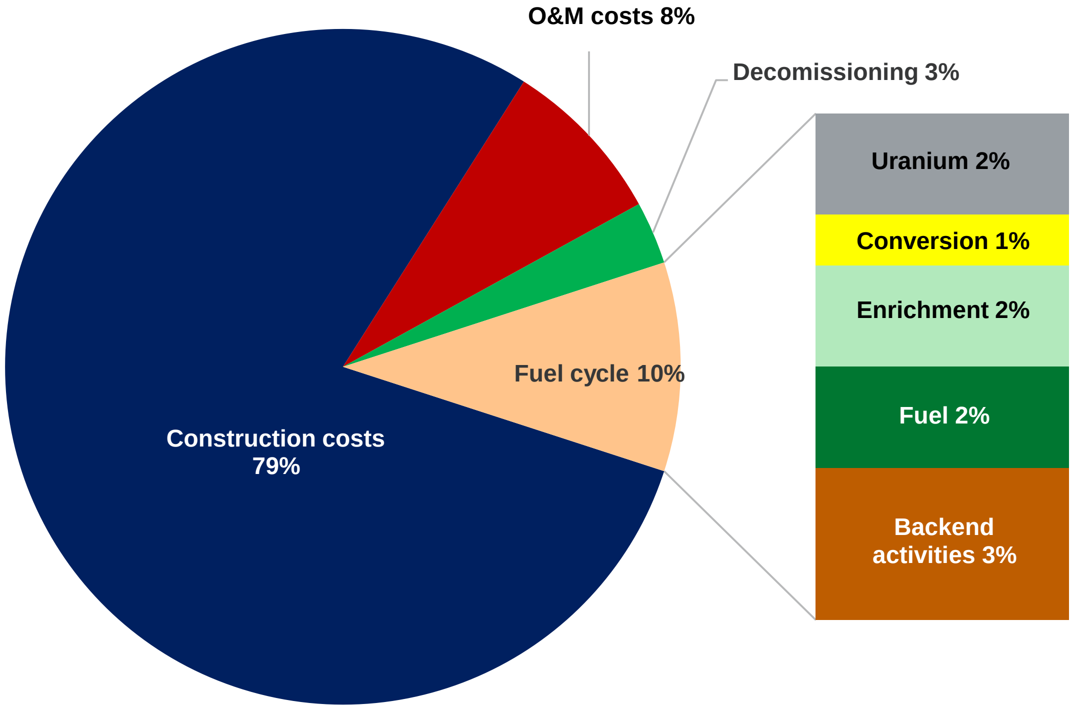
Economics of Nuclear Power

Economics of Nuclear Power Plants

- Capital costs (CAPEX)
- Operating costs (OPEX)
- External costs
- Other costs

- LCOE – levelized cost of electricity
- LDEGC – levelized discounted energy generation cost

- Overnight cost
- Escalations
- Discount rate
- Interest rate



LCOE vs LDEGC

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

$$\text{LDEGC} = \frac{\text{PW(CAP) + PW(O\&M)+ PW(FUEL)}}{\text{PW(ENERGY)}}$$

$$\text{PW} = E_{A/B} \sum_{t=T_R}^{T_E} \frac{C_{B_t}}{(1+e_{iB})^{t-T_r}(1+d_r)^{t-T_r}}$$

I_t	investment expenditures in the year *t*
M_t	operations and maintenance expenditures in the year *t*
F_t	fuel expenditures in the year *t*
E_t	electrical energy generated in the year *t*
r	discount rate
n	expected lifetime of system or power station

PW	present worth
C_{Bt}	cash requirement in currency B at time t
e_{iB}	general inflation rate for currency B
d_r	real discount rate
T_E	discount rate
T_R	reference date
$E_{A/B}$	exchange rate to the reference currency A which is assumed to be known at time $t = T_R$

Discount Rate and LCOE

Projected nuclear LCOE costs for 'nth-of-a-kind' plants completed from 2025, $/MWh

Source: OECD IEA & NEA, *Projected Costs of Generating Electricity, 2020 Edition*, Table 3.13a, assuming 85% capacity factor. In 2018 currency values.

Country	At 3% discount rate	At 7% discount rate	At 10% discount rate
France	45.3	71.1	96.9
Japan	61.2	86.7	112.1
South Korea	39.4	53.3	67.2
Slovakia	57.6	101.8	146.1
USA	43.9	71.3	98.6
China	49.9	66.0	82.1
Russia	27.4	42.0	56.6
India	48.2	66.0	83.9

OECD electricity generating costs for year 2025 onwards – 3% discount rate and 10% discount rates, $/MWh

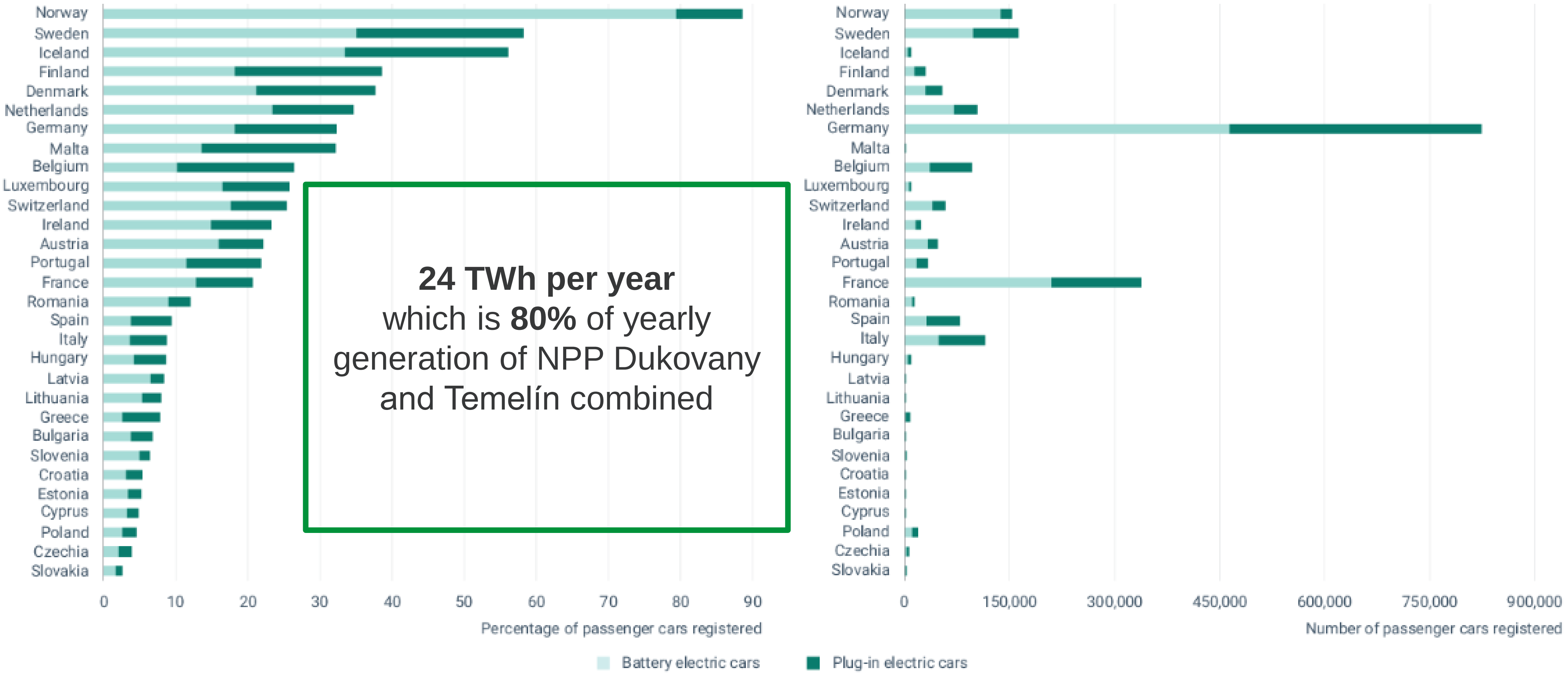
Source: OECD IEA & NEA, *Projected Costs of Generating Electricity, 2020 Edition*, Tables 3.11a, 3.12, 3.13a, assuming 85% capacity factor. In 2018 currency values.

Country (3%)	Nuclear	Coal	Gas CCGT
France	45.3	-	-
Japan	61.2	87.6	87.6
Korea	39.4	69.8	83.0 - 91.0
Slovakia	57.6	-	-
USA	43.9	75.1 - 96.3	40.7
China	49.9	70.6	81.5
Russia	27.4	-	-
India	48.2	64.7 - 94.6	-

Country (10%)	Nuclear	Coal	Gas CCGT
France	96.9	-	-
Japan	112.1	111.3	97.1
Korea	67.2	81.0	90.2 - 100.4
Slovakia	146.1	-	-
USA	98.6	100.2 - 148.8	48.9
China	82.1	78.5	86.3
Russia	56.6	-	-
India	83.9	76.0 - 105.5	-

Increase in Electromobility

Shares of electric vehicles registered in 2022



24 TWh per year
which is **80%** of yearly generation of NPP Dukovany and Temelín combined

Conclusions

Position of the Market

- Support schemes to be notified
- Two-way CfD
- NPP and RES are different types of sources with their own specifics

Advantages of Nuclear Power

- Energy density and efficiency
- Stability & reliability
- Carbon-neutral energy
- Safety

All successfully commissioned nuclear power plants in the world have fully covered their costs. No NPP was closed because of economy of their operation.

MOTTO

RES and NPP are not antagonistic but rather complementary. Effective way how to reach carbon neutrality is to emplovy both types of sources

Thank you for your attention…