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Sustainability at risk

A critical analysis of the EU Joint Research Centre technical assessment of nuclear energy with respect to the "do no significant harm" criteria of the EU Taxonomy Regulation

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Executive Summary

The findings of this joint policy brief challenge the flawed underlying assumptions of the original EU Joint Research Centre (JRC)'s assessment, published in April 2021, which concluded that nuclear energy is detrimental neither to people nor to the environment. These concern chiefly four aspects: the role of nuclear energy for power generation in the EU27; nuclear waste management; the risk assessment of nuclear technologies; and nuclear proliferation.

Nuclear power generation in the EU

Although, the EU27 still relies for a quarter of its electricity production on nuclear power plants, nuclear production is decreasing. Most of the major nuclear producers in Western Europe decreased their production, while countries in Central and Eastern Europe increased their production. Overall, due to the very high age of running reactors on one hand and a very low number of new reactors coming online on the other hand (due to on-going financial and technical problems), reactor closures are outpacing nuclear new builds rapidly. These developments already question the possible contribution nuclear power can make to climate change mitigation in the EU27 (objective 1 in the Taxonomy Regulation).

Nuclear waste management

A closer look at the assessment of nuclear waste management by the JRC shows various shortcomings of the analysis. For its assessment of nuclear waste management, JRC refers to a very limited amount of scientific literature, mostly to publications by the international nuclear organizations (IAEA, NEA). The assessment neglects the issues of decommissioning. In the EU27, only three reactors have been fully decommissioned. It also fails to mention, that, still, after several decades of using nuclear power for electricity production, nearly half of the EU Member States with nuclear power plants have no operational disposal facility for low-level waste. The large-scale decommissioning of nuclear power plants, looming on the horizon, will put further stress on the Member States without an operational low-level waste disposal facility but also on Member States, where the operational facilities are reaching storage capacity. The JRC's report does not assess the management of intermediate-level radioactive waste (ILW). The assessment omits, that not one Member State has a disposal solution for intermediate-level waste. The few Member States that disposed ILW need to retrieve waste due to safety concerns, while plans for ILW disposal still need to be developed.

Furthermore, the JRC presents geological disposal as a solved issue but theoretical assumptions and practical implementation are very different. As of today, still no geological disposal is in operation. One Member State is constructing the worldwide first geological disposal facility, while two others are in advanced licensing stage. The remaining Member States have no concrete plans yet. Most Member States have not even entered the lengthy site selection process, while planned operations are estimated to occur mostly in the second half of this century. Finally, the JRC's assessment does not mention any costs or funding mechanisms for radioactive waste management. To manage its radioactive waste (not including decommissioning), the EU27 will have to spend a minimum of 422 to566 billion euros.

Risk assessment and severe accidents

For its assessment of the potential consequences of severe accidents, JRC refers to a very limited amount of scientific literature, which does not provide a comprehensive assessment of different consequences of severe accidents. The assessment discusses only two indicators with respect to severe accidents – maximum number of fatalities and fatality rates –, that are clearly an insufficient risk metric to fully represent the consequences of severe accidents. At the same time, it relies on theoretical analyses to assess these indicators without discussing the underlying uncertainties and methodological limitations of such an approach. Beyond this, the JRC's assessment does not discuss other indicators with respect to severe accidents – although they are relevant and there exists scientific literature making clear that these indicators have to be taken into account. Among them are for example the number of people evacuated or relocated, the area of land contaminated for decades or even centuries nor the economic consequences of a severe accident. Finally, the JRC finds that severe accidents in nuclear power plants have significant consequences both for human health and for the environment. Severe accidents in nuclear power plants can happen and they do have significant consequences for human health and the environment. Thus, taking into account all consequences of severe accidents, nuclear power clearly violates any possible meaningful definition of a "do no significant harm" criterion.

Nuclear Proliferation

Fundamentally, the JRC report does not assess the risks of nuclear proliferation when assessing the "do not significant harm" DNSH criteria for nuclear energy production. Any use of nuclear weapons would have catastrophic impacts on human health and the environment.

The system of international security is set up to disincentivise the acquisition and use of nuclear weapons. Yet, these systems are not fail-proof. If the protective systems fail, there could be catastrophic effects. The consequence of nuclear weapons use is not in any meaningful sense comparable to risks by other technologies in terms of casualties and harm done. Effects would not only effect humanity and the environment today, but future generations as well.

The JRC reports evades the complex history and an in-depth discussion of the use of nuclear energy and nuclear proliferation. However, the simple fact is that all nuclear technologies have a dual-use characteristic and therefore carry a potential for misuse. Any discussion of a "do no significant harm" criterion not covering nuclear proliferation is thus incomplete.

For all these reasons, we conclude that the JRC report is clearly not sufficient to draw a meaningful and comprehensible conclusion with respect to the "do not significant harm" (DNSH) criteria for nuclear power.

1. Introduction

The EU taxonomy for sustainable activities is the EU's flagship plan to steer the financial economy towards the European Green Deal. It is an exhaustive rulebook listing which investments are "sustainable". The fundamental premise is that they should benefit the environment without harming other environmental objectives or people. Earning the label will facilitate access to funding, both public and private. A row over fossil gas and nuclear power led to a proposal published at the end of April 2021, which excludes both technologies temporarily.

The proposal for the taxonomy regulation (EC 2018b; 2021b) goes back to the EU's "Action Plan: Financing Sustainable Growth" (EC 2018a), which called for the creation of a classification system for sustainable activities. The European Commission launched the Technical Expert Group (TEG) on sustainable finance to develop recommendations for technical screening criteria which respond to the framework laid out in the taxonomy regulation. According to (TEG 2020b) the

> *"… TEG mandate has been to focus on economic activities that can make a substantial contribution to climate change mitigation or adaptation, while avoiding significant harm to the other environmental objectives."*

In its final report, the TEG found it impossible to conclude that nuclear energy does not cause significant harm to other environmental objectives on the time scales in question. A robust "do no significant harm" (DNSH) assessment was infeasible to undertake, as no permanent, operational disposal site for high-level waste exists yet, from which long-term empirical data can be drawn in order to evaluate nuclear energy (TEG 2020a, p. 210). Furthermore, the TEG also recommended an in-depth study of the DNSH criteria of nuclear power (TEG 2020a, p. 211).

In the aftermath, the European Commission asked the EU's Joint Research Centre (JRC) to assess whether nuclear meets the criteria to be included in the taxonomy and which technical screening criteria should be used to assess the "no significant harm" aspects of nuclear energy. This includes environmental risks with respect to the environmental objectives listed in the taxonomy regulation with particular attention to protection of water, waste prevention and recycling (in particular if waste may cause significant and long-term environmental harm), pollution prevention and control, and protection of ecosystems and biodiversity. In March 2021, the JRC published its report and concludes that the analyses did not reveal any science-based evidence that nuclear energy does more harm to human health or to the environment than other electricity production technologies already included in the Taxonomy (JRC 2021).

The Heinrich-Böll-Stiftung European Union office commissioned two policy briefs that challenge the assumptions and methodology upon which the JCR report builds its arguments on. The policy briefs have been synthesised in this joint brief. One focuses on waste management (section A, written by Dr. Ben Wealer), the other takes a closer look on the risk analysis (section B, written by Dr. Christoph Pistner and

Dr. Matthias Englert). They show that there is a number of omitted variables, a failure to account for interconnected and accumulative risks, as well as inadequate premises concerning final disposal, decommissioning and new forms of nuclear power.

The objective of this paper is not to deliver a detailed analysis of the entire report, but to focus on key arguments upon which the JRC report is built and which do not hold at closer look. For further discussions of the JRC report see for example (Österreichisches Ökologie Institut 2021; BASE 2021; GoE Art. 31 2021; SCHEER 2021). To have a better understanding on the situation of nuclear energy usage in Europe, the paper starts with an overview over operational, planned and closed reactors and their significance for electricity generation across the European Union.

2. Overview: Nuclear power in Europe

2.1. Operational nuclear power fleet in the EU27

In mid-2020, 13 countries used a total of 107 nuclear reactors for electricity generation in the EU27 (see Table 1). Three quarters of all the reactors are located in Western Europe (80); more than half (56) of the EU reactors are operated in France; which has by far the largest national nuclear share in the electricity mix (71%). In mid-2020, three more countries depend on nuclear power plants for roughly half of their electricity generation: Slovakia (54%), Hungary (49.2%), and Belgium (47.6%). Although, Eastern and Central Europe has only a quarter of all EU reactors, they rely, except for Romania, the most on nuclear power for electricity generation. In 2019, nuclear power plants in the EU27 generated around 766 Terawatt-hours (TWh) of electricity. This represents around a quarter (26.4%) of the (gross) electricity produced in the EU27. Around 84% of this electricity was produced in only five Member States. France alone accounts for more than half of this (52.1%), followed by Germany (9.8 %), Sweden (8.7 %), Spain (7.6 %), and Belgium (5.7%) (Table 2).

Table 1: Operational nuclear fleet in the EU27 in mid-2020, ordered by nuclear share.

Country	Operational reactors	Closed reactors	Average age	Nuclear share
France	56	14	35.10	70.6%
Slovakia	4	3	28.3	54.0%
Hungary	4	0	35	49.2%
Belgium	7	1	40.3	47.6%
Bulgaria	2	4	30.8	37.5%
Slovenia	1	0	38.7	37%
Czech Republic	6	0	29	35.2%
Finland	4	0	41.3	34.7%
Sweden	7	7	39.1	34%
Spain	7	3	35.4	21.4%
Romania	2	0	18.5	18.5%
Germany	6	30	33.6	12.4%
Netherlands	1	1	47	3.2%
Lithuania	0	2	22	0%
Italy	0	4	20	0%
	107	**69**	**35**	

Source: Based on Schneider et al. 2020, 304–5.

In the last decade total electricity production from nuclear power plants decreased by 11%. Except for Sweden, four of the five major nuclear producers decreased their production. On the other hand, except for Romania, which started nuclear generation in 1996, countries in Central and Eastern Europe increased their production. The largest increases were in the Czech Republic and Bulgaria (Table 2).

Table 2: Nuclear generation in Gigawatt-hours (in 2010, 2019) and nuclear shares.

Country	2010	2019	Growth 2010-2019	Share of total EU27 generation
France	428,521	399,011	-6.9%	52.1%
Germany	140,556	75,071	-46.6%	9.8%
Sweden	57,828	66,130	14.4%	8.6%
Spain	61,990	58,349	-5.9%	7.6%
Belgium	48,157	43,523	-9.6%	5.7%
Czech Republic	27,998	30,246	8%	4.0%
Finland	22,800	23,870	4.7%	3.1%
Bulgaria	15,249	16,555	8.6%	2.2%
Hungary	15,761	16,288	3.3%	2.1%
Slovakia	14,574	15,282	4.9%	2%
Romania	11,623	11,280	-3%	1.5%
Slovenia	5,657	5,821	2.9%	0.8%
Netherlands	3,969	3,909	-1.5%	0.5%
	854,683	**765,335**	**-10.5%**	

Source: Eurostat[1]

2.2. Ongoing and planned new construction

In the last two decades, only three reactors were connected to the EU-grid, all three in Eastern Europe. In 2002/03, the Czech Republic started operations of two reactors (Temelin) and in 2007 in Romania the Cernavoda-2 reactor came online. Construction of these reactors already began in the 1980s. As of 2021, two reactors of the French EPR-Design are under construction in France and Finland and two Russian VVER-440 reactors in Slovakia.[2] Construction of the two EPR reactors was originally estimated to take four to five years. Olkiluoto-3 is expected to start operations in 2022 and Flamanville-3 in 2023. Both reactors are 14 resp. 12 years behind schedule and with a threefold construction time and costs as initially estimated. Three more reactors have been ordered bindingly in the EU27: one by Finland (Hanhikivi) and two by Hungary (Paks). All three reactors are going to be supplied by Russian Rosatom (INRAG 2021, 7).

1 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Nuclear _ energy _ statistics#Nuclear _ heat _ and _ gross _ electricity _ production, accessed at 30th of July 2021.

2 At the Mochovce site two reactors (Mochovce-3 and -4) are under construction since 1985 (Schneider et al. 2020).

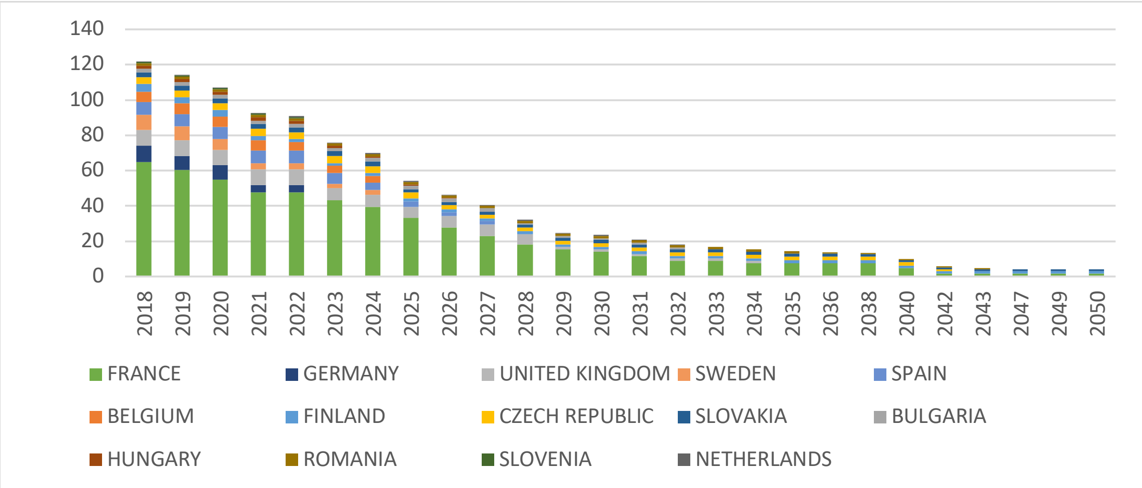
In Eastern Europe, Bulgaria, Poland, Romania, and the Czech Republic (and Ukraine) have made repeated attempts to build new nuclear power plants. However, these have been unsuccessful due to high costs and financing issues difficulties. "Nevertheless, the determination of these governments to build new reactors does not seem to be waning" (INRAG 2021, 6). These five countries have also experiences with abandoned construction sites: A total of nine reactors were cancelled even after construction started and ended up in construction ruins. In the EU27 alone, 27 nuclear construction projects were cancelled after the official construction start.[3] Overall, worldwide, one in eight reactor construction sites has been abandoned (Schneider et al. 2020, 53).

2.3. Closed reactors and planned lifetime extension

Without significant new construction in the past decades, the average age of the EU27 fleet is 35 years. More than 80% of the reactors have been operating for more than 30 years (INRAG 2021). Three countries operate reactors with an average age over 40 years: Belgium, Finland, and the Netherlands (see Table 1). As of mid-2021, 69 reactors have been closed in the EU27. Most of the European reactors have been closed after an average operating time of 25 to 35 years (INRAG 2021, 6) One in three closed reactors worldwide is located in the EU27.

In the next five years, two of the top-5 nuclear electricity producing countries will phase out nuclear power: Germany (in 2022) and Belgium (in 2025). This will be followed by Spain in 2035, and Sweden 2040. This would even further increase France's share of nuclear generation in the EU27 to more than two thirds. Given the scheduled closures and end of lifetimes, the installed power capacity in the EU would drop sharply (see Figure 2). In the next few years, installed capacity would decrease by more than 50%. By 2035, only around 14 Gigawatt of capacity would be in the EU-grid. The remaining nuclear power plant operators would primarily be located in Eastern Europe: the Czech Republic, Romania, and Slovakia (Wealer et al. 2019).

Figure 1: Installed capacity in Gigawatt of nuclear power plants in EU-28 given the scheduled shutdowns and end of life dates.



Source: Wealer et al. 2019.

3 In Austria (1), Bulgaria (2), Czech Republic (2), Germany (6), Italy (3), Lithuania (1), Poland (2), Romania (3), Spain (4), and Sweden (1).

2.4. Summary

Although, the EU27 still relies for a quarter of its electricity production on nuclear power plants, nuclear production is decreasing:

- Most of the major nuclear producers in Western Europe decreased their production, while countries in Central and Eastern Europe increased their production.
- Overall, due to the very high age of running reactors on one hand and a very low number of new reactors coming online on the other hand (due to on-going financial and technical problems), reactor closures are outpacing nuclear new builds rapidly.
- This already questions the possible contribution nuclear power can make to climate change mitigation in the EU27 (objective 1 in the Taxonomy Regulation).

3. Shortcomings of the JRC assessment on nuclear waste management

This section takes a closer look at the assessment of nuclear waste management in the JRC report. Of special interest are i/ low-and intermediate-level waste management, ii/ decommissioning of nuclear reactors, and iii/ high-level waste management. First some of the main findings of the JRC are summarized, in a second step the shortcomings of the analysis are presented.

3.1. Low-level and intermediate-level waste management

3.1.1. Definition

The International Atomic Energy Agency (IAEA) (2018) defines low-level waste (LLW) as radioactive waste that is above clearance levels, but with limited amounts of long lived radionuclides. Typical materials that fall into the LLW category include clothing, packaging material, soil, or waste from decommissioning. Intermediate-level waste (ILW) is waste of higher activity levels than LLW, containing relatively large quantities of long-lived radionuclides. Characteristic sources of ILW are nuclear fuel cladding, some reactor components during decommissioning, various types of sludge from treating radioactive liquid effluents. Large volumes of ILW are also created during the reprocessing of spent nuclear fuel (WNWR 2019).

3.1.2. Low-level waste (LLW)

> *"There is international consensus that very low level waste, low level waste and short-lived intermediate level waste can be safely disposed of in near-surface facilities at a depth of no more than 30 m."* (JRC 2021, 164).

Only reading this statement gives the impression, that near-surface disposal is the common disposal route for LLW. Only later in the report (p. 244), the JRC mentions that other countries plan to dispose LLW in geological disposal facilities. There is also no consensus, that near-surface disposal is the disposal route for (short-lived) ILW. On the contrary, the disposal of ILW "requires a greater degree of containment and isolation than that provided by near surface disposal" (IAEA 2018, 250) (see next section).

> "*In Europe, repositories of this type exist in France, Hungary, Slovakia, Spain and the United Kingdom. In Finland and Sweden low level waste and short-lived intermediate level waste are disposed of in mined facilities at up to 100m depth. In addition to these seven countries, other EU Member States, with as well as without nuclear power plants, are at various stages of implementation of low-level waste repositories [3.3.8-9]).*"[4] (JRC 2021, 165)

Already in 2017 and again in 2019, in its reports on the progress of implementation of Council Directive 2011/70/EURATOM to the European Parliament and to the Council, the European Commission observed that although, indeed most Member States have routes for the disposal of (very[5]) low-level waste in place, other Member States still have to develop concrete disposal plans (EC 2019c, 8). As of mid-2021, the following countries that operate(d) nuclear power plants have no operational LLW disposal facility: Belgium, Bulgaria, Germany, Italy, Lithuania, and Slovenia (EC 2019b, Table 8). The JRC correctly acknowledges that the majority of (V) LLW is yet to come with the decommissioning of the reactors. This puts further stress on the Member States without an operational LLW disposal facility but also on Member States, where the operational facilities are reaching storage capacity. Therefore, about half of the Member States are planning to build new disposal facilities in the next decade (EC 2019b, Table 8).

3.1.3. Intermediate-level waste (ILW)

The JRC does not treat the issue of intermediate-level waste (ILW) in detail. The disposal routes for ILW are not analyzed in chapter 3. On page 2013, the JRC assessment cites the definition of ILW of the IAEA (2009), which states that ILW "because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal." However, the report does not go into detail on possible disposal routes for ILW.

4 With the exception of the last segment, the entire section 3.3.8.8 of the report can be found in the cited source (3.3.8-9 in the report; ("existing waste management routes" hosted on the website of the European Nuclear Safety Regulators Group). Interestingly, the last segment of the source did not make it into the JRC assessment, as it is outdated: "By 2020 it is likely that all the states with nuclear power plants will have an operational repository for this type of waste, with the exception of the Netherland." http://www.ensreg.eu/safe-management-spent-fuel-and-radioactive-waste/existing-waste-management-routes, accessed 28.07.2021.

5 Many national classification systems do not recognize the category of very low-level waste.

The JRC provides the inventory of ILW as well as the 12 thousand m³ of disposed ILW citing from (EC 2019a) but withholds, that the report from the European Commission states that in most cases Member States, which have disposed ILW, plan to retrieve the waste in order to re-dispose it in new facilities (EC 2019a, 11). This is motivated by safety concerns as the "the current disposal facilities do not meet present safety requirements" (EC 2019a, 17). In the EU27, there are also countries with unconditioned ILW, meaning that the wastes are stored as generated and not in stable and immobilized form. This is for instance the case in Hungary with 3,252 m³ (EC 2019a, 38).

But these new facilities for ILW still have to be planned, conceptualized, constructed, and eventually commissioned. Although, already in 2017, the Commission identified the lack of plans and concrete disposal concepts for the ILW management as one of the main challenges. Two years later, the Commission observed "no significant progress" in this respect. The report continued that "[t]he engagement of the Member States needs to increase in developing long-term management solutions for intermediate-level waste [...] including research, development and demonstration activities as soon as possible to avoid placing an undue burden on future generations" (EC 2019c, 9–10). In its conclusion, the European Commission encourages "Member States, which have not yet done so, to take a swift decision on their policies, concepts and plans for the disposal of radioactive waste, in particular intermediate-level waste" (EC 2019c, 17).

3.2. Decommissioning of nuclear power plants

Overall, decommissioning does not play a major role in the JRC report but as "decommissioning of nuclear power plants will become an increasingly important activity for the European nuclear industry in the coming years due to the ageing of the fleet" (EC 2016, 30), this section not only takes a more detailed look at the JRC's findings but also at the challenges lying ahead.

3.2.1. Decommissioning definition and decommissioning strategies

The JRC assessment treats decommissioning as a part of the operation phase of a nuclear power plant (JRC 2021, 123). This is not standard. According to the IAEA (2018, 53) decommissioning contains the "administrative and technical actions taken to remove all or some of the regulatory controls from a facility." Dismantling, on the other hand, refers to "the taking apart, disassembling and tearing down the structures, systems and components of a facility for the purposes of decommissioning." This is not part of the operating phase.

The JRC mentions "immediate dismantling", "safe enclosure", and "entombment" as the three main decommissioning strategies (JRC 2021, 129–31). This is again not standard. Entombment, the de facto "burial" of a reactor, is not considered as an acceptable strategy for decommissioning. It only may be considered acceptable under exceptional circumstances, for instance after a severe accident (IAEA 2018, 54). Worldwide there are only five cases, where entombment had been applied: St. Lucens in Switzerland, reactor 4 of the Chernobyl station, and the three

U.S. Department of Energy reactors BONUS, Hallam, and Piqua (Suh, Hornibrook, and Yim 2018).

Another shortcoming of the JRC analysis is that the assessment fails to report on the actual progress of decommissioning. As of mid-2021, only 20 commercial nuclear reactors have been dismantled worldwide. These represents only 6 GW of capacity and constitutes mostly early demonstration, prototype, and smaller reactors. A "classical" nuclear reactor, with 1 GW of electrical capacity and 40 years of operation has not been decommissioned nor dismantled so far worldwide (WNWR 2019). Although immediate dismantling is turning out to be the preferred decommissioning strategy, as the JRC states correctly, still decommissioning of more than a third of all closed reactors is deferred for several decades (Schneider et al. 2020). The few on-going decommissioning projects encounter delays as well as cost increases (e.g. (Scherwath, Wealer, and Mendelevitch 2020). In the EU27, only three reactors have been fully decommissioned (EC 2019c, 4), all in Germany.

3.2.2. Waste generation and classification

> "*Most of the radioactive waste resulting from decommissioning activities is short-lived waste classified as very low or low level waste. Moderate quantities of intermediate level waste might come from the most activated parts of the reactor (such as internals of the vessel and biological shield), whereas generally no HLW is generated in this step, since spent fuel is removed from the plant before starting the decommissioning." JRC (2021, 141)*

To prove this assessment, a "typical" distribution of decommissioning waste is shown in figure 3.3.7-9. The figure uses the forecast of radioactive waste inventory generated from decommissioning activities in France during the period of 2017-2040.

There are two shortcomings for this assessment. First, looking at the cited publication of the IAEA, one finds that decommissioning can be expected to generate a quantity of short lived LILW between 5,000 and 6,000 tons as mentioned in the JRC tons but withhold from the JRC assessment is that another up to 1,000 tons of long lived LILW and HLW can be generated. Although generally less than 1,000 tons (IAEA 2008, 16), the publication nonetheless mentions that ILW and HLW can emerge. This is for instance the case for the decommissioning of José Cabrera and Vandellos reactors in Spain, where 185 m^3 of "special waste" was generated, that needs to be disposed of with HLW, mainly from cutting of the reactor vessel internals (Spain 2017). Especially the cutting of the reactor vessel internals creates waste disposal problems, as they represent ILW, for which no disposal route exists so far (see above). It is expected that ILW by 2030 will increase by approximately 35%, with the biggest part of this increase coming from decommissioning activities (EC 2019a, 27). Overall, all generation estimates have to be taken with caution as only one reactor as big as 1 GW has been decommissioned worldwide yet but this reactor (Trojan in the US) was only operational for 17 years. The quantity of decommissioning waste depends among others on the operating time, the reactor technology, and the size of the reactor (WNWR 2019, 34).

Second, the presented typical waste category distribution for decommissioning (Figure 3.3.7-9.) is based on estimated decommissioning projects in France in the years 2017 to 2040. In mid-2021, France has not yet fully dismantled one single reactor.

3.2.3. Decommissioning waste, clearance, and recycling

> *"The decommissioning process generates a large amount of waste [...] Nevertheless, large amounts of the materials generated are neither contaminated nor activated above background levels. Such materials can be cleared from any further regulatory control (clearance) and disposed of as a conventional waste, reused or recycled. [...] Various estimations and practical experience show that 90% or more of the total material produced when dismantling and demolishing a nuclear installation is potentially clearable." (JRC 2021, 139)*

For the reported 90% potentially clearable share of the total decommissioning waste, the cited sources are reporting estimates and not practicable experiences. In addition, relevant information for decommissioning waste was withhold from one of the sources used for the 90% clearance rate. Schmittem (2016) was used to cite the clearance rate of 95% but the source also states on decommissioning in Japan (its focus): "[however] except for a local solution for low-level radioactive waste (LLW) in both the JPDR and the Tokai I NPP decommissioning projects, the question of radioactive waste disposal remains largely unsolved in Japan" (p. 14). The local solution for LLW disposal for the two sites was to bury the waste on site just below surface level (p. 16).

Another shortcoming is that the JRC report does not go into detail, what happens with the materials after they have been cleared. Only a fraction of the cleared waste will be reused or recycled. A major problem is the lack of markets for cleared material to renter the value-added chain: "The opportunity to clear materials can optimise the volume of (V)LLW requiring management; recognising, however, that this is not possible in some countries, or that there may be limited or no markets for cleared materials" (OECD/NEA 2020, 52).

3.2.4.Decommissioning costs, funding, and market

The JRC report does not mention any costs for decommissioning.

The Commission aggregates the various national decommissioning cost estimates of the Member States (excluding the Netherlands and Italy) to around €123 billion (EC 2016). Even though, some academics raised the risk of underestimating decommissioning cost and the risks of underfunding early on (e.g., Solomon 1982; Pollock 1986; DuBoff and Stenger 1991; Cantor 1991); decommissioning costs were largely ignored as they were always discounted away. With no large-scale (~ 1 GW) reactor with 40 years of lifetime being decommissioned cost estimates still must be considered "tentative at best". Complicating the matter, is that cost estimates are often based on outdated engineering studies or are not publically available (WNWR 2019). Elements and approaches of cost estimation methodologies differ internationally, as well as the differences on uncertainties, cost escalations, or contingencies (OECD/NEA 2016).

3.3. High-level waste management

3.3.1. Definition

High-level waste (HLW) contains large concentrations of long-lived radionuclides. It is also waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process (IAEA 2018, 250). HLW arises essentially from the irradiation of nuclear fuel, and is managed either as spent nuclear fuel, where this is treated directly as waste, or as the streams of actinide and fission products separated in reprocessing (WNWR 2019, 26).

3.3.2. Strategies for HLW Management

> *"EU Member States use different strategies with regards to the management of spent fuel. Some Member States have chosen to reprocess spent fuel; some Member States have chosen the once-through fuel cycle option by which spent fuel will be directly disposed of in deep geological disposal. A few Member States applied both approaches – part of their spent fuel is reprocessed and the remaining spent fuel will be directly disposed. [...] The first deep geological repository for spent fuel disposal will start its operation within the present decade in Finland. Corresponding repositories are in advanced licensing stages in Sweden and France as well." (JRC 2021, 217)*

The JRC presents geological disposal as a solved issue and describes on many pages the Finish, French, and Swedish concepts. The above statement gives the impression, that all Member States have concrete plans for the disposal of HLW. This is not the case. The segment "current spent fuel inventory in the European Union" where the above statement is from, is based on the report from the European Commission. But the JRC again fails to mention, that one of the main challenges identified by the Commission (already in 2017) was the lack of concrete disposal concepts for HLW (EC 2019c, 9). The remaining 12 Member States also have plans for a deep geological repository but they are not concrete and at different stages of implementation. Most Member States have not even entered the lengthy site selection process, while planned operations are estimated to occur mostly in the second half of this century. Table 3 gives an overview of the status of the projects for geological disposal in the EU27 nuclear countries, as of 2019.

Table 3: Status of the projects for geological disposal in the EU27 nuclear countries, as of 2019.

Member State	Siting	Planned start of operations	Underground research laboratory
Belgium	No date defined pending national policy	Not available	HADES in operation
Bulgaria	Prefeasibility study ongoing and 6 potential sites selected	Not available	
Czech Republic	Ongoing site selection. Two sites to be selected by 2022	2065	Site to be selected, operation by 2030
Germany	Site selection by 2031	2050	
Spain	Site selection 2023-2027	2069	
Finland	- Construction license granted for Eurajoki (Olkiluoto-3) in 2025. - Fennovoima submitted an environmental impact assessment for the Hanhikivi site in 2016	- 2024 - planned for 2090	
France	Site selected	2025	Bure in operation since 2006, Tournemire in operation since 1990
Croatia	Start of siting in 2050	2068 or 2088	
Hungary	Site selection ongoing	2064	Planned to start operations by 2032
Italy	Not available	Not available	
Lithuania	Site to be selected by 2033	2066	
Netherlands	Decision in 100 years	About 2130	
Romania	Siting in 2025	2055	Planned on the selected site
Sweden	License application for construction under review for Forsmark site	Until 2032	Aspo in operation since 1995
Slovenia	Site to be selected until 2055	2065	
Slovakia	Site to be selected by 2030	2065	

Source: Based on (EC 2019b).

As it is the case with disposing of ILW, Member States need to increase engagement in "developing long-term management solutions for HLW including research, development and demonstration activities as soon as possible to avoid placing an undue burden on future generations" (EC 2019c, 9–10). Following §12 (1)(f) of the Directive, each Member state is required to include in its national programme "the research, development and demonstration activities that are needed in order to implement solutions for the management of spent fuel and radioactive waste". As of today, only four Member States (France, Sweden, Belgium, and Finland) operate underground research laboratories, while three more Member States (Hungary, Romania, and Czech Republic) planning to set up a laboratory in the next decade only (Table 3). In addition, only very little information is provided by the Member States on research, development and planned demonstration activities planned "to support implementation of the solutions needed for safe long term management of spent fuel and radioactive waste" (EC 2019b, 64).

The references and sources for Chapter 5 are mostly publications by the nuclear agencies (NEA, IAEA). Interestingly, one publication by Ramana (2019) is listed as one of the cited sources but no reference in the text could be found. Ramana (2019) stresses that technological solutions for HLW are insufficient as there are no easy technical fixes for the conundrum of nuclear wastes. Ramana emphasizes the relationship between the technical and social dimensions of the nuclear waste problem and why these dimensions make the problem so hard to solve. An aspect completely missing from the JRC assessment or to quote Ramana (2019, 30): "Public concern about proposals for nuclear waste disposal is often dismissed by members of the nuclear establishment as not being based on scientific or technical facts."

Implementing HLW disposal solutions is a not a simple technological problem but a "wicked problem" in the parlance of political and social scientists. It has political, economic, and social challenges, for which a solution is often not satisfactory for everyone, or in the extreme case, not solvable at all (Brunnengräber 2019, 337). Nuclear waste management is strongly determined by the political, social, and cultural background of a country and characterized by a landscape of conflicting actors with different ideologies and interests, which provoke conflicts. Especially, a deep geological disposal facility has still no blueprint, given the complex interactions of social, and technical dynamics (see Brunnengräber 2019 for more details).

3.3.3. Operational experience for geological disposal facilities

The JRC (2021, 273) states in its concluding remarks of chapter 5 "Disposal of radioactive waste":

> "*There are presently no deep geological repositories in operation, but after four decades of research and technology development the construction and operation of several repositories is expected in the present decade. The process for the design, licensing, construction, operation and final closure of deep geological repositories is regulated by national law, based on international conventions and*

European directives; this means that there is a common ground shared by all programmes based on the best available principles and concepts."

There are several shortcomings in these concluding remarks.

First, there is one geological disposal facility for HLW in operation: the Waste Isolation Plant Project (WIPP) in the U.S., which is not mentioned in the JRC assessment. The WIPP repository, used for transuranic wastes from the U.S. weapons complex, has been plagued by various accidents, incidents, and mismanagement (Klaus 2019). Second, arguing that a common European Directive and national regulation will lead to best available principles and concepts is a bold statement without evidence. Starting with the European Directive first. Although the Member States are required to incorporate the Council Directive 2011/70/EURATOM into their national frameworks, which could eventually in the end lead to common ground, the Commission found that more than half of the Member States had not correctly transposed the Directive's provisions. The Commission has thus started infringement procedures against 15 Member States. Among them the nuclear states Hungary, Czech Republic (case closed in 2019), Italy, the Netherlands, Romania, and the U.K. The main issues concerned for half of the Member States were the requirements on i.a. financial resources, safety demonstrations of facilities or activities, and expertise and skills (EC 2019c, 10).

Also, the "regulation by national law" does not mean that all programmes are therefore based on the best available principles and concepts. Still, the effectiveness of a regulatory agency depends of many factors, i.e. staff competence, funding, technical support organizations etc. But in order to assess this on a European level information on these aspects must be reported to the Commission, which only half of the Member States have done so far. In addition, a few Member States have not reported any information on the competences of their employed staff or on mechanisms in place to maintain staff competence (EC 2019b, 23).

3.3.4. Costs and funding of HLW management

The JRC report does not mention any costs or funding mechanisms for radioactive waste management.

§9 of the Directive requires the Member States to ensure adequate financial resources for the implementation of their waste management programmes, while §12 requires them to estimate the costs and implement financing schemes. No country has yet both estimated costs precisely and closed the gap between cost estimates and set-aside funds (WNWR 2019; EC 2016). The overall sums for waste management are staggering. To manage its radioactive waste (not including decommissioning), the EU-28 will have to spend a minimum of 422-566 billion Euros. Although, due to "a lack of completeness of the costs, nor an indication of timing, it is not possible for the Commission to report a consistent figure discounted to the present" (EC 2019b, 53). Discounting is one key factor leading to the underestimation of costs. It is based on the expectation that the funds will grow over time, which is usually achieved through investing the funds but little information on the funds' investments and management are publically available or are even reported to the European Commission by the Member States. This puts the Commission in a position, where it is unable to assess, whether it is assured that funds are available when needed in the future (EC 2019b, 63). The usage of overly optimistic discount rates in the current low interest rate environment is a fundamental issue of funding waste management (and decommissioning).

> *"The cost of management of radioactive waste and spent fuel must be done by those who produced the waste, or "polluter's pay principle." (JRC 2021, 203)*

Although, the polluter-pays-principle is embedded in most domestic legislation, it is not rigorously applied. Instead, the long-term costs and risks are passed on to future generations. The operators may only be required to contribute to the financing of the long-term costs (von Hirschhausen 2017; Wealer, Seidel, and von Hirschhausen 2019; Jänsch et al. 2017). In addition, an operator of a nuclear power plant will not be held financially liable for any problems arising during the long-term storage of the waste (Irrek 2019).

3.3.5. "Closing" the fuel cycle

Reprocessing nuclear wastes or "closing" the fuel cycle plays a prominent role in the JRC assessment but this will not solve the waste management issues. Or to quote from the report: "The geologic repository for final disposal of HLW is a necessary facility in the lifecycle of nuclear energy independently from the fuel cycle implemented" (JRC 2021, 163).

Most countries have abandoned reprocessing, mainly due to economic reasons and the overwhelmingly dominant expectation since several decades is that higher activity wastes will at some point be buried in a deep geological disposal (MacKerron 2019, 289). In Europe, reprocessing is still part of the waste management concept in some countries (France, the Netherlands, Russia), while most countries have suspended or stopped it for mainly economic reasons (Belgium, Bulgaria, Germany, Hungary, Sweden, Switzerland, and most recently the UK) (WNWR 2019). Only France is still and two Member States (Czech Republic and Hungary) are considering entering reprocessing (EC 2019c, 7). Most countries had to send their spent nuclear fuel abroad for reprocessing to either France, the UK, or Russia (only a few central European countries continue to do so). As of mid-2020, only France (apart from Russia) still operates an industrial reprocessing facility. As the vitrified waste (mostly HLW) is sent back to the country of origin (WNWR 2019), reprocessing includes transboundary movements of HLW. A risk, which has not been assessed in the JRC report.

"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" (JRC 2021, 53).

Fast reactors are not new and have a several decades-long history of development (Pistner and Englert 2017). Despite several attempts to commercialize these reactors, they have proofed problematic and very costly and are unlikely to be pursued by any private companies without large government subsidies (Thomas 2019).

3.4. Summary on nuclear waste management

A closer look at the assessment of nuclear waste management by the JRC shows various shortcomings of the analysis. For its assessment of nuclear waste management, JRC

- refers to a very limited amount of scientific literature, mostly to publications by the international nuclear organizations (IAEA, NEA);
- neglects the issues of decommissioning. In the EU27, only three reactors have been fully decommissioned;
- fails to mention, that, still, after several decades of using nuclear power for electricity production, nearly half of the Member States with nuclear power plants have no operational disposal facility for low-level waste. The large-scale decommissioning of nuclear power plants, looming on the horizon, will put further stress on the Member States without an operational low-level waste disposal facility but also on Member States, where the operational facilities are reaching storage capacity;
- does not assess the management of intermediate-level waste;
- fails to mention, that not one Member State has a disposal solution for intermediate-level waste. The few Member States that disposed of ILW, need to retrieve waste due to safety concerns, while plans for ILW disposal still need to be developed;
- presents geological disposal as a solved issue but theoretical assumptions and practical implementation are very different. As of today, still no geological disposal is in operation. One Member State is constructing the worldwide first geological disposal facility, while two others are in advanced licensing stage. The remaining Member States have no concrete plans yet. Most Member States have not even entered the lengthy site selection process, while planned operations are estimated to occur mostly in the second half of this century;
- does not mention any costs or funding mechanisms for radioactive waste management. To manage its radioactive waste (not including decommissioning), the EU-28 will have to spend a minimum of 422-566 billion Euros.

Therefore, we conclude, that the JRC report is clearly not sufficient to draw a meaningful and comprehensible conclusion with respect to the DNSH criteria for nuclear power.

Thus taking into account the generation of large quantities of radioactive waste, the missing disposal pathways for intermediate- and high-level waste, the very limited decommissioning experience, the limited or no markets for cleared materials from decommissioning as well as the staggeringly high and highly uncertain decommissioning and waste management costs, nuclear power clearly violates any possible meaningful definition of a "do no significant harm" criterion.

Section B

4. Shortcomings of the JRC assessment on severe accidents

In this section we analyse the discussion of severe accidents and their importance by JRC with respect to the "do no significant harm" (DNSH) criteria. A full analysis of the JRC report, its underlying scientific literature as well as the generally available scientific literature on severe accidents is beyond the scope of this paper. But even a coarse analysis of the JRC report shows significant shortcomings, contradictions, and open issues.

4.1. What JRC concludes

In its Executive Summary, JRC draws a key conclusion with respect to the DNSH criteria (JRC 2021, p. 7):

> "*The analyses did not reveal any science-based evidence that nuclear energy does more harm to human health or to the environment than other electricity production technologies already included in the Taxonomy as activities supporting climate change mitigation.*"

The assignment given to JRC was to present scientific analysis and evidence whether nuclear energy does significant harm or does no significant harm in the framework of the taxonomy regulation. The task has not been to assess whether nuclear energy does more or less harm than other energy technologies. A finding that nuclear energy does not do more harm than other energy producing technologies is not equivalent to a finding that it does no significant harm as required for a technology to be recommended under the Taxonomy Regulation.

The JRC analysis compares nuclear energy with other energy production technologies for which significant harm occurred in the past decades. Therefore, the finding of the analysis did in fact reveal that nuclear energy does significant harm and that also other electricity production technologies can do significant harm.

The above concluding statement is questionable with regard to the part that such other electricity production technologies *"are already included in the Taxonomy as activities supporting climate change mitigation"*. The Taxonomy Regulation does not accept any energy technology as DNSH without further qualifications and criteria. A delegated regulation under the taxonomy regulation act has established specific criteria (e.g. for hydropower plants) resulting in specific limitations, exclusions, benchmarks or criteria specific to those technologies that ensure that no significant harm is done along their life-cycles (EC 2021a). Examples of energy technologies used for comparison of harm in the JRC report would not qualify under the Taxonomy Regulation.

JRC does not state in the key conclusions section, whether the assessment of potential consequences of severe accidents are included in its key conclusion.
In Chapter 4 of the JRC report, which gives a summary of the DNSH assessment for nuclear energy, the same conclusion as above is drawn, but here it is clearly restricted to the analyses of Chapter 3.2 of the JRC report. Consequences of
severe accidents are not covered by the discussion of human health consequences in Chapter 3.2 but are discussed in Chapter 3.5 of the JRC report.

The above conclusion

- is thus not including consequences of severe accidents and
- there is no key conclusion with respect to the potential consequences of severe accidents.

In the section on key findings following the key conclusions section, JRC states that the potential impact of severe accidents has been discussed extensively. In fact, Chapter 3.5 of the JRC report – which covers the potential impact of severe accidents – comprises 6 of 397 pages or 1.5% of the whole report.

As indicators to assess the potential consequences of a severe accident, JRC refers to severe accident fatality rates and maximum consequences (fatalities). No other indicators with respect to the consequences of severe accidents are considered.

Based on the fatality rate, they present the finding that current nuclear power plants as well as Gen III plants like the EPR have a very low fatality rate.

With respect to maximum consequences (fatalities), JRC finds:

> *"Very conservative estimates of the maximum consequences of a hypothetical severe nuclear accident, in terms of the number of human fatalities, … are compared with the maximum consequences of severe accidents for other electricity supply technologies."*

JRC does not summarize or assess these estimates of maximum consequences or their importance to assess the DNSH criteria.

Finally, JRC recognizes:

> *"While the number of human fatalities is an obvious indicator for characterising the maximum severity of accident consequences, nuclear accidents can lead to other serious direct and indirect impacts that might be more difficult to assess. Whereas the public is well aware of the devastating consequences on property and infrastructure, as well as on the natural environment, from historical cases of anthropogenic catastrophes, the disaster and risk aversion might be perceived somehow differently for nuclear related events. Evaluating the effects of such impacts is not in the scope of the present JRC report, although they are important for understanding the broader health implications of an accident."*

Thus, the assessment of the JRC with respect to the fulfilment of the DNSH criteria for severe accident in nuclear power plants is based on the indicator of fatality rates alone (no assessment for maximum consequences is carried out, no other indicators are taken into account). This is clearly insufficient to assess the risk of severe accidents in nuclear power plants. Despite these findings, JRC acknowledges in its key findings that (JRC 2021, p. 10)

> *"Severe accidents with core melt did happen in nuclear power plants …"*

and adds that

> *"Severe accidents are events with extremely low probability but with potentially serious consequences and they cannot be ruled out with 100% certainty."*

Furthermore, JRC states clearly that

> *"The consequences of a severe accident at a nuclear power plant can be significant both for human health and the environment."*

To summarize:

- A major risk factor of nuclear energy, the potential consequences of severe accidents, is covered by only 1.5% of the total report what JRC calls "extensive".
- JRC recognizes that severe accidents did happen and that they can happen.
- JRC finds that severe accidents have significant consequences both for human health and the environment.
- JRC assesses the fatality rates for severe accidents and finds that the consequences of severe accidents – based on this indicator – are comparable to other energy technologies.
- JRC does not draw conclusions on the indicator of maximum fatalities in its key findings, nor does it evaluate further indicators for the potential consequences of severe accidents, despite acknowledging that they exist and are relevant in relation to the taxonomy regulation.

- Still, JRC comes to the overall key conclusion, that nuclear power does not do more harm to human health or to the environment than other electricity production technologies already included in the Taxonomy.

Thus, JRC at one hand recognizes that accidents do happen and that they do have severe consequences. This must be understood as being equivalent to the finding that significant harm has occurred and can occur. At the same time, they conclude that nuclear power does not violate the DNSH criteria.

While it is already evident from this discussion, that the key conclusion of the JRC report is not backed by the actual assessment of the JRC, we will further discuss these aspects in the following section.

4.2. Discussion of the JRC analyses

In this section we discuss what JRC, the literature that JRC cites and the literature that JRC does not cite has to say about severe accidents and their consequences. The JRC analysis of the potential consequences of severe accidents is based on six references.

Two of those refer to (legally non-binding) recommendations with respect to regulatory requirements of the Western European Nuclear Regulators' Association (WENRA).

One reference covers the consequences of the severe accident of the Fukushima Daiichi nuclear power plant in 2011 (no reference is given with respect to the consequences of the other severe accidents referenced by JRC, namely Three Mile Island (1979, USA) and Chernobyl (1986, Soviet Union)).

One reference discusses possible consequences of severe accidents (U.S. NRC 2020). JRC refers to an older version of this study (the Revision 1 of 2012). Both versions are based on fundamental work, more fully covered by (U.S. NRC 2012).

Two references are based on the work of Burgherr and Hirschberg (Burgherr und Hirschberg 2014; Hirschberg et al. 2016), who analyse consequences of severe accidents in the energy sector.

In Chapter 4 of the JRC report, one further work by Burgherr and Hirschberg is referenced with respect to severe accidents, namely (PSI 2003), which is not referenced in Chapter 3.5.

No other work on severe accidents is referenced by JRC. Limitations of the literature cited by JRC will be discussed in the following. Still, it is quite evident from this list already, that JRC does not cover the broad spectrum of available literature on severe accidents and thus clearly does not represent different approaches available in scientific literature to assess the possible consequences of severe accidents.

4.2.1. Appropriate risk metric for nuclear accidents

JRC discusses only fatality rates and maximum consequences with respect to severe accidents in nuclear facilities.

Severe nuclear accidents can lead to significant off-site consequences due to the release of large amounts of radioactivity. The release of radioactivity will impact human health by inhalation of airborne radionuclides, ingestion of radionuclides by food or water or by direct radiation due to radionuclides deposited on land. To minimize the consequences to human health, different countermeasures will be taken after a nuclear accident. These countermeasures include sheltering, evacuation, short- or long-term relocation of humans as well as restrictions on land use or drinking water supplies (BfS 2015). While these countermeasures can drastically reduce the impact on human health (and thus the number of fatalities and corresponding fatality rates), they will result in significant consequences concerning other indicators of severe accidents like land loss or costs.

A discussion of severe accidents based only on fatality rates and maximum consequences in terms of fatalities for a severe accident without taking into account the consequences of countermeasures taken to limit these is clearly insufficient.

Indeed, as cited above, JRC concludes itself that nuclear accidents can lead to other serious direct and indirect impacts that might be more difficult to assess. Even the literature underlying the JRC analyses makes clear, that (Hirschberg et al. 2016, p. 374)

> *"… decisions may not be solely based on objective and quantitatively measurable risk indicators, but subjective aspects of risk perception and acceptance can play a role too …. Finally, risk assessment is always embedded into the broader context of risk perspectives … and risk concepts …, which can influence the study boundaries and scope, and in turn may affect the choice of risk metrics …."*

This is also clearly addressed in (Burgherr und Hirschberg 2014), who mention aspects like land and water contamination, damage and external costs, human health and risk aversion. Furthermore, they note that different time horizons can be of importance, because consequences can be short (e. g. immediate fatalities) or long (e.g. latent fatalities, land and water contamination) term.

In fact, even in (PSI 2003), another important risk indicator, land contamination due to the consequences of severe accidents is discussed in the form of interdicted and condemned areas, but no reference is given to this analyses by JRC.

Thus, already the literature cited by JRC makes clear, that indicators like land and water contamination, damage and external costs as well as human health need to be taken into account to assess the effects of severe accidents with respect to the different dimensions of sustainability. These aspects will be discussed in more detail below.

Indeed, the question of an appropriate risk metric is not new. Already in discussions about the risk of nuclear power taking place in the 1980s, extensive literature discussed the possible impacts of different electricity production technologies on aspects of sustainability. A critical review of this was performed for example in (Oeko-Institut e.V. 1989, Kap. 3.3) and it is recognized already at that time, that indicators like 'fatalities' or 'deaths per year of operation of a plant' may not be sufficient depending on the nature of the risk at hand.

(Oeko-Institut e.V. 1989, Tab. 3.3-1) summarizes different consequences of severe accidents, that would have to be taken into account in a comprehensive discussion of the impact of severe accidents on sustainability, which comprise among others consequences for life and health of humans; consequences for infrastructure including consequences for drinking water supplies or land contamination; consequences for other lifeforms including loss of livestock, loss of wildlife, loss of rare species, loss of biotopes and finally economic costs including cost for civil protection, remediation activities, evacuations, loss of production, damage to image of companies or industries.

A discussion for some of these indicators will take place below.

To summarize:

The JRC assessment of severe accidents using only two indicators clearly represents an insufficient risk metric to fully represent the consequences of severe accidents and does not take into account aspects of risk perception and risk aversion.

4.2.2. Maximum number of fatalities

The maximum number of fatalities discussed in the JRC report and shown in Figure 3.5-1 of (JRC 2021) are taken from (Hirschberg et al. 2016).

With respect to the maximum number of fatalities for non-nuclear electricity production technologies, JRC states (JRC 2021, p. 187)

> *"Note that in Figure 3.5-1 the 'maximum consequences' data for the non-nuclear electricity production technologies are real historical data reflecting the officially registered number of casualties (e.g. after a major hydropower-dam accident)."*

Contrary to this statement of JRC, (Hirschberg et al. 2016; Burgherr und Hirschberg 2014) explain with respect to the maximum number of fatalities for hydropower in OECD countries, that these number is derived by a site-specific consequence modelling for a Swiss dam with a relatively high population density downstream from the dam.

Indeed, (Burgherr und Hirschberg 2014) lists actual data with respect to severe accidents in hydropower. According to this, there is one event in the database for OECD countries with a total of 14 fatalities and one event for EU 27 countries with 116 fatalities. For a hypothetical dam failure in OECD countries with zero pre-warning time, they cite a maximum number of up to 11,000 fatalities. But with a pre-warning time of about 2 hours, this number could be reduced to between 2 to 27.

Contrary to what JRC claims, maximum consequences for hydro plants in OECD countries are thus not based on actual data but on a conservative theoretical calculation for a specific site. Actual maximum consequences for OECD countries and EU 27 countries are 116 fatalities. Even in non-OECD countries, maximum consequences from dam failures are far less than 10,000 fatalities with the exception of a specific Chinese dam accident.

With respect to the numbers for nuclear accidents, JRC states (JRC 2021, p. 187)

> "… *Contrary to this, for nuclear energy the 'maximum consequences' values correspond to calculated data which were derived by using highly conservative assumptions ...*"

With respect to nuclear accidents, (Hirschberg et al. 2016) explains, that they used a simplified probabilistic safety assessment (PSA) methodology to analyse the risk and that latent fatalities are included in the numbers for nuclear.

In (Burgherr und Hirschberg 2014) they estimate that for the Chernobyl accident

> "*expected latent fatalities range from about 9,000 for Ukraine, Russia and Belarus to about 33,000 for the whole northern hemisphere in the next 70 years.*"

For maximum fatalities, they give a number of 6,596 for a Generation II PWR and of 46,990 for a Generation III EPR (with the higher number due to a much larger radioactive inventory of the EPR).

(Hirschberg et al. 2016) conclude with respect to the maximum consequences:

> "*Nuclear and hydro accidents may, however, have very large consequences. … The experience-based maximum consequences of accidents with new renewables are small.*"

Interestingly, (Hirschberg et al. 2016) continues with an estimate of the risk of a terrorist attack on energy facilities. In this context, they analyse the possible consequences of an attack on nuclear power plants in the US, Finland, and China as well as on dams that are largest in the respective countries. In the context of this analysis, the authors achieve considerably higher values for the maximum number of fatalities both for hydropower as well as for nuclear power.

To summarize:

- The maximum consequences for nuclear power in Fig. 3.5-1 of the JRC report do not represent absolute maximum consequences.
- A discussion of maximum consequences for nuclear power has to include mitigative countermeasures (like evacuation, permanent relocation, land use restrictions and others). Without taking the consequences of these countermeasures into account, the "maximum consequences" in terms of fatalities show only a limited picture (see the discussion of other indicators below).
- Still, already given the numbers in Fig. 3.5-1 of the JRC report, the maximum consequences of nuclear power are at least three orders of magnitude higher than for new renewables like photovoltaic, wind, biogas, solar-thermal or geothermal.

- Only for very large hydro plants, and thus a limited number of actual facilities, comparable maximum consequences could be possible. Hydropower plants with such potential fatalities are not be covered by the EU Taxonomy, corresponding technical criteria to exclude them have already been implemented in a Delegated Act under the Taxonomy Regulation (EC 2021a). The comparison made with accidents in some badly designed hydropower dams in China in the seventies or hydropower dams in Finland that were never built is not valid for the purposes of the taxonomy where strict criteria are applied to hydropower excluding the examples taken into account in the JRC study.

Already based on the analyses of possible maximum fatalities of severe accidents in nuclear power plants, it is clear that nuclear energy cannot fulfil any meaningful definition of a "do no significant harm" criterion.

4.2.3. Fatality rates

The fatality rates discussed in the JRC report represent averaged or mean values derived by multiplying the (expected) fatalities with (empirical or calculated) probabilities of an accident. For nuclear power, the probabilities as well as the possible number of fatalities corresponding to a certain accident as used by JRC are not based on actual empirical data (which is sparce) but on theoretically derived values based on so called probabilistic safety assessments (PSA). No discussion of uncertainties for fatality rates takes place in the JRC report.

PSA is a very valuable tool to estimate the (theoretical) safety level of a nuclear power plant design. It is used to identify weaknesses in the design and to identify possible safety enhancements (FAK PSA 2005b; 2005a).

Nevertheless, use of PSA results to estimate the actual risk of operating nuclear power plants faces several hurdles. PSA results may be limited to internal events or take into account only selected external events like earthquakes or flooding. For example, (Kumar et al. 2015) discuss the PSA results for the Fukushima Daiichi nuclear power plant which were published before the accident took place. They highlight that:

> "*The Core Damage Frequency (CDF) and Containment Failure Frequency (CFF) for the Fukushima Dai-ichi plants were determined only for internal initiating events. The results obtained by TEPCO ... for the CDF of up to 10-7 per year were very low compared to other results for other Boiling Water Reactors (BWR), including those with more backfitting and/or newer designs.*"

Based on today's knowledge, (Kumar et al. 2015) conclude that

> "*It is recognized today that the determination of the design basis tsunami for the Fukushima Dai-ichi site underestimated both the maximum probable tsunami height as well as the tsunami height for a likelihood of 10^4 per year. This led to a false belief in sufficient safety margins even for beyond design tsunamis.*"

Some external hazards are often not (yet) taken into account in PSA, especially with respect to man-made hazards like intentional terrorist attacks on a nuclear facility or possible consequences of military conflicts. Nuclear power plants, but potentially also other facilities of the nuclear supply chain like reprocessing facilities could be targets of terrorist attacks or could be impacted by consequences of military conflicts (be it intentional or by accident). JRC does not discuss the risks of terrorist attacks or military conflicts. This is especially questionable, as the literature cited by JRC does discuss at least the risk of terrorist attacks (Hirschberg et al. 2016). Other literature does also discuss at least qualitatively the risks associated with nuclear facilities in crises regions (Oeko-Institut e.V. 2017).

The methodologies for PSA have developed considerably during the past decades (FAK PSA 2016; U.S. NRC 2020). Especially the consideration of human factors as well as common cause failures in PSA has a relevant impact on results. Thus, usually relevant uncertainties have to be taken into account, especially when assessing severe accidents. Several limitations of this approach are also recognized by (Hirschberg et al. 2016; Burgherr und Hirschberg 2014).

(Hirschberg et al. 2016) discuss the uncertainties included in their analyses. They conclude:

> *"Overall the uncertainties are lowest for severe accidents in the fossil energy chains due to the large number of historical events, moderate for the normal operation, quite large for hydro and PSA-based estimates for nuclear accidents and largest for the terrorist threat."*

A very simplified calculation can illustrate significant uncertainties associated with the use of the theoretically derived fatality rates especially for severe accidents. Assuming an average nuclear electricity production of 2,000 TWh per year during the timeframe 1970 to 2008, roughly 75,000 TWh electric energy has been produced. (Burgherr und Hirschberg 2014) estimate the total amount of fatalities for the Chernobyl accident, the only severe accident in the evaluation period, for which they estimate the fatality rates, between 9,000 and 33,000 latent cancer deaths. Assuming just 10,000 fatalities for this accident alone, one would receive an empirical value of approx. 10^4/GWh for the fatality rate of nuclear power. This has to be compared with the theoretically derived number of less than 10^6/GWh for today's Gen II power plants as estimated by (Hirschberg et al. 2016), a difference of more than two orders of magnitude.

An early critic of the probabilistic approach to risk assessment was formulated already in (Hsü 1987). (Wheatley et al. 2016) take up these thoughts and criticise the approach to assess nuclear accident risks based on probabilistic safety analysis, as such techniques are known to poorly predict events and to under-appreciate incidents that cascade into failures. (Wheatley et al. 2016) estimate the rate of severe accidents in nuclear facilities based on a database including 216 nuclear accidents and incidents. They conclude, that for an operational fleet of 388 nuclear reactors, there is a 50% chance that a Fukushima event (or a more costly one) occurs every 60-150 years.

In addition to the limitations of the theoretically derived PSA numbers, further problems with respect to the significance of a purely statistical value like the fatality rate exist. Within the European Research Project ExternE, a methodology to assess external costs of different energy technologies was developed. With respect to accidents, the ExternE project concludes (IER 2018):

> *"Accidents are rare unwanted events in contrast to normal operation. A distinction can be made between impacts to the public and occupational accident risks. Public risks can in principle be assessed by describing the possible accidents, calculating the damage and by multiplying the damage with the probability of the accidents. An issue not yet accounted for here is the valuation so-called 'Damocles' risks, for which high impacts with low probability are seen as more problematic than vice versa, even if the expected value is the same. A method for addressing this risk type has still to be developed.*

This is also clearly addressed in (UBA 2018), which recognizes that for so called disaster risks like nuclear power accidents, aspects of risk aversion have to be taken into account.

As (Kumar et al. 2015) conclude on the use of PSA:

> *"PSA results are often narrowed down to very few numbers or even one risk-aggregate figure of merit. ... While this certainly simplifies the problem space for the decision maker, this kind of risk aggregation can obfuscate or distort specific PSA results and related plant vulnerabilities. Risk-informed decision making should consider the risk profile of the plants based on sets of PSA risk measures/metrics ..., which are understood and presented as uncertainty distributions. These should be accompanied with sensitivity analyses demonstrating the influence of different important sources of uncertainty. Risk-informed decision making should consider always potential long-term consequences of accidental releases. Moreover, the decision making should take into account uncertainty assessments on safety margins, particularly those to known or suspected cliff-edge effects."*

To summarize:

- No discussion of uncertainties for PSA results and especially fatality rates takes place in the JRC report;
- While fatality rates might be a valuable indicator especially for normal operation or for technologies without 'Damocles' risks;
- for nuclear power, fatality rates alone are not a good indicator to assess the risk associated with severe accidents and
- fatality rates are not sufficient to conclude on the DNSH criteria of the EU Taxonomy based on this indicator (alone).

4.2.4. Other indicators

As shown above, even the scientific literature taken into account by JRC makes clear, that indicators like land and water contamination, damage and external costs as well as human health need to be taken into account. In this section, a tentative discussion of some of these indicators takes place.

Example: Human health aspects (besides fatalities)

According to (Ashley et al. 2017), following the Chernobyl nuclear accident, a total of 335,000 people have been evacuated from highly contaminated area. Following the Fukushima Daiichi nuclear accident, a total of 160,000 people have been evacuated from the vicinity of the plant. (Ashley et al. 2017) estimate that about 48,000 people who lived in the restricted area have moved outside of the Fukushima prefecture.

Example: Land and water contamination

Hirschberg et al. give an estimate on land contamination in (PSI 2003). They estimate possible maximum consequences in terms of lost land at 3,500-4,500 km^2 (about twice the size of the state of Luxembourg).

(IRSN 2013) estimates the possible sizes of contaminated land for major accidents in a French 900 MW nuclear power plant. Areas of up to 18,800 km^2 may be contaminated in the case of a major accident. 1,300 km^2 of those may be contaminated to a degree that people would have to be relocated from that area.

JRC does not estimate the possible impact of nuclear energy and especially of severe nuclear accidents on water bodies. Based on the lessons learned from Fukushima, an analysis of the possible consequences of an severe accident in a swiss nuclear power plant shows a strong impact on drinking water supplies not only in Switzerland but also in Germany, as the lakes under consideration and the flowing waters of the Aare and Rhine would be at high risk in the event of an accident (Oeko-Institut e.V. 2014).

Example: Damage and external costs

To estimate the actual cost of a nuclear accident is by far not straightforward. (OECD; NEA 2000) already discussed relevant methodological aspects, a comparison of different approaches was given in (OECD; NEA 2018).

An analysis for an accident in a 900 MW power plant in France is performed by (IRSN 2013). They estimate the total cost and distinguished grave and major accidents. For grave accidents, they estimate an average value of 120 billion Euros with an error margin of 50 to 250 billion euros. For major accidents, they estimate an average value of 450 billion Euros with an error margin of 200 to 1,000 billion euros.

(Wheatley et al. 2016) estimate, that the average cost of nuclear energy events per year worldwide is around the cost of the construction of a new plant.

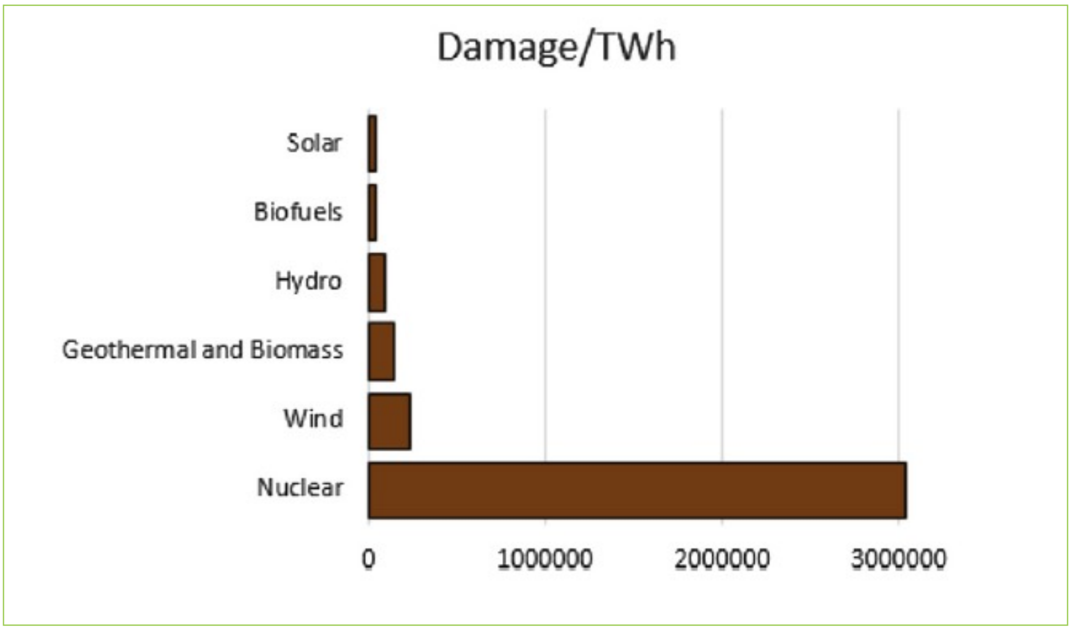
(Sovacool et al. 2016) assess the risks of energy accidents and analyse the frequency, fatality, and scope. By scope they estimate the property damage inflicted by the accidents. An average accident in their database inflicts a mean of 388 million US$ in damage.

For accidents in nuclear energy, they evaluate a mean value of 1.4 billion US$ in property damage, approx. twice the value for hydro and more than fifty times the value for other renewables (wind, solar, hydrogen, biofuels, biomass, geothermal). Even the normalised risk in terms of damage per TWh amounts to 3 million US$ for nuclear, compared to between 35,500-235,400 US$ for the other technologies. Thus, the authors conclude that nuclear accidents are the most expensive, inflicting a total of 265.1 billion US$ (or 90.8 percent of the total damage of energy accidents). For the Fukushima accident, they assume property damage of 162.7 billion US$, the Chernobyl accident is listed with a total property damage of only 7.7 billion US$ and the Three Miles Island accident accounts for 2.7 billion US$.

(Ashley et al. 2017) summarize costs of the nuclear accidents in Fukushima, Chernobyl and Three Mile Island. For the Fukushima nuclear accident, they cite a total amount of 107.8 billion US$. For the Chernobyl accident, they cite estimates of losses of up to hundreds of billions of dollars.

(JCER 2019) estimates the clean-up costs after the Fukushima accident to 35-80 trillion Yen (around 270-617 billion euros).

Graph: Low-carbon energy accident damage normalized to TWh, 1990-2013



Source: Sovacool et al. 2016.

Nuclear accidents are infrequent, but extremely expensive when they occur.

To summarize:

- There are other indicators with respect to severe accidents – like the number of people evacuated or relocated, the area of land contaminated for decades or even centuries or the economic consequences of a severe accident – that are relevant to assess the consequences of severe accidents;
- there exists scientific literature making clear that these indicators have to be taken into account and
- that severe accidents in nuclear power plants have significant consequences besides fatalities.

4.3. Summary on severe accidents

For its assessment of the potential consequences of severe accidents, JRC

- refers to a very limited amount of scientific literature, which does not provide a comprehensive assessment of different consequences of severe accidents;
- discusses only two indicators with respect to severe accidents – maximum number of fatalities and fatality rates –, that are clearly an insufficient risk metric to fully represent the consequences of severe accidents;
- relies on theoretical analyses to assess these indicators without discussing the underlying uncertainties and methodological limitations of such an approach;
- does not discuss other indicators with respect to severe accidents – like the number of people evacuated or relocated, the area of land contaminated for decades or even centuries nor the economic consequences of a severe accident – although they are relevant and there exists scientific literature making clear that these indicators have to be taken into account;
- finds that severe accidents in nuclear power plants have significant consequences both for human health and the environment.

Therefore, we conclude, that the JRC report is clearly not sufficient to draw a meaningful and comprehensible conclusion with respect to the DNSH criteria for nuclear power.

Severe accidents in nuclear power plants can happen and they do have significant consequences for human health and the environment.

Thus, taking into account all consequences of severe accidents, nuclear power clearly violates any possible meaningful definition of a "do no significant harm" criterion.

5. Shortcomings of the JRC assessment on proliferation

Nuclear technology can be used for peaceful energy production and for military purposes such as nuclear deterrence and ultimately to wage nuclear war. Nuclear proliferation is the spread of nuclear weapons, nuclear weapons technology, fissile materials and fissile material production technologies, and of other materials or know-how relevant to the use and fabrication of nuclear weapons. Any discussion of a "do no significant harm" (DNSH) criterion for nuclear energy needs to address the inherent dual-use characteristic of nuclear technologies and the danger of nuclear weapons for human wellbeing.

5.1. What the JRC concludes

The JRC report addresses proliferation risks only in chapter 3.3.5.1.5 and 3.3.5.1.6 on reprocessing and in a brief section on the European safeguards system in Annex 1. The authors acknowledge the military history of plutonium production and reprocessing and the proliferation implications of plutonium separation. However, they focus on the civilian use (JRC 2021, p. 312):

> *"As this report focuses on the effects originating from the authorized use of radioactive materials in the nuclear fuel cycle, the nuclear safeguards' legal framework is only briefly described here."*

It is implied, that the current system of control with international treaties, safeguards and physical protection measures is sufficient to separate civilian from any military use of nuclear technologies. The report also addresses a potential benefit of a closed fuel cycle for long term proliferation risks, if all fissile material will eventually be consumed in such a closed fuel cycle (JRC 2021, p. 109).

5.2. Discussion of the JRC analysis

5.2.1. Humanitarian impact of nuclear weapons and proliferation

Any use of a nuclear weapon would have catastrophic impact on human health and the environment. The conferences on humanitarian impact of nuclear weapons in Vienna, Nayarit and Oslo 2013-2014 summarized the evidence of the immediate and longer-term impacts of the use and testing of nuclear weapons. The last conference was attended by 157 states. The humanitarian impact of nuclear weapons is also the background against which the Treaty on the Prohibition of Nuclear Weapons was negotiated and entered into force in January 2021.

The unimaginable destructiveness of nuclear weapons was shown at the attacks on Hiroshima and Nagasaki. This led to the doctrine of nuclear deterrence that frames the international security environment to this day. Due to sheer luck, nuclear war was avoided – so far. In the nuclear arms race tens of thousands nuclear weapons were fabricated, and more than 2,000 tested in the atmosphere, in the oceans and underground. The environmental legacy of highly radioactive waste to produce fissile materials and from nuclear testing will impact generations to come.

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) is the cornerstone treaty to curb proliferation. Nuclear disarmament efforts as enshrined in Article VI did not make much progress. Instead today the world faces renewed interest in nuclear weapons with nuclear weapon states modernizing their arsenals and emerging new nuclear weapon states. According to article IV of the NPT, all states have an inalienable right to the peaceful use of all nuclear technologies and parties to the treaty should also facilitate the development and distribution of peaceful technologies. This includes sensitive technologies such as reprocessing and enrichment (see below). The International Atomic Energy Agency (IAEA) is the international body that implements safeguards to control the boundary between peaceful and military use according to article III, and also to encourage international cooperation to further develop and distribute nuclear technology for peaceful purposes. Every party to the treaty can withdraw from the NPT with a three-month notice period, as was the case with North Korea 2003.

The risk of nuclear proliferation is also acknowledged by the Intergovernmental Panel on Climate Change (IPCC) in its 2018 report (IPCC 2018, p. 461). They argue that increasing the share of nuclear energy to reach the goal of only a 1,5°C global temperature increase,

> *"can increase the risks of proliferation (SDG 16)".*

The IPCC refers to the Sustainable Development Goals (SDG) that the United Nations laid out in its "2030 agenda for sustainable development". Central for nuclear proliferation in this set of goals is the SDG 16 (peace, justice and strong institutions). But literally all other SDGs would be impacted by nuclear testing, nuclear war, or an inadvertent use of nuclear weapons. Also, the IAEA acknowledges unique challenges of nuclear power – among which is nuclear proliferation – for sustainable development (IAEA 2017, p. 7).

5.2.2. Nuclear Proliferation and the Do No Significant Harm Criterion

The JRC report only focuses on authorized use of nuclear technologies. It implicitly argues, that since large institutional arrangements of engineered safeguards designed to reduce the risks of nuclear proliferation are applied, the risks will be mitigated. The assumption is that the current system of control is capable of discovering actors that intend to acquire nuclear weapons early enough and that there are effective means available to stop them.

The Taxonomy regulation is about economic activities to be considered as 'green investments' globally, thus the approach should not be limited to sites within Europe or OECD countries, but should be valid globally. An appropriate assessment has to take into account the risks of nuclear proliferation in non-European countries because the criteria aim at a global not only a European context.

The JRC may not have been mandated to use criteria in its report beyond those related to environmental goals. We, however, argue that a broader set of criteria needs to be taken into account to review the sustainability of nuclear power. And that includes an in-depth discussion of the consequences of nuclear proliferation.

Also, the Technical Expert Group on Sustainable Finance (TEG) did not restrict exclusion criteria only to detrimental effects for the environment (BASE 2021). The technical screening criteria process of the TEG explicitly points out for sectoral activities with high mitigation potential that other (TEG 2020a, p. 33)

> *"material issues whereby an activity is considered unsuitable for inclusion in the Taxonomy may include but are not limited to [...] intergenerational risks."*

As with severe nuclear accidents the DNSH criteria have to account for low probability, high risk events. The vast infrastructure of international and European safeguards and physical protection measures is a certain protection against the risk of nuclear proliferation. Also, the system of international security is set up to disincentivize the acquisition and use of nuclear weapons. But these systems are not failproof. States can have incentives to build nuclear weapons (Sagan 1996) and use the dual-use characteristic of nuclear technologies to their advantage, but also terrorists could acquire fissile materials (nuclear terrorism) (Belfer Center 2016).

If the protective systems fail, there could be catastrophic effects. Even a very localized nuclear war, would have global climatic effects as (Robock et al. 2007) showed. The consequence of nuclear weapons use is not in any meaningful sense comparable to risks by other technologies in terms of casualties and harm done. Effects would not only effect humanity and the environment today, but future generations as well. Ultimately, an all-out nuclear war is still possible and could literally destroy human civilization within one hour. Consequently the world-renowned Doomsday Clock (Bulletin of the Atomic Scientist 2021), first started in 1947, is currently set to 100 seconds to midnight, closer to midnight than ever.

We argue therefore, that for an assessment of the sustainability of nuclear power the risk of nuclear proliferation and nuclear weapons use needs to be treated as seriously as global warming. Such a treatment is lacking in the JRC report.

5.2.3. Proliferation and Dual-Use

Historically, the dual-use characteristic of nuclear technology is an integral part of nuclear weapons programs. Of course, not every country with a civilian nuclear program will develop a nuclear weapons program. Although historically, an astonishing number of countries with nuclear infrastructure explored at some point in time to do so (Sagan 2011) and exploited the dual-use characteristics of nuclear technologies. Almost all these states used synergies between their military exploration and civilian nuclear programs.

The JRC report neglects this important dimension of dual use and therefore does not address e.g. the problem of technology transfer. Historically, some states had an incentive to provide sensitive nuclear assistance under certain strategic conditions by transfer of dual-use materials and technology (Kroenig 2010). Such transfer for peaceful use is even mandated by the NPT under article IV (see above). The taxonomy decision will also have economic impact on nuclear related economies outside of the European Union, thus possibly strengthening nuclear countries that purposefully walk the dual-use path to establish a nuclear infrastructure.

Finally, it is fair to say, that a civilian nuclear energy program gives a country a technological potential, a latent nuclear weapons option. A state may even acquire dual-use technology with only peaceful intent, but only later give in to the temptation to initiate weapons research depending on the international security environment (Fuhrmann 2009). The former IAEA director general El Baradei coined the phrase "virtual nuclear weapon states" for such countries with certain nuclear capabilities. The international concern about the civilian nuclear energy program in Iran exemplifies this today. The inherent dual-use characteristic of nuclear technologies therefore turns any transfer or financial assistance for these technologies into a bet on the future, that no circumstances will arise that lead states to use a nuclear infrastructure for military instead of peaceful purposes.

5.2.4. Proliferation prone nuclear technologies

The development of a civilian nuclear energy program establishes a nuclear infrastructure with corresponding facilities, know-how, materials, and manufacturing processes. This latent potential (latent proliferation) is henceforth available for use in a parallel or subsequently pursued military nuclear weapons program. Furthermore the technology itself can proliferate (Braun und Chyba 2004) to state and non-state actors (nuclear terrorism).

This connection is most obvious for fissile materials and fissile material production. Of course, not all technologies and fissile materials are equally suitable for military use (proliferation resistance). Especially the technologies to enrich uranium and separate plutonium from spent nuclear fuel are considered sensitive.

The JRC report does not mention the proliferation risks of uranium enrichment in the life cycle analysis of uranium enrichment. Historically e.g., the Pakistani nuclear weapons program started by a theft of blueprints for uranium enrichment technologies from the European enrichment company URENCO in the 1970s. Pakistan tested its first nuclear weapon 1998 and sold the technology globally to countries like North Korea, Lybia, Iran and Irak and thereby shaped the current international security environment (Braun und Chyba 2004).

The JRC report addresses the proliferation risks of reprocessing technologies to separate plutonium. It also acknowledges that plutonium from spent fuel is less attractive to fuel a nuclear weapon, although it is still usable for a nuclear weapon, depending on the technical skills of an actor. What the report does not discuss is that the "quality" of the plutonium produced in a reactor depends mostly on the time that a fuel element producing plutonium is being used in the reactor. The longer it is being used the less attractive the plutonium contained is for weapon use. Under normal circumstances, nuclear fuel will be used as long as possible in a reactor due to economic reasons. However, the fuel could also be taken out of the reactor earlier than planned. If the irradiation time is short enough it would contain weapon grade plutonium (NPEC 2004). Therefore, all nuclear reactors, also light water reactors which make up the current fleet of reactors, could be used for weapons plutonium production.

The JRC report also mentions the – still theoretical – closed fuel cycle (reusing plutonium and other fissile elements) and even discusses the closed fuel cycle as a benefit for long term proliferation risk, if eventually all plutonium would be consumed after many decades or centuries of operating such a closed fuel cycle. But such a closed fuel cycles involves the operation of reprocessing plants and the handling of separated plutonium as well as the use of breeder reactors during the whole operation time, implying significant proliferation risks.

5.3. Summary on nuclear proliferation

The JRC report does not assess the risks of nuclear proliferation when assessing the DNSH criteria for nuclear energy production. Any use of nuclear weapons would have catastrophic impacts on human health and the environment.

The JRC reports evades the complex history and an in-depth discussion of the use of nuclear energy and nuclear proliferation. But the simple fact is, that all nuclear technologies have a dual-use characteristic and therefore carry a potential for misuse. Any discussion of a DNSH criteria not covering nuclear proliferation is thus incomplete.

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