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# Seminar on Nuclear Energy and the EU Sustainable Finance Economy

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# Nuclear Power in Europe - Status Quo

- In 2018, NPP generated around 762 TWh or 28% of the (gross) electricity.
- Four member states produced 80.5 % of the total amount of electricity generated in nuclear facilities in the EU-27: France (54.2%), Germany (10%), Sweden (9%), Spain (7.3%)
- Nuclear share peaked in 1997 with 33 % of electricity generation, while nuclear generation peaked in 2004 with around 1,000 TWh.
- More than half of the EU reactors are operated in France: The country has by far the largest nuclear share (71 %) followed by (in that order) Slovakia, Hungary, and Belgium.
- A total of nine countries rely around one third on nuclear power.
- Average age of the EU-27 fleet is ~ 35 years.

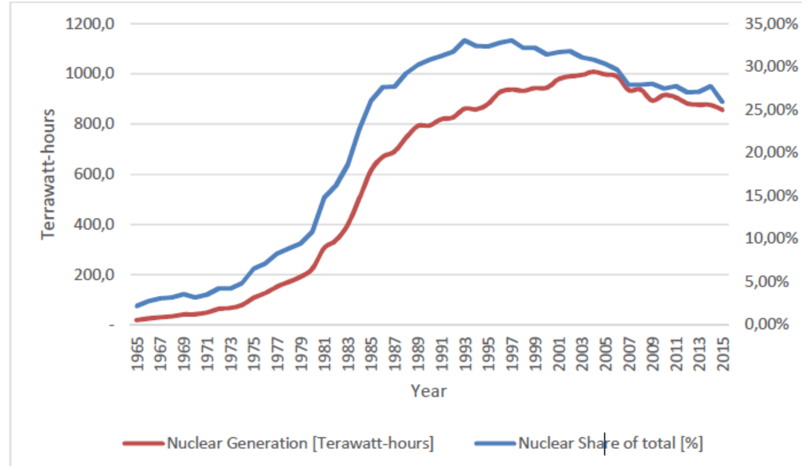



**Figure 21: Nuclear generation and nuclear share in the EU-28, 1965-2015.**

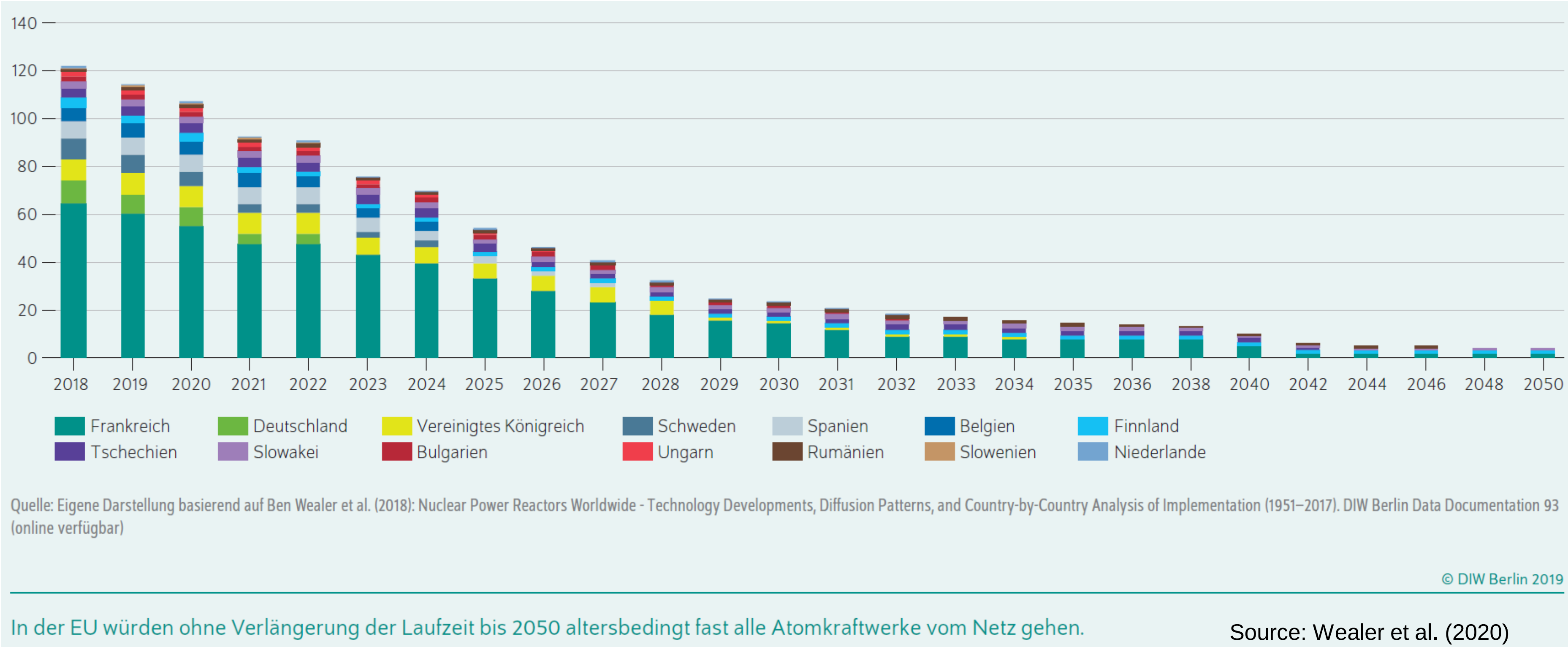
Source: Own depiction based on World Bank (2019) and BP (2019).

**Table 2: Operational nuclear fleet in EU-27 in 2019, ordered by nuclear share**

| Country | Capacity in GW (NPPs) | Average age of the fleet in years | Nuclear share |
|---|---|---|---|
| France | 62.2 GW (57) | 35 | 70.6 % |
| Slovakia | 1.9 GW (4) | 28 | 53.9 % |
| Hungary | 1.9 GW (4) | 35 | 49.2 % |
| Belgium | 5.9 GW (7) | 40 | 47.6 % |
| Bulgaria | 1.9 GW (2) | 31 | 37.5 % |
| Slovenia | 0.7 GW (1) | 39 | 37.0 % |
| Czech Republic | 3.9 GW (6) | 29 | 35.2 % |
| Finland | 2.8 GW (4) | 41 | 34.7 % |
| Sweden | 7.7 GW (7) | 39 | 34.0% |
| Spain | 7.1 GW (7) | 35 | 21.4 % |
| Romania | 1.3 GW (2) | 19 | 18.5 % |
| Germany | 8.1 GW (6) | 34 | 12.4 % |
| Netherlands | 0.5 GW (1) | 47 | 3.2 % |
| | **106 GW (108)** | **~ 35 years** | |

Source: Own depiction based on IAEA PRIS Database.

# EU: Almost all NPPs would be taken offline by 2050 due to their age without an extension of their operating lives




Source: Wealer et al. (2020)

**Timeline without new reactor constructions and lifetime extensions:**

- **By 2025: from 122 GW to only 54 GW**
- **By 2035: only 14 GW in France, Finland, Czech Republic, Romania, Slovakia**
- **By 2050: only 4 GW remaining in France, Finland, Slovakia**

# Taxonomy Regulation Framework

The Taxonomy Regulation sets up a framework for the development of an EU classification system (“EU Taxonomy”) of environmentally sustainable economic activities for investment purposes. It establishes six environmental objectives:

(1) climate change mitigation;

(2) climate change adaptation;

(3) the sustainable use and protection of water and marine resources;

(4) the transition to a circular economy;

(5) pollution prevention and control;

(6) the protection and restoration of biodiversity and ecosystems.

For an economic activity to be included in the EU Taxonomy, it must contribute substantially to at least one environmental objective and do no significant harm to the other five.

# Taxonomy Regulation Framework

**The Taxonomy Regulation sets up a framework for the development of an EU classification system ("EU Taxonomy") of environmentally sustainable economic activities for investment purposes. It establishes six environmental objectives:**

**(1) climate change mitigation; (costs, construction duration, availability)**

**(2) climate change adaptation;**

**(3) the sustainable use and protection of water and marine resources;**

**(4) the transition to a circular economy; (decommissioning, radioactive wastes)**

**(5) pollution prevention and control;**

**(6) the protection and restoration of biodiversity and ecosystems.**

**For an economic activity to be included in the EU Taxonomy, it must contribute substantially to at least one environmental objective and do no significant harm to the other five.**

# Economics in the JRC report

***"Nuclear is the most capital-intensive baseload technology and therefore, as shown in the figure above, retrofitting of the existing fleet is a favourable option in the mid-term. Extending the lifetime of the existing nuclear generation capacities often involves significant works in order to replace ageing components and improve safety to meet higher safety requirements and expectations of the regulatory authorities. However, despite these additional costs, lifetime extension of existing plants remains an economically very attractive option and one that is already implemented or planned in several EU Member States. Regarding new build, some Member States are already undertaking, or are planning, the construction of new large nuclear power plant projects. Moreover, there is an increasing interest in smaller scale nuclear power reactors, so-called Small Modular Reactors (SMRs)."*** **(p. 38)**

# Not One Gen III/III+ Reactor Was Completed in the Western Economies

- Only 24 Gen III/III+ NPPs or 26 GW connected to the grid (~ 7% of operational capacity).
- Not one Gen III/III+ NPP was completed in the Western economies.
- Initial construction durations of around five years increased at least threefold.
- Cost escalation in the sector continue until today: Initial cost estimations increased by ~ 25-370%.

| Site | Reactor | Capacity in MW | Construction start | Original / latest estimated construction end | Original / latest cost estimate $USD_{2018}$/kW |
|---|---|---|---|---|---|
| Olkiluoto-3 | *EPR* | *1.600* | *2005* | *2009 / 2021* | *3,111-3,422 / 7,750* |
| Flamanville-3 | *EPR* | *1.600* | *2007* | *2012 / 2022* | *3,300 / 9,000* |
| Hinkley Point C-1 | *EPR-1750* | *1.630* | *2018* | *2025* | *6,750 / 8,300* |
| Hinkley Point C-2 | *EPR-1750* | *1.630* | *2019* | - | |
| Vogtle-3 | *AP-1000* | *1.117* | *2013* | *2016 / 2021* | *2,350 / 11,000* |
| Vogtle-4 | *AP-1000* | *1.117* | *2013* | *2018 / 2022* | |

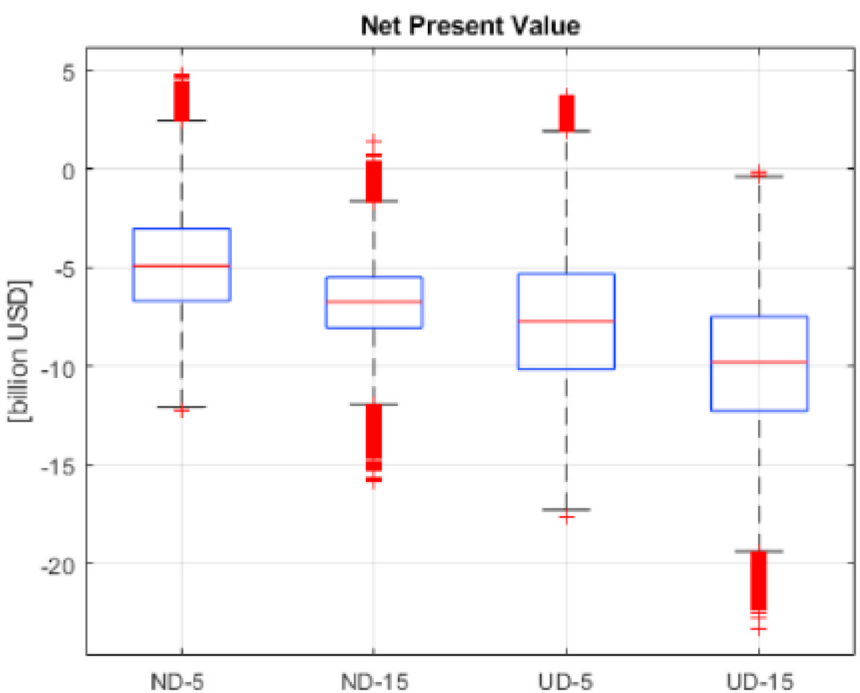
**Overview of Gen III/III+ construction projects in the European Union, U.K., and the U.S., as of 13th of March 2020.**

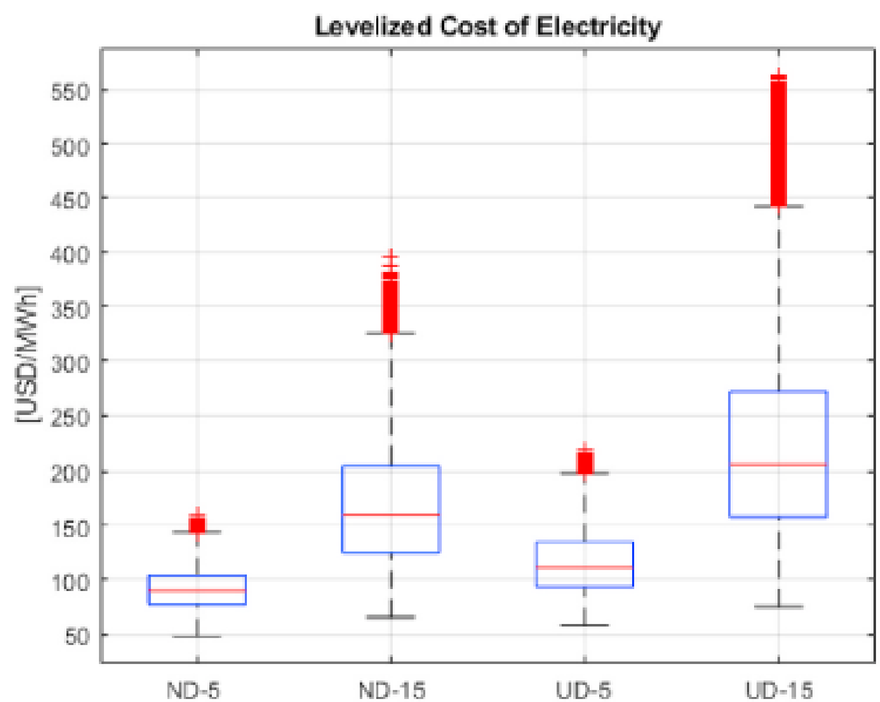
Source: Wealer et al. (2021)

# Nuclear is Not a Profitable Business Case

- Even without accounting for decommissioning and waste management costs the expected net present values are highly negative (-5 to -10 billion USD).

- The levelized cost of electricity, i.e. the needed price for an investor to reach a net present value of 0, are between around 100 and 200 USD/kWh.




Source: Wealer et al. (2021)

# Lifetime Extensions are Expensive too

- **Longer lifetimes** (60 years) made possible by new reactor design is **no game changer** for profitability in the assessment of investments.

- **Extending lifetimes** for existing nuclear power plants **is expensive too**.
- For instance in France EDF's 'Grand Carénage' programme
  - to extend life from 40 to 60 years.
  - Court des Comptes (Court of Audit) forecast €100bn for 2015 to 2030.
  - Cost per reactor €1.7-2.2bn.

- In the U.S., between 2009 and 2025, 15 NPP (will) enter **early-retirement before reaching their lifetime** even after being granted lifetime extensions to 60 years, mainly due to economic reasons.

# Small Modular Reactors: Unproven and to Late

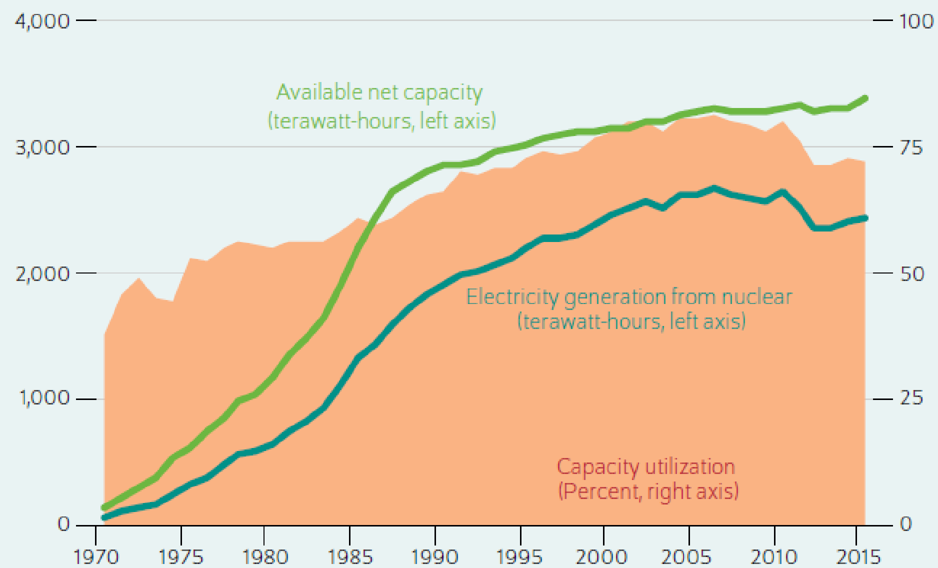
- Due to the low electrical power, the **specific construction costs are higher** than for large nuclear power plants due to the loss of economies of scale.
- SMRs promise shorter production times as well as lower production costs due to their modularity. Individual components or even the entire SMR are to be **industrially (mass) produced**.
- **But** a production cost calculation taking into account scale, mass and learning effects from the nuclear industry shows that, **an average of three thousand SMRs would have to be produced before it would be worthwhile** to start SMR production for a reactor vendor.
- Thus, **it is not expected that the structural cost disadvantage of small-capacity reactors can be compensated** by learning or mass effects.
- Another justification is the expectation of **shorter construction times**. Looking at plants currently under construction or operation, this assumption does **not appear to be empirically founded..**

Source: Pistner et al. (2021)

# Nuclear power subject to fluctuations: NPPs have long outages and low capacity utilization

- **The aggregated capacity utilization factor of all NPP since the 1970s is 66 percent, meaning over a third of the capacity has not been used to generate electricity, largely due to long outages.**
- **From the 2000s up until the Fukushima major accident capacity utilization was at around 80 percent; since 2012, it has decreased to 71 percent.**
- **Planned and unplanned outages are increasing due to i.a. aging reactors and external events like droughts.**

**Electricity generation from nuclear, available electricity capacity, and capacity utilization globally (1970 to 2015)**
In terawatt-hours (left axis), percent (right axis)




Source: Authors' own depiction based on PRIS.



Over a third of the nuclear capacity is not being used.

# Decommissioning (in the European Union)

- Experience in **decommissioning a large-scale NPP** with 1 GW of capacity and with 40 years of operation is **non-existent** worldwide.
- Worldwide only 20 NPPs have been decommissioned.
- In the EU, only Germany has some experience in completing decommissioning projects.
- **High cost variance**:
  - U.S: US$280/kW (Trojan) to US$1,500/kW (Connecticut Yankee) .
  - DE: 1,560€/kW (Würgassen) to 9,280€/kW (Gundremmingen-A). Both are only latest cost estimates.
- This leads to **underestimation of costs** and hence increases funding risks.
- A study by the **European** Commission aggregates the various national **decommissioning cost** estimates of the Member States (excluding the Netherlands and Italy) to around **€123 billion** (EC 2016).

# High-level waste in the JRC Report

***"Spent fuel comprises large amounts of recoverable uranium and plutonium that can be used in fast breeder reactor fuel. While fast breeder reactors are not deployed yet on a large-scale commercial basis, they are very much an option for the future for some countries, and so the uranium and plutonium within the spent fuel is considered a valuable resource."*** **(p. 53)**

- Only 1/3 of the worldwide discharged spent fuel (SNF) was reprocessed.
- Reprocessing of fuel is still done in some countries (France, Netherlands, Russia), while most countries have abandoned it (Belgium, Bulgaria, Germany, Hungary, Sweden, Switzerland, and most recently the U.K.)
- France has the last commercial reprocessing plant in Western Europe.
- Vitrified waste (mostly HLW) is sent back to the country of origin.
- Only two fast breeder reactors are (commercially) operational, both in Russia.
- France abandoned ASTRID project in 2018
- The majority of the SMR concepts currently being pursued or at an advanced stage of development can also be classified as light water reactors. No fundamental differences in the areas of fuel supply or waste management are to be expected for such concepts

# High-level waste in Europe*: No Disposal Facility and 81% of Spent Nuclear Fuel in Wet Storage

- Spent nuclear fuel (SNF) is categorized as **high-level radioactive waste**.
- So far, worldwide **no disposal facility** operational.
- In Europe (excluding Russia and Slovakia) more than ca **60,500 tons** of SNF are stored.
- The majority in **France** (25%), **Germany** (15%) and **U.K.** (14%).
- SNF is generally stored in reactor cooling pools or interim storage facilities (dry or wet). Around 49,000 tons or **81% of the SNF is wet storage.**

**TABLE 3:** Reported spent nuclear fuel inventories in Europe and amount in wet storage as of December 31, 2016

| Country | SNF inventory [tons] | Fuel Assemblies* | Wet Storage [tons] | SNF in wet storage [%] |
|---|---|---|---|---|
| **BELGIUM** | 501** | 4,173 | 237 | 47% |
| **BULGARIA** | 876 | 4,383 | 788 | 90% |
| **CZECH REPUBLIC** | 1,828 | 11,619 | 654 | 36% |
| **FINLAND** | 2,095 | 13,887 | 2,095 | 100% |
| **FRANCE** | 13,990 | n.a. | 13,990 | 100% |
| **GERMANY** | 8,485 | n.a. | 3,609 | 43% |
| **HUNGARY** | 1,261 | 10,507 | 216 | 17% |
| **LITHUANIA** | 2,210 | 19,731 | 1,417 | 64% |
| **THE NETHERLANDS** | 80*** | 266 | 80 | 100% |
| **ROMANIA** | 2,867 | 151,686 | 1,297 | 45% |
| **SLOVENIA** | 350 | 884 | 350 | 100% |
| **SPAIN** | 4,975 | 15,082 | 4,400 | 91% |
| **SWEDEN** | 6,758 | 34,204 | 6,758 | 100% |
| **SWITZERLAND** | 1,377 | 6,474 | 831 | 60% |
| **UKRAINE*** | 4,651**** | 27,325 | 4,081 | 94% |
| **UNITED KINGDOM** | 7,700 | n.a. | 7,700 | 100% |
| **TOTAL** | **ca. 60,500** | | **ca. 49,000** | **81%** |

Source: Own depiction, based on reports under the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management.

Notes: * SNF inventory calculations vary by weight per assembly assumptions: Belgium and Hungary assume 120 kg per assembly; Lithuania 112kg, Slovakia 119kg, and Romania 18.1 kg (Romania lists fuel assemblies in units of CANDU bundles). ** 2011 data (Belgium has not published more recent data). *** 2010 data (the Netherlands has not published more recent data). **** 2008 data (the Ukraine has not published more recent data).

*excluding Russia and Slovakia, as of 31.12.2016

Source: World Nuclear Waste Report (2019).

# Low- and Intermediate Level Waste in Europe*: Only Half of the Countries Have Disposal Facilities for LILW

- More than 550,000 m³ are currently in **interim storage**.
- **Only half** of the observed countries have disposal facilities for LILW (mostly LLW).
- Close to **2,000,000 m³ disposed** (1.8 million m³ by UK and France).
- **However, this does not mean that the waste is successfully eliminated for the coming centuries.** Asse II in DE: 220,000 m³ of mixed disposed waste and salt need to be retrieved.
- Therefore, **the term final disposal should be used with caution**.

*excluding Russia and Slovakia, as of 31.12.2016

**TABLE 2:** Low- and intermediate level waste in Europe in interim storage and disposed (rounded figures) as of December 31, 2016

| Country | LILW in interim storage (m³) | LILW disposed (m³) | Total generated LILW (m³) |
|---|---|---|---|
| BELGIUM | 23,200 | No disposal facility operational. | **23,200** |
| BULGARIA | 11,900 | No disposal facility operational. | **11,900** |
| CZECH REPUBLIC | 1,750 | 11,500 | **13,250** |
| FINLAND | 1,970 | 7,600 | **9,600** |
| FRANCE | 180,000 | 853,000 | **1,033,000** |
| GERMANY | 45,200 | 84,100 | **129,300** |
| HUNGARY | 10,600 | 876 | **11,500** |
| LITHUANIA | 44,000 | No disposal facility operational. | **44,000** |
| THE NETHERLANDS | 11,100 | No disposal facility operational. | **11,100** |
| ROMANIA | 1,000 | No disposal facility operational. | **1,000** |
| SLOVENIA | 3,400 | No disposal facility operational. | **3,400** |
| SPAIN | 6,700 | 32,200 | **38,900** |
| SWEDEN | 13,800 | 39,000 | **52,800** |
| SWITZERLAND | 8,400 | No disposal facility operational. | **8,400** |
| UKRAINE * | 59,400 | No disposal facility operational. | **59,400** |
| UNITED KINGDOM | 130,000 | 942,000 | **1,072,000** |
| TOTAL | **552,400** | **1,970,000** | **2,522,000** |

Source: Own depiction based on reports under the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management and ONDRAF/NIRAS 2017.
Note: *Excluding (stored and disposed) waste in the Chernobyl zone.

Source: World Nuclear Waste Report (2019).

# Key Findings with Respect to Environmental Objectives

- **Climate change mitigation**
  - nuclear power is the most capital-intensive generation technology („to expensive“)
  - Current construction projects take +15 years to built („to slow“)
  - unplanned and planned outages increase („volatile“)
  - SMRs are not available („to late“)

- **The transition to a circular economy**
  - reprocessing abandoned and advanced reactors are not available for a foreseeable future
  - large amounts of HLW with no disposal facility
  - large amounts of LILW with only ½ of MS have diposal facility in place

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# Thank you for your attention!

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