SUSTAINABLE NUCLEAR

An Assessment of the Sustainability of Nuclear Power for the EU Taxonomy Consultation 2019

By

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1. Introduction

The European Commission Technical Expert Group (TEG) considered including nuclear energy in the EU Sustainable Finance Taxonomy as a sustainable activity and investment. The TEG Technical report on EU Taxonomy[1] published in June 2019 proposed to leave nuclear energy out from the first version of the Taxonomy, pending further assessment.

The TEG opened a public consultation for feedback on their report, running until 13th September 2019. In that report, the TEG also "*recommends that more extensive technical work is undertaken on the DNSH (Do No Significant Harm) aspects of nuclear energy in future and by a group with in-depth technical expertise on nuclear life cycle technologies and the existing and potential environmental impacts across all objectives.*"

This assessment report, which is longer than the space allowed by the public consultation, aims to provide the needed in-depth technical information regarding the environmental impacts of nuclear energy production across all the TEG objectives. It is intended to provide sufficient evidence and references to facilitate the necessary Do no Significant Harm (DNSH) assessment for nuclear energy.

The TEG uses six objectives to evaluate what is considered sustainable. **An activity can be considered sustainable when it strongly contributes to at least one of the objectives without doing significant harm to any of the others**. The six objectives are:

I. Climate change mitigation

II. Climate change adaptation

III. Sustainable use and protection of water and marine resources

IV. Transition to a circular economy, waste prevention and recycling

V. Pollution prevention and control

VI. Protection of healthy ecosystems

The climate change mitigation potential of nuclear energy was found to have strong base in the TEG report. Authorities such as IPCC (Intergovernmental Panel on Climate Change), International Energy Agency (IEA) and OECD see nuclear as low-carbon source of energy that can help mitigate climate change at a reasonable cost. While TEG acknowledges that nuclear energy has low lifecycle emissions and can therefore help mitigate climate change, they cite confusing and mixed evidence regarding the Do No Significant Harm-criteria (DNSH) on some of the sustainability objectives.

Almost half of Europe's low-carbon energy is provided with nuclear power today, and it is the single biggest source of low-carbon energy in Europe, sustaining an estimated 1.1 million jobs. It currently has an essential role in low-carbon energy production and climate mitigation, and modelling suggests that role would need to expand significantly (IPCC 2018) in future to enable timely and cost effective decarbonization across the whole economy.

1 https://ec.europa.eu/info/files/190618-sustainable-finance-teg-report-taxonomy_en

The TEG appears to have received mixed evidence on the nuclear lifecycle regarding DNSH. However, the most important point regarding DNSH of nuclear energy lifecycle is that **all commercial nuclear activities in the EU are already rigorously regulated to a 'Do no harm' standard through the Laws, Regulations, and Procedures of the EU and the Member States.**

2. Summary of Conclusions

This document assesses the case from multiple points of view considering the best available evidence. **That evidence shows clearly that under current treaties, guidelines, regulations and legislation, the nuclear energy lifecycle does not and will not cause significant harm to the sustainability objectives.**

Within this report we demonstrate that **the question of whether the nuclear energy lifecycle meets the Do No Significant Harm criteria is not a relevant question**. Today, all commercial nuclear activities in the EU are rigorously regulated to a 'Do no harm' standard through the Laws, Regulations, and Procedures of the EU and the Member States. This is done on both EU level (Euratom Treaty[2]) and national level (national legislation and regulation), supported by international guidelines and recommendations from expert organizations such as ICRP (International Commission for Radiological Protection). This includes the short-term storage of spent nuclear fuel, and the provisions that are being made for its permanent disposal.

Additionally, the world's scientific consensus concludes that maintaining and expanding nuclear energy is <u>necessary</u> to achieve sustainability objectives, such as climate change mitigation. This is also reflected in the significant number of European Union member states whose climate and sustainability policies include a future role for nuclear energy, including: France, Finland, Sweden, Poland, Bulgaria, Lithuania, Romania, the United Kingdom, Slovenia, Slovakia, Hungary and the Czech Republic.

As nuclear energy is an integral part of current European Union member states' climate mitigation efforts, it would call for very strong evidence for risk of significant harm and a severe lack of methods and institutional oversight (regulatory, legislative and technical) to mitigate that risk to justify the exclusion of nuclear energy from the taxonomy. No such evidence is present in mainstream scientific research.

Claiming that there is not enough empirical evidence on safe long-term spent nuclear fuel storage to make a robust DNSH assessment for nuclear energy is in contradiction to the Laws, Regulations and Procedures already in place in the member states of the European Union. For example, the nuclear law in Finland[3] states that a Final Repository may not cause a larger than 0.01[4] mSv dose per year to the most exposed member of the public under normal operations. To put this level in context, 0.01 mSv is over two orders of magnitude smaller than the average dose of 3.2

2 Council Directive 2011/70/EURATOM that regulates nuclear waste. The DNSH and requirement derives from preamble 21 and 23.

3 YEA 161/1988 22 d §. (19.12.2017/1001)

4 This limit has been considered by the IAEA to be so low as to not warrant any regulatory control, and by definition could not cause significant harm.

mSv that a Finn gets from all sources annually[5].

In other words, a final repository that would cause significant harm cannot be permitted or built according to European Union member state laws. The DNSH criteria is already engineered into the processes at every stage. A facility for the permanent storage of used nuclear fuel has been permitted by the Finnish Parliament, after a careful assessment and supportive statement by the independent Finnish nuclear regulator STUK. This facility is currently under construction and is slated to enter operation in 2020s.

European nations such as France, Sweden, Belgium and Switzerland have already effectively decarbonized their electricity sector with significant help from nuclear energy and have decades of empirical evidence of no significant harm to people or the environment caused by the nuclear energy lifecycle. European Union member states have accumulated half a century of experience in regulating the safe handling, storing and ultimate disposal of high-level nuclear waste, without any significant harm done. **Indeed, there is no evidence whatsoever that these activities have ever hurt a single member of the public anywhere in the European Union.**

The statements and details above are substantiated by best available evidence on each of the objectives throughout the nuclear energy lifecycle in this document. We also discuss the other points for the case, such as relevant EU legislation, proportionality and equal treatment, and help compare the benefits of nuclear with the environmental impact nuclear energy has, as well as those of other energy sources and sustainable activities covered in the taxonomy.

2.1. Key Arguments

The TEG justification for not including nuclear in the Taxonomy at this point has various, perhaps unintentional, implications and problems. These are briefly summarized below.

First, all commercial nuclear activities in the EU are already regulated to a 'Do no harm' standard through the Laws, Regulations, and Procedures of the EU and the Member States. This is done on both EU level (Euratom Treaty) and national level (national legislation and regulation). This includes the interim storage of spent nuclear fuel (Radioactive Waste and Spent Fuel Management Directive), the protection of workers and members of the public throughout the entire nuclear life cycle and the provisions that are being made for its permanent disposal. For the TEG assessment to indirectly question the competence and capability of EU member states national nuclear regulatory bodies requires strong evidence.

Second, the TEG decision to, as yet, not include nuclear energy undermines the sovereign energy and climate policies of EU nations. Nuclear energy currently provides 49% of the EU's low-carbon electricity[6] and the industry supports`an estimated 1.1 million jobs[7]. Ministers from 10 EU countries recently petitioned the European Commission, calling for a technology neutral approach in creating a level playing field for investment in all low-emissions

5 Also, it is roughly three orders of magnitude smaller than the variation in background dose received by the people in Finland, which can be in the tens of millisieverts, mostly due to radon.

6 BP Statistical Review of World Energy 2019

7 Foratom Press release: Investing in low carbon nuclear generates jobs and economic growth in Europe (April 2019)

sources as crucial for delivering affordable energy security and decarbonization[8]. While exclusion from the Taxonomy does not forbid the construction of nuclear power plants, it does severely hinder efforts of many nations to achieve a just transition by making nuclear projects more difficult to finance. The possible exclusion of nuclear energy from the Taxonomy must therefore rest on a solid base of evidence in order to justify its impact on national sovereignty within the EU.

Third, **the TEG justification to not include nuclear undermines climate mitigation scenarios and roadmaps that have been identified as feasible and necessary by some of the world's most credible and authoritative international institutions and organizations, including the IPCC[9], IEA[10] and the European Commission[11]**. All of these bodies conclude that nuclear energy should continue to take on a significant role in a cost effective, timely and successful climate mitigation effort. The possible exclusion of nuclear energy from the Taxonomy risks making climate mitigation much more challenging by decreasing funding opportunities available to nuclear projects and by needlessly increasing the cost of capital for nuclear energy projects. An exclusion of nuclear energy from the taxonomy should only be considered if strong evidence proving actual significant harm has or could take place is presented. if such evidence were presented (and it is not), it would need to be weighed against the evidence of potential harm caused by excluding nuclear from climate change mitigation efforts.

Fourth, **the TEG justification to not include nuclear undermines the integrity and independence of national and international regulations and responsible regulators; legislation (such as the Euratom Treaty and its associated Directive); and international best practices and guidelines (for example from IAEA and ICRP); whose collective remit is to guarantee full lifecycle safety, radiological protection and responsibility in all nuclear operations**. By claiming a need for long term empirical data from permanent waste facilities to prove that they are safe, the TEG appears to be disregarding internationally verified standards and legislation. It is also questioning and undermining trust in the capability of the Euratom Legal Framework and independent national regulators appointed by their governments to ensure safe and sustainable long-term operations in the interests of protecting people and the environment. For example, the Finnish regulator STUK has licensed the Finnish final repository that is now under construction, subject to compliance with safety regulations and radioactive waste management procedures for its intended long-term operation. To our knowledge, no evidence was requested or considered by the TEG from any nuclear regulatory authority of a European Union member state with regards to the potential harm from long term management and storage of radioactive waste. The inclusion of nuclear energy in the taxonomy should be considered in the light of such expert input and the associated substantial evidence.

Fifth, the evaluation of all forms of low-carbon electricity generation should be made on equal grounds. The TEG's technical report does not consider the relative detriment of the different options for generating low-carbon electricity. Specifically, the treatment of nuclear energy in the TEG's technical report differs to other technologies with respect to waste management. All forms of low-carbon electricity generation incur some waste products and involve some element that cannot be considered 'environmentally sustainable'. The full life cycle of electricity generation should be taken into account and compared fairly across all technologies.

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8 http://www.world-nuclear-news.org/NP-Ten-nations-petition-Brussels-for-nuclear-0407141.html

9 IPCC 2018 SPM, https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

10 Nuclear Power in a Clean Energy System, IEA, 2019. https://www.iea.org/publications/nuclear/

11 A Clean Planet for All, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773, European Commission, 2018

Finally, by creating a different set of requirements for one activity over the others, the TEG is compromising its own integrity and credibility as an independent technical expert group. As an example, by demanding long term empirical evidence for nuclear waste repositories, while no such evidence is demanded from any other industry or sector managing hazardous wastes, the TEG risks compromising the technology neutrality requirement of the Taxonomy. Clear inconsistencies in the application of the EU principle of equal treatment in relation to the Do No Significant Harm (DNSH) criteria risks undermining confidence of financiers that the definition of a sustainable activity has been developed with rigour, robustness and in an objective way. Such unequal treatment and the present exclusion of nuclear (despite its critical role in reaching net zero emissions) is potentially damaging to the reputation and credibility of both the Taxonomy and the TEG, which in turn may limit the adoption of the Taxonomy and EU Green Bond Standard by the wider financial community.`

Legal Arguments

Under established EU case-law, measures adopted by the EU institutions must comply with general principles of EU law, including the principles of equal treatment and proportionality.

2.1.1. EU General Law Principle of Equal Treatment

Under the general EU law principle of equal treatment, comparable situations must not be treated differently, and different situations must not be treated in the same way unless such treatment is objectively justified[12].

In the TEG report, empirical long-term evidence is demanded for an activity that is highly regulated and which has strong national, EU and international legislation and guidelines. Most of the other activities accepted in the taxonomy are similarly required to follow existing regulation and best practices in order to meet the DNSH requirements. For activities other than nuclear energy, adherence to such regulations and best practices seems sufficient in TEG evaluation for inclusion in the Taxonomy. This treatment can be seen as not equal, and justifying it would require evidence, which is not presented by the TEG.

Eu General Law Principle of Proportionality

Under the established EU case-law, in order to comply with the principle of proportionality, a legislative measure must pursue a legitimate objective and:

a) be an "*appropriate*" means of achieving that objective (i.e. suitable or capable of meeting its objective);

b) be "*necessary*" and the "*least onerous*" means of achieving that objective; and

c) not impose a burden which outweighs the benefits of the measure.[13]

12 See for example, Case C-127/07 Arcelor Atlantique and Lorraine and Others, para 23; Case C-264/18 P.M. and Others v Ministerraad, para 28; Case C-220/17 Planta Tabak-Manufaktur Dr. Manfred Obermann GmbH & Co. KG v Land Berlin, para 36; Case C-477/14 Pillbox 38, para 35. The principle of non-discrimination is similarly enshrined under Article 21 of the Charter of Fundamental Rights of the European Union.

13 See for example, Case C-331/88 R v Minister of Agriculture, Fisheries and Food, ex parte FEDESA EU:C:1990:39, para 13, Case C-128/17 Republic of Poland v European Parliament and Council of the European Union, para 94; Case C-358/14 Republic of Poland v European Parliament and Council of the European Union, para 78.

Excluding nuclear from the Taxonomy on the basis of lack of empirical proof to facilitate a robust DNSH assessment is disproportionate on the basis that:

a) The *net* impact of nuclear energy from an environmental perspective is positive; and

b) The detrimental consequences of excluding nuclear to EU's emissions reduction targets would outweigh any minor environmental impacts – which are well-regulated even as it is – that nuclear energy has. In essence, the avoidance of these minor impacts would be disproportional compared to the negative impacts that leaving nuclear out from the taxonomy could have for the climate targets.

Freedom of Member States to Determine Energy Mix Under The TFEU (Article 194)

Member States that are "nuclear friendly" (such as those 10 countries mentioned above) risk being severely impacted by of nuclear energy's exclusion from the Taxonomy in terms of their ability to develop and sustain nuclear capacity. Any proposal to exclude nuclear energy (that cannot be robustly and scientifically justified) would make it difficult for EU member states who wish to pursue nuclear generation to exercise that discretion allowed under Article 194 TFEU to include nuclear in the future energy mix, together with other forms of low-carbon generation.

2.2. Concluding Notes

We have reached some serious conclusions in the summary above, the evidence for which we present below. The technical evidence of the subject matter is substantial and clear, but also technical in nature and not very accessible for non-subject-matter-experts.

This assessment report was prepared for the TEG group, as well as for the international investment and financing community, to help them fairly and robustly evaluate the overall sustainability of nuclear energy as an investment.

Our central finding is that **nuclear energy is a sustainable energy investment**. Given that we need nuclear to play a part in the global climate change mitigation challenge, every effort should be made to move the discussion closer to the evidence base.

3. About This Document

This chapter describes the methodology used to undertake this assessment, and what elements were taken into consideration when evaluating evidence.

3.1. Objective

The objective of this assessment is to provide enough evidence-based and factual information regarding the Do No Significant Harm criteria to justify following additions to the taxonomy list:

- Production of Electricity from Nuclear Energy
- Cogeneration of Heat/Cool and Power from Nuclear Energy
- Production of Heat/Cool from Nuclear Energy

Given that nuclear energy production is based on first producing heat, using that heat to make steam which in turn is used to make electricity, all of these activities can be viewed as one in relation to their climate mitigation potential as well as the evidence for the DNSH criteria for other sustainability objectives. These activities would also enable nuclear energy to be used to make hydrogen (through electrolysis or thermolysis) and other synthetic fuels, which are already included in the taxonomy as a sustainable activity.

3.2. Methodology

To better evaluate the DNSH criteria, the nuclear energy lifecycle is split into three activities, essentially the front end, mid end and back end:

1. Uranium production (mining, milling, transportation), enriching and fuel fabrication.
2. Construction and operation of nuclear power plants (including Long Term Operations, new conventional units and new small/advanced reactors).
3. Decommissioning of facilities, management of waste products.

Each of these activities are assessed against the DNSH objectives, by asking and presenting evidence for:

a. What would generate significant harm during the life cycle of the activity?
AND
b. Can this risk be addressed by complying with EU legislation and best practices, international standards or guidelines?

to find out if significant harm is done and whether it can be mitigated, as per TEG report objectives and conditions for causing significant harm (page 46):

Objective	Conditions for causing ‘significant harm’
Sustainable use and protection of water and marine resources	The activity is detrimental to a significant extent to good status of Union waters, including freshwater, transitional waters and coastal waters, or to good environmental status of marine waters of the Union.
Transition to a circular economy, waste prevention and recycling	The activity leads to significant inefficiencies in the use of materials in one or more stages of the life-cycle of products, including in terms of durability, reparability, upgradability, reusability or recyclability of products; or where that activity leads to a significant increase in the generation, incineration or disposal of waste.
Pollution prevention and control	The activity has relative high emissions to air, water and land compared to a level of environmental performance that is based on BAT principles.
Protection of healthy ecosystems	The activity is detrimental to a significant extent to the good condition of ecosystems.

For easier reading, most chapters start with a summary of the key findings in the chapter.

3.3. Significant harm

Significant harm is somewhat of a subjective term and measuring it can be complicated. The TEG report from June 2019 cites various sources of information in its discussion of nuclear energy, some of which have undergone assessment through scientific peer-review, and some that have not. Some of the sources used are also commissioned by organizations that have defined themselves publicly and/or professionally as anti-nuclear. While this, by itself, does not render what they say wrong, biased or incorrect, it is prudent to take this into account when reviewing their work, and especially so when said work is not peer-reviewed or scientifically published.

All human activity causes harm to some extent from some perspective, and subjectively this can be experienced also as significant due to personal preferences and biases. Therefore, the case in this document is assessed by:

1. **Providing best available mainstream evidence and research** from reputable sources. These include studies commissioned by European Commission (such as the ExternE-study[14]) and those done by United Nations expert organizations such as IPCC, WHO and UNSCEAR. Secondary sources might include rigorous meta-studies/literature reviews or reports done by reputable international organizations such as OECD, IEA, IAEA or reports by private organizations such as the BP Statistical Review of World Energy for statistical information. Thirdly, environmental, safety and security assessments by highly regarded independent national safety regulators tasked with ensuring demonstrated compliance with rigorous standards designed to protect people and nature.

2. **Comparing the potential harm/risk and what is done to mitigate it with other sustainable activities** within a level playing field, when appropriate. This will help give context to what can be considered as significant harm or risk, and ensures that the findings and conclusions are as technology neutral as possible.

3.4. Reviewing the Taxonomy Criteria

While the TEG report cited lack of empirical evidence on geological repository performance as a reason for them being unable to make a DNSH assessment on nuclear energy, it needs to be noted that there is no requirement for empirical evidence for any of the other activities included in the taxonomy.

The objectives and conditions for causing significant harm, as stated in the taxonomy report, are:

Objective	Conditions for causing 'significant harm'
Sustainable use and protection of water and marine resources	The activity is detrimental to a significant extent to good status of Union waters, including freshwater, transitional waters and coastal waters, or to good environmental status of marine waters of the Union.

14 The methodology in ExternE-project has since been used in many studies that assess external costs of energy, many of which are cited later in this assessment. http://www.externe.info/externe_d7/

Transition to a circular economy, waste prevention and recycling	The activity leads to significant inefficiencies in the use of materials in one or more stages of the life-cycle of products, including in terms of durability, reparability, upgradability, reusability or recyclability of products; or where that activity leads to a significant increase in the generation, incineration or disposal of waste.
Pollution prevention and control	The activity has relative high emissions to air, water and land compared to a level of environmental performance that is based on BAT principles.
Protection of healthy ecosystems	The activity is detrimental to a significant extent to the good condition of ecosystems.

While each of these are viewed through two questions:

a. What would generate significant harm during the life cycle of the activity?
   AND
b. Can this risk be addressed by complying with EU legislation and best practices, international standards or guidelines?

The technical screening criteria (TSC, page 47) states that:

> *3. Sectoral activities with high mitigation potential not included in the Taxonomy. Where 'significant harm' to one or more environmental objectives by the activity cannot be avoided through TEG requirements, the activity was not included in the Taxonomy. Material issues whereby an activity is considered unsuitable for inclusion in the Taxonomy may include but are not limited to: lack of empirical data for reasonable evaluation of DNSH (in line with the precautionary approach), lock-in and intergenerational risks.*

However, it seems that "lack of empirical data" is only used when assessing nuclear energy. For practically all other energy sources included, it is clearly the assessment of the TEG that the potential problems can be mitigated by following EU legislation, regulations, best practices, international standards or guidelines. When it comes to nuclear fuel cycle and waste, there are strict regulations, legislation and guidelines already in place on how to handle these both on the European (Euratom treaty) and on national levels. These are without exception already defined on the principles of "do no significant harm".

These limits are very strict, several orders of magnitude on the safe side regarding significant harm. Generally, the international scientific consensus screens out radiological impacts below 0.01 mSv. In Sweden's case, the final repository can at most cause an annual additional dose of 0.014 mSv[15], and in Finland the limit for normal operations of a final repository is 0.01 mSv[16]. These maximum limits represent an increase of less than half percent to the average global dose and are well within natural background variation, which can be in the tens of millisieverts.

15 SSMFS 2008:37, https://www.stralsakerhetsmyndigheten.se/publikationer/foreskrifter/ssmfs-engelska/ssmfs-200837/

16 YEA 161/1988 22 d §. (19.12.2017/1001)

3.4.1. Equal Treatment

With these regulations and compliance in place, there is no basis to assume that significant harm would be done, thereby violating taxonomy objectives. By demanding further empirical evidence on something that has

1. robust scientific evidence saying it can be done very safely and
2. decades worth of evidence on safe management of interim storage of high-level waste as well as on the geological storage of low and medium level waste,

the TEG seems to be treating nuclear energy by different standards. The taxonomy is emphasised as being **technology neutral**, so similar evaluation standards should be used with all potential technologies.

Under established EU case-law, measures adopted by the EU institutions must comply with general principles of EU law, including the principles of equal treatment and proportionality. Under the general EU law principle of equal treatment, comparable situations must not be treated differently, and different situations must not be treated in the same way unless such treatment is objectively justified.

3.4.2. Proportionality

It can also be argued that the potential positive contribution should be weighed with the potential risk (likelihood and scale of impact) of a negative harm being done to the environment, in accordance with the proportionality principle of EU law. From this perspective, we have a situation where:

First, Nuclear energy is being excluded from the taxonomy based on not having empirical evidence on final repositories which is said to prevent a robust DNSH assessment from being done. **Second**, it is done despite the fact that final repositories are regulated, researched and managed to be one of (if not the) safest part of the nuclear lifecycle.

To put this in proportion, nuclear energy is the EU's biggest source of low-carbon energy today. It is currently our only significantly expandable source of *dispatchable*[17] low-carbon energy. It is also seen as being integral part of a timely and cost-effective decarbonization by any credible climate mitigation scenario by relevant major organizations such as the IPCC, IEA, European Commission.

Exclusion from the taxonomy does not forbid or prevent anyone from investing in nuclear energy. But it could have major impacts on the feasibility and likelihood of those investments, both directly and indirectly. First, it will directly decrease the sources of financing opportunities for projects. This will make financing harder (more unlikely) and increase financing costs (such as the cost of capital, demands for collateral).

Further, indirectly, this will label nuclear energy as not sustainable both in the eyes of the investment community and in public discussion, making public perception and opinion less favourable. This will make projects both harder to finance (again) and harder to get national and local policy support for. Further, as the taxonomy aims to become

17 Dispatchable, or on-demand energy sources make expanding energy supply simpler and less costly than using energy sources that are variable or not dispatchable, as those energy sources need more additional back-up, flexibility and storage systems to offer a reliable energy service.

a more widely used standard for sustainable investments beyond EU, all these effects will multiply to a global scale, meaning we will have less access to low-carbon energy at any given time.

While the potential for significant harm with nuclear lifecycle is both small and well-managed and regulated as it is, the potential for significant harm if it is excluded from the taxonomy could be large. This proportionality, which is based on EU law, should also be taken into consideration.

Below are some comparisons, taken from the TEG report (June 2019), on how other energy sources are expected to mitigate their DNSH potential.

3.5. Technology Neutrality in Criteria Assessment

To have the taxonomy come out as technology neutral as possible, it is useful to take a step back and take a broader look. Are different activities being evaluated on similar principles and criteria?

Other energy sources (for power, heat and co-generation) being included in the list of sustainable activities for the Taxonomy are:

- Solar PV
- Wind (onshore and offshore)
- Concentrated Solar
- Ocean Energy
- Hydropower
- Geothermal
- Gas Combustion
- Bioenergy

Carbon capture and storage (CCS) is also included. It is a potentially very useful technology for facilitating the significant negative emissions we will need to meet our climate targets in the future. Some energy sources (namely natural gas) also require the use of CCS to be able to go below the lifecycle emissions threshold of 100 gCO_2/kWh.

The decision to not include nuclear energy in the taxonomy at this stage was justified to a significant extent on the argument that there is no empirical long-term evidence available to ensure that high level waste can be stored in a way that it will not cause significant harm to some of the objectives. We have not had a working final repository for HLW, from which we could have gathered empirical evidence of its performance. Therefore, some might argue that precautionary principle should be used.

However, one should not lightly use the absence of empirical evidence as proof that the opposite is certainly, or even potentially, the case. There is ample evidence in the form of studies, analysis and scenario modelling that for example geological repositories, and the regulations they have in place, make it practically certain that they will not cause significant harm.

So, the other piece of evidence to consider is the lack of evidence that well-managed HLW *would* cause significant harm. **First**, there is no evidence that civilian nuclear waste anywhere has caused significant harm up to date, as it has been managed carefully and responsibly. **Second**, there are no credible studies or scenarios out there that quantify any possibility of HLW repository causing what could be called “significant harm” in any reasonable context – the regulations that need to be followed include a safety margin of several orders of magnitude[18].

It should be noted that dealing with legacy military-related radioactive waste is somewhat more complicated, as many governments chose not to act responsibly in their quest to obtain weapons grade plutonium for nuclear weapons programmes after the Second World War and during the Cold War. These are problems caused by earlier governments and military doctrine and practices, not civilian nuclear power generation[19]. References to nuclear waste, high level waste and spent fuel in this assessment refer only to civilian nuclear energy waste products, as is relevant in the context of the taxonomy.

3.5.1. Production of Electricity from Solar PV

From TEG report:

> *The main potential significant harm to other environmental objectives from the installation and operation of photovoltaic (PV) panels relate to:*
>
> - The PV installation siting: impacts on ecosystems and biodiversity if built in a designated conservation area or other areas with important ecosystem and biodiversity value.
> - The impacts from the production and end-of-life management of the PV systems and its component/materials: potentially significant environmental impacts are associated with the sourcing/production of materials and components of PV systems (see 'Manufacture of Low Carbon Technologies' for DNSH criteria)

And the cited "Manufacture of Low Carbon Technologies":

> *The main potential significant harm to other environmental objectives from the manufacture of low carbon technologies is associated with:*
>
> - the (potential) use of toxic substances and generation of toxic wastes (both at the manufacturing stage as well as at other stages of the product/equipment lifecycle); and
> - the potential for polluting emissions to air, water and soil from the manufacturing process.
>
> *Depending on the product/equipment being manufactured, there may, also be issues with respect to the embodied carbon and the demand for certain metals and materials (e.g. rare earth metals) which are in limited supply and may have significant environmental impact issues associated with the mining phase.*

These will be mitigated (regarding pollution prevention and control):

> *Compliance with the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) Regulation (1272/2008/EC) and the RoHS (Restriction of Hazardous Substances) Regulation (2002/95/*

18 This topic is more thoroughly discussed later, in DNSH assessment of Pollution prevention and control.

19 For example, the Sellafield site in the UK has both military legacy waste and civilian waste, and when discussing the costs and environmental effects of them, they should not be confused with one another.

EC) or the equivalent for equipment manufactured and used outside the EU (n.b.: equipment manufactured outside of the EU but imported into the EU must comply with the REACH and RoHS Regulations).

Solar PV panels, depending on the type, may contain toxic heavy metals, and harmful substances are also used in their manufacturing. Yet there is no control or even requirement to ensure that PV panels do not end up in the environment after dismantling. They are not accounted for, yet the toxins in them – such as cadmium and lead – can be very harmful if they are not properly and *indefinitely* stored. These toxics do not have half-lives but stay hazardous for ever.

Regarding radioactive doses of various energy sources, the UNSCEAR (2016[20]) has stated that "The largest occupational collective dose normalized to energy generated in 2010 resulting from the mining for metals for construction materials was from solar photovoltaic (PV) technology, which was a factor of forty and eighty larger than for the nuclear fuel cycle and coal cycle, respectively."

PV panels in EU are within electronic waste directive (WEEE), so funds for their handling has been collected at the point of sale, but this does not entail any actual responsibility or control over what happens with the panels and the harmful materials in them after end-of-life. For comparison, in nuclear energy sector, all harmful waste is explicitly accounted for and managed by the producer of that waste, according to regulations.

There is no solid empirical evidence that the materials in solar PV panels cannot end up in the environment, causing significant harm. However, clearly it is enough for TEG that there are regulations in place, and that those regulations are followed.

3.5.2. Production of Electricity from Wind Turbines

With wind power, some of the TEG DNSH criteria mentioned include:

- Underwater noise (for offshore wind turbines)
- The composite waste from the turbines
- The possible disturbance, displacement or collision of birds and bats by the construction and operation of wind farms

These can be mitigated by "considering and minimizing the amount of noise and composite waste" and by "considering and minimizing collision risks of bats and birds." An Environmental Impact Assessment needs to be completed to recognized standards.

With nuclear energy, the case is already that the operator is required to consider and minimize all the potential harm that nuclear waste could cause. If the operator does not do this, it will lose its licence to operate by the national regulatory body and may face other severe consequences. These activities are, therefore, already part of the everyday operations.

3.5.3. Production of Electricity from Gas Combustion

Gas combustion, when it can be done with emissions under 100 gCO2/kWh, is included in the taxonomy. This

20 http://www.unscear.org/docs/publications/2016/UNSCEAR_2016_Annex-B.pdf

implies either the combustion of bio/syngas or natural gas with sufficiently effective carbon capture and storage, and also requires assurance that almost no methane leakages occur at upstream, midstream or downstream activities.

Gas combustion is similar to nuclear in the sense that it is thermal production and requires a heat sink (normally air or water). DNSH assessment from the TEG report:

> *The key environmental aspects to be taken into account when investing in this activity are the impact on local water (consumption and sewage), the fulfillment of the applicable waste and recycling criteria, the NOx and CO emissions control in line with BREF indicators and the avoidance of direct impacts on sensitive ecosystems, species or habitats.*

These are mitigated by following regulations in place and fulfilling and complying to the requirements of relevant directives and by having an Environmental Impact Assessment done to recognized standards.

3.5.4. Production of Electricity from Bioenergy

Production of electricity with bioenergy is included as well. While the sensibility of an expanded role of bioenergy is debatable (IPCC 2019) and the global warming potential (GWP) merits of bioenergy are questionable (IPCC 2014, AR5) and depend greatly on the feedstock, these are referred to EU's RED II documentation.

Burning biomass produces air pollution and ash with toxic heavy metals in it. The mitigation presented in the taxonomy is for the plants to follow the relevant directives and limit releases under certain thresholds. Nuclear power plants operate in the same way; limiting emissions under regulated thresholds.

3.5.5. Carbon Capture and Sequestration

Carbon sequestration is an activity included in the taxonomy. The reasoning in the TEG report is as follows (page 293):

> *Carbon capture and sequestration (CCS) is a key technology for the decarbonisation of Europe. It is included in all pathways presented by the European Commission in its Long-Term Strategic Vision document and is relied upon heavily in three-out-of-four scenarios outlined by the IPCC in the Special Report on 1.5 Degrees.*
>
> *A typical CCS chain consists of three main stages: capture, transport and storage. CO2 transport and storage are established and proven processes, with decades of operation and well-established regulation here in Europe.*

While this is all true, almost the exact same justification can be said of nuclear energy. Regarding the capture of carbon from different processes, the TEG report states for example (page 294):

> *CCS facilitates the direct mitigation of both fossil and process emissions in many industrial sectors including steel, cement and chemicals. Time is a crucial factor: the later options for deep decarbonisation in an industry arise, the more costly they become, and the more likely the need for greater carbon dioxide removal (CDR) in the future. 2050 is only one investment cycle away for many industries. Thus, decisions need to be made today.*

> *In addition to renewable energies, energy storage and demand-side management, CCS on dispatchable generation allows all aspects of the electricity supply system to be deeply decarbonised. CCS provides a backstop to the unabated operation of flexible electricity generation plants that are required to guarantee the operation and supply of year-round electricity. This is especially true in more isolated grids with a high penetration of seasonally variable renewables (e.g. onshore and offshore wind) where the reliable operation of electricity networks requires on-demand electricity generation.*
>
> *The availability of CCS means that no remaining segment of the electricity supply system will be capable of emitting CO2 to the atmosphere.*
>
> *Whilst some CO2 capture technologies can incur an 'energy penalty' of 10-15%, others do not. For example, the Allam cycle being developed by Net Power on natural gas combustion for power generation does not incur an energy penalty, as supercritical CO2 is integrated fully into the power cycle as a coolant. This significantly reduces both energy and water demand. It is therefore inaccurate to say that CCS is a highly energy-intensive technology.*

Again, this is all true, and one could substitute "Nuclear energy" for "CCS" almost 1:1 (the exceptions are some process emissions), especially when small and advanced nuclear reactors with innovative flexibility mechanisms built in are considered.

TEG report also discusses transport and storage of CO2. Many of the points raised there apply also for nuclear. For example:

> *It can aid electricity grid expansion, the integration of renewables and the deep decarbonisation of energy intensive industries; support and enable CO2 removal; and help stimulate a green hydrogen market. Without CO2 transport and storage infrastructure, Europe will not achieve its climate objectives.*

The main environmental impacts associated with **Permanent Sequestration of captured CO2** are due to:

- the risk of leakage
- The long-term impermeability of the reservoirs, central issues regarding the monitoring and the interrelation of carbon with physical, chemical and geological conditions in the reservoir is still a debated argument, however the safety of CO2 storage may be assured with the implementation of specific rules and requirements.

As with nuclear waste, the required time scales are long, and there is no long-term evidence that the carbon will stay underground. While there are unknowns (*central issues regarding the monitoring and the interrelation of carbon with physical, chemical and geological conditions in the reservoir is still a debated argument*) in the long term storability of CO2, the TEG argues that *"the safety of CO2 storage may be assured with the implementation of specific rules and requirements."*

As we noted above, CCS is an integral part of a successful decarbonization strategy, although perhaps not comparable to nuclear energy in its scalability, impact and effect on overall costs of decarbonization. As such an important piece of the decarbonization puzzle, TEG has appropriately included CCS as part of various activities in the taxonomy. It is also clearly willing to give CCS the benefit of a doubt and trusts that any potential, yet-unknown problems that arise can be handled with the implementation of specific rules and requirements.

This approach for CCS raises the critical question: Why is the principle not applied to nuclear energy? There is both more reason to (it is already a commercially scaled activity helping tremendously with climate mitigation) and much more knowledge and certainty regarding the safe management of the whole lifecycle, with high-level waste included. Indeed, as we will see later in this assessment, one has to be very selective and one-sided in choosing the evidence and studies regarding nuclear lifecycle to have any doubt at all on the relative overall safety, responsibility and sustainability of the nuclear lifecycle. This inconsistency of treatment does not appear to be in line with the EU law regarding equal treatment, nor proportionality.

3.6. Precautionary Principle and Opportunity Costs – Putting risks in context

Nuclear is best used to replace baseload power generation from coal and other combustion-based power plants. As such, it fills a different role in the energy system – meeting baseload demand 24/7 – than variable renewable energy sources (VRE) such as wind and solar.

If nuclear power plants are closed prematurely or not built, there is an associated opportunity cost: something that can fill the same role will be built (or not shut down) instead. For example this could be a coal plant or a natural gas plant, as has often been the case[21]. Reasons why nuclear power plants might be shut down or not built at all can be for example:

- Policy / legislation that forbids the operation of nuclear power now or in a future date (Germany, Austria, Luxemburg and others).
- Policies that subsidise some energy sources and / or penalize others in an unfair manner, or set (minimum/ maximum) limits for certain technologies in the mix (portfolio standards).
- Bad market design or biased incentives. The value of reliable low-carbon generation is not currently monetized on the market, while the costs of variable production profile are both externalised and these energy sources are rewarded in various ways (subsidies, merit order).
- Lack of affordable financing.

As a clear example, while Germany has commendably been spending hundreds of billions to expand wind, solar and bioenergy production, it has also chosen to close its fleet of nuclear reactors. This has resulted in Germany not reaching its full potential in closing down coal power with the help of these RE additions. The continuous burning of coal (and other fossil fuels) is the opportunity cost of Germany's nuclear closure, and this has resulted in both substantial climate emissions as well as thousands of premature deaths each year[22]. Meanwhile there is no evidence that the German nuclear fleet operations have ever caused a fatality. Had Germany chosen to keep their nuclear fleet operating, the additions of RE would have likely been enough to meet their 2020 emissions reductions target, which the country is now missing by a large margin, as acknowledged by the German government[23].

21 Germany has continued to rely on coal and gas while shutting down nuclear even with very large subsidies and investments into wind and solar. In the US, natural gas and coal has mainly been the replacement for lost nuclear: https://www.eia.gov/todayinenergy/detail.php?id=28572

22 Kharecha, P. A., & Sato, M. (2019). Implications of energy and CO2 emission changes in Japan and Germany after the Fukushima accident. Energy Policy, 132, 647–653. http://doi.org/10.1016/j.enpol.2019.05.057

23 https://www.cleanenergywire.org/news/germany-track-widely-miss-2020-climate-target-government

The precautionary principle is mentioned in the TEG report, to be used when conclusive evidence is not available. The precautionary principle as a policy guideline has several problems regarding the case of nuclear energy. For example, it does not take into account the verified and well-known harm from current situation – for example the thousands of annual deaths caused by coal power in Europe alone. Instead, it only accounts the potential and unknown risks of a new technology, requiring solid, empirical proof of no harm (while the current actions and technologies cause harm continuously that is often much worse).

Regarding nuclear specifically, we have a very good idea of the risks of using nuclear energy and storing its waste products for long durations, and that evidence is extensively presented in this document. We know that modern western nuclear reactors are safe to operate, and we know that the fuel cycle, including high level waste from reactors, causes practically no harm and can and has been responsibly managed.

The potential and quite well-known risk and harm from nuclear operations and long-term storage of high-level waste (HLW) needs to be compared with the harm done by alternatives such as that of coal combustion. This comparison can and should be done as long as there is coal burning happening that could be replaced by cleaner energy[24].

3.6.1. Risk Context: Air Pollution and Radiation

Air pollution and its effect on people's health has been studied and modelled extensively. Globally, ambient outdoor air pollution is linked to 4.2 million premature fatalities annually, according to World Health Organization (WHO[25]). From WHO website:

Worldwide ambient air pollution accounts for:

- 29% of all deaths and disease from lung cancer
- 17% of all deaths and disease from acute lower respiratory infection
- 24% of all deaths from stroke
- 25% of all deaths and disease from ischaemic heart disease
- 43% of all deaths and disease from chronic obstructive pulmonary disease

Human activities that are major sources of outdoor air pollution, include:

- Fuel combustion from motor vehicles (e.g. cars and heavy duty vehicles)
- Heat and power generation (e.g. oil and coal power plants and boilers)
- Industrial facilities (e.g. manufacturing factories, mines, and oil refineries)
- Municipal and agricultural waste sites and waste incineration/burning
- Residential cooking, heating, and lighting with polluting fuels

The nuclear fuel cycle causes roughly 0.007 % of our average ionizing radiation dose[26]. The average dose itself can

24 If wind and solar are said to replace nuclear, they can't replace coal at the same time. Therefore, the marginal opportunity cost is always that which is the most harmful activity taking place.

25 https://www.who.int/airpollution/

26 Sources and effects of ionizing radiation, UNSCEAR, 2008

vary by an order of magnitude (1,000 %) depending on the location a person lives in, so the proportional change caused by the nuclear fuel cycle is practically insignificant. The share of invasive cancers that are potentially caused by nuclear fuel cycle is so small that it is statistically impossible to see and fits within a rounding error. The continued effects of the Chernobyl nuclear accident gives the current Finnish population an average dose of 2 mSv throughout a person's lifetime[27]. This is more than a hundred times more than the radiation we get from the nuclear fuel cycle during our lives, and two hundred times more than what is the regulatory maximum dose limit that a final repository can cause during its normal operations in Finland. After extensive studies, no extra cancers can be detected in Finnish population due to Chernobyl fallout[28].

An OECD (2016) study "The economic consequences of outdoor pollution[29]" quantifies the economic costs of pollution today and in the future in absence of additional and more stringent policies. Global healthcare costs caused by outdoor pollution will increase from $21 billion in 2015 to $176 billion (using constant 2010 USD and PPP exchange rates) in 2060. Lost productivity due to sick days will increase from $1.2 billion to $3.7 billion. The number of premature fatalities will grow two or threefold from today (in the report, from ~3 million fatalities to 6-9 million annual fatalities by 2060).

The annual global welfare costs associated with the premature deaths from outdoor air pollution, calculated using estimates of the individual willingness-to pay to reduce the risk of premature death, are projected to rise from $3 trillion in 2015 to $18-25 trillion in 2060.

3.6.2. Air Pollution from Coal in Europe

Coal combustion caused over 22,000 premature deaths in 2013, according to "Europe's Dark Cloud", a report[30] published by Climate Action Network (CAN), The Health and Environment Alliance (HEAL), Sandbag and WWF in 2016. Depending on the statistical value we use for a loss of life, the health cost estimates for Europe vary between 32 and 62 billion euros per year.

In 2013, electricity production from nuclear was on a similar level to electricity from coal in EU, 875 terawatt hours for nuclear and 890 terawatt hours for coal. If we assume the European nuclear fleet directly and indirectly replaces coal combustion 1:1, it prevented roughly 20,000 premature fatalities in Europe, in addition to other significant health benefits from cleaner air and environment. While it is true that nuclear reactors might not replace coal 1:1, they often play a very similar role in the energy system as coal; meeting baseload electricity demand 24/7, and in some countries, providing load following services for fluctuating demand (which happens in France and Germany). The savings from using nuclear in terms of premature fatalities, sickness and human suffering are very substantial even today, and could be much larger in the future.

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27 https://www.stuk.fi/en/web/en/topics/environmental-radiation/deposition/the-effects-of-the-chernobyl-accident-in-finland

28 Auvinen, A., et al., 2013, Chernobyl fallout and cancer incidence in Finland 1988–2007, International Journal of Cancer. https://doi.org/10.1002/ijc.28554

29 http://www.oecd.org/environment/indicators-modelling-outlooks/Policy-Highlights-Economic-consequences-of-outdoor-air-pollution-web.pdf

30 Europe's Dark Cloud, 2016, http://wwf.panda.org/?272916/Europes-dark-cloud-How-coal-burning-countries-make-their-neighbours-sick

4. Contribution for Climate Change Mitigation

4.1. Summary

- **Nuclear energy can and does substantially contribute to climate change mitigation**.
    - Globally nuclear is our second largest source of low-carbon energy (after hydro) and, unlike hydro, can be expanded regardless of topography or most other local, physical limitations.
    - In Europe, nuclear energy is our largest source of low-carbon energy, producing almost half of our non-combustion-based energy (BP 2019[31]) and almost 30 % of EU's electricity[32].
- Globally, we need to increase nuclear energy roughly 2 to 6 times from 2010 levels by 2050 and 1.6 to 2 times 2010 levels by 2030 to have a reasonable chance of staying under 1.5 C warming in the long run (according to the four main scenarios by IPCC 2018[33]).
- Failing to replace, or extend the operating lifetime, of the existing nuclear fleet could result in an additional 4 billion tons of carbon dioxide emissions (IEA 2019).
- Nuclear energy has very low median life-cycle emissions, comparable to wind and hydro (IPCC 2014).
    - 11 gCO2-eqv/ kWh for onshore wind
    - 12 gCO2-eqv/ kWh for nuclear
    - 12 gCO2-eqv/ kWh for offshore wind
    - 24 gCO2-eqv/ kWh for hydro
    - 48 gCO2-eqv/ kWh for large-scale solar
    - 230 gCO2-eqv/ kWh for biomass
- Nuclear power plants produce reliable, dispatchable energy with little need for additional capacity to act as backup or to load-follow production variability.
- Nuclear reactors can be used to directly decarbonize industrial process and heating. Heat accounts for about half of Europe's (and global) end energy use.

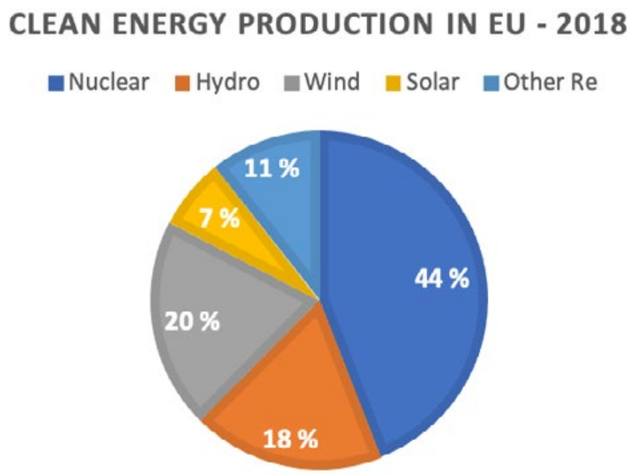

Figure 1: Nuclear is EU's most significant clean energy contributor. Data: BP 2019.

31 BP Statistical Review of World Energy 2019. If bioenergy is counted as clean, nuclear share drops to around 44%.

32 https://ec.europa.eu/energy/en/topics/nuclear-energy

33 IPCC 2018 SPM, https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

4.2. Substantial contribution for climate change mitigation

The TEG report (2019) stated the following:

> *"The TEG assessed nuclear energy as part of its review on energy generation activities. Nuclear energy generation has near to zero greenhouse gas emissions in the energy generation phase and can be a contributor to climate mitigation objectives. Consideration of nuclear energy by the TEG from a climate mitigation perspective was therefore warranted."*

And:

> *"Evidence on the potential substantial contribution of nuclear energy to climate mitigation objectives was extensive and clear. The potential role of nuclear energy in low carbon energy supply is well documented."*

These statements are backed by best available mainstream evidence. IPCC did a review (2014, AR5, WG3) of the available evidence and literature and found out that the median life-cycle emissions from nuclear power are very low. As the rest of the economy decarbonizes, the life-cycle emissions from nuclear will drop further.

A median estimate of nuclear Life Cycle Emissions according to IPCC (2014) is:

- 12 gCO2/kWh for electricity
- 4 gCO2/kWh for heating/cooling (achieved either with a heat pump using electricity at seasonal coefficient of performance (SCOP) of 3.33 or by using direct steam/heat from the powerplant in combined heat and power or heat only -mode).

A more recent study, "Life Cycle Assessment of Energy" (Dincer 2018[34]) has similar result, giving nuclear electricity a Global Warming Potential (GWP) of 11 g CO2 eq/kWh for boiling water reactors and 13 g CO2 eq/kWh for pressurized water reactors. This study used the TEG approved ISO 14040:2006 and ISO 14044:2006 standards for the analysis.

4.3. Nuclear Growth Requirements

Many global bodies recommend that humanity maintain and increase its nuclear energy production as part of our climate mitigation efforts. Politically, the EU as a whole and several powerful countries within it, have been in conflict with these recommendations and mainstream science in their policy regarding nuclear, even though the recent European Commission's Clean Planet for All -report defined a significant role for nuclear energy as well. This chapter summarizes the views of some of the institutions that see nuclear as an integral part of our climate mitigation efforts. The evidence they have used to reach these positions needs to be taken into consideration and weighed proportionally against the strength of the case to exclude nuclear energy from the taxonomy.

As can be seen below, to make a major ruling against all these institutions and their publications, an extremely strong case with supporting evidence would need to be presented to exclude nuclear energy. So far, no such evidence has been presented in the TEG report of June 2019.

34 Dincer, I., Bicer, Y., (2018), 1.27 Life Cycle Assessment of Energy. Comprehensive Energy Systems. Pages 1042-1084. https://doi.org/10.1016/B978-0-12-809597-3.00134-6

4.3.1. IPCC: 2-6 times more nuclear by 2050

The IPCC Special Report on 1.5 C warming (2018) laid out four main scenarios for decarbonization. EU countries have signed the Paris agreement which aims to keep long term warming well below 2 C, and are aiming for carbon neutrality by 2050. While IPCC scenarios are global, it is ethically clear that as developed countries that already have much of the capital, institutions, infrastructure and know-how in place, most EU countries need to do more than just their fair share to decarbonize. This will give developing nations more time to grow their economies, build institutions and infrastructure with the help of fossil fuels, and still have a chance to keep us within our emissions budget.

IPCC four main scenarios see global nuclear growing roughly 60-100 % already by 2030, and 100-500 % by 2050, depending on scenario. The EU currently has 130 nuclear reactors producing over 820 TWhs of clean, reliable electricity each year. The EU produces roughly 30 % of global nuclear energy[35], and clearly has both the potential and willingness for increase.

If EU were to simply "do its share", it would need at least a hundred, and up to 500, new large nuclear reactors[36] by 2050, plus replacements for all the reactors shutting down by then. This is in addition to very ambitions increases in renewable energy sources and efficiency. Further, given as some major European economies have chosen to exclude nuclear from their energy mixes on a political decision, the remaining countries would need to do much more than their relative share.

The IPCC macro-scenario might even prove to be too conservative. The EU chemical industry alone would need thousands of terawatt-hours (according to a recent technology study[37] commissioned by The European Chemical Industry Council) of clean energy to decarbonize its operations and to provide a much-needed net carbon sink.

4.3.2. European Investment Bank likely continues to support nuclear investments

The new Energy Lending Policy draft of European Investment Bank (EIB) maintains support for nuclear power as part of its plan for climate mitigation lending. To quote[38]:

> *"In addition to wind and solar, long-term decarbonisation targets are expected to require investment in a wide portfolio of technologies, including some renewables which currently have relatively high costs.....Other low-carbon technologies are also playing an important role in long-term net-zero emission scenarios by 2050. The Bank's eligibility conditions for support for nuclear power generation and fuel cycle projects remain unchanged from the previous policy..."*

The EIB also sees greater demand for reliable electricity as heating, transportation and industries electrify, as well as for decarbonization of sectors that remain hard to electrify:

35 BP Statistical Review of World Energy 2019

36 Or equivalent capacity in small reactors.

37 Low carbon energy and feedstock for the European chemical industry, DECHEMA e.V. (2017)

38 EIB Energy Lending Policy Draft on July 26th 2019

> *"The heat, industry and transport sectors are expected to become increasingly electrified, as a way to reduce greenhouse gas emissions, driving up electricity demand and increasing sector integration;*
>
> *Achieving net-zero emissions will require a diverse portfolio of technologies including renewables, but also nuclear, carbon capture and storage, power-to-X (converting surplus renewable power into a different energy carrier) , as well as bioenergy, storage and digital technologies. Increased innovation and deployment is needed across the portfolio."*

EIB also notes that nuclear energy, among many other sectors and activities, is not on track to meet Paris Agreement:

> *"Despite this consensus on the necessary direction of travel, the scale of investment and progress across individual technologies differs widely. As monitored by the International Energy Agency report on Tracking Clean Energy Progress, the scale of investments in energy efficiency, clean mobility, decarbonisation of heating, carbon capture and storage and nuclear are considered to be not on track to reach the Paris Agreement."*

4.3.3. European Commission's *Clean Planet for All* has Nuclear in Significant Role

In its "A Clean Planet for All" communication[39], the European Commission confirmed that, together with renewables, nuclear will form the backbone of a carbon-free European power system. The latest Intergovernmental Panel on Climate Change (IPCC) report (Global Warming of 1.5°C)[40] also recognises that nuclear power has an important role to play if the world is to keep global warming to below 1.5 degrees. In particular, numerous modelling scenarios referenced by the IPCC indicate that technologies in addition to renewables, such as nuclear (current and advanced) and carbon capture and storage may be useful, expedient, or even necessary.

Reports published by the International Atomic Energy Agency (IAEA)[41] and the Joint Research Center (JRC)[42] also confirm the role of nuclear energy in the fight against global warming. It is worth noting that even if every country met the pledges it has made to date through the Paris Accord, average global temperatures would still be on a trajectory to rise by between 3°C to 4°C by 2100 (depending on one's level of optimism or pessimism) compared to 6°C increase with no action.

As stated above, decarbonisation (and increased efficiency) of the power sector is critical, but represents only part of the challenge. All sources of clean energy are needed to achieve deep, economy-wide decarbonisation. Yet as electricity only accounts for a fifth of global energy use and has been increasing its share at a modest speed of ~2 % per decade, it is clear we also need to find ways to tackle emissions in heating, industrial processes and transportation fuels directly, which account for most of the rest of our energy use.

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39 A Clean Planet for All, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773, European Commission, 2018

40 Global Warming of 1.5°C https://www.ipcc.ch/sr15/, IPCC, 2018

41 Climate Change and Nuclear Power, IAEA, 2018. https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

42 Global Energy and Climate Outlook 2017: How climate policies improve air quality. Global energy trends and ancillary benefits of the Paris Agreement, Joint Research Center/ European Commission, JRC Science for Policy Report, 2017. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC107944/kjna28798enn(1).pdf

The application of nuclear technologies (current and advanced) and carbon capture and storage can make a major contribution in these sectors. They can produce high grade process heat and cost-efficient clean gaseous and liquid transportation fuels (such as hydrogen and ammonia) for multiple applications.

4.3.4. IEA sees nuclear as an important part of the climate mitigation

IAE recently released a report "Nuclear Power in a Clean Energy System" (2019)[43]. The report warns that the nuclear fleet in advanced economies is 35 years old on average and that many plants are nearing the end of their designed lifetimes. Given their age, plants are beginning to close, with 25% of existing nuclear capacity in advanced economies expected to be shut down by 2025. The IEA raises the alarm that the absence of further lifetime extensions and new projects could result in an additional **4 billion tonnes of CO2 emissions**, underlining the importance of the nuclear fleet to low-carbon energy transitions around the globe.

While the report states that refurbishing for long term operations and uprating current fleet of nuclear power plants is among the most economical way to add (or to not lose) low-carbon energy production, it also states that new build of nuclear is necessary if there is to be a role for it in the future. Given that this role is very much needed, it means that new build of nuclear needs to be viable, and policies which make it more viable need to be in place. To quote from page 19:

> *"The greatest barrier concerns the ability of nuclear power to compete with other generating technologies on cost, especially in countries that have introduced competitive wholesale markets (discussed in detail in the next chapter). This is exacerbated in power sectors where nuclear's low-carbon nature is not recognised, either through policies such as carbon pricing or wholesale market designs and mechanisms supporting investments in low-carbon technologies in general."*

Other risks include the sheer size of large nuclear power plants, which are closer to major infrastructure projects in scale, the policy risk over longer timelines, potential for delays and cost overruns and disruption risks for the electricity system itself.

The report states very clearly that the loss of the very substantial contribution already made by the existing nuclear plants – and without further expansion from new nuclear build - will make reaching the already unprecedented level of ambition to achieve climate targets even harder, and more expensive. Consequently, this also means that reaching climate targets will also be more uncertain and slower than with nuclear, as the public and industries will more likely oppose higher costs.

Most of these problems, along with the cost of financing that these concerns drive up, can be mitigated directly or indirectly by including nuclear energy in the taxonomy. It would give policy-acceptability and reduce policy risk, it would likely lower financial costs, as more projects came online, it would help reduce project management risks as there would be potential for learning throughout the supply-chain and project execution, through multiple projects.

On the other hand, leaving nuclear out from the taxonomy will likely worsen these concerns and problems, making it even more unlikely to reach climate goals in time and on relatively reasonable, socio-politically acceptable budget. As already noted above, this risk would need to be in proportion to the risk used by the TEG to exclude nuclear from the taxonomy, which it is clearly not.

43 Nuclear Power in a Clean Energy System, IEA, 2019. https://www.iea.org/publications/nuclear/

Nuclear power has avoided about 55 Gt of CO_2 emissions over the past 50 years, nearly equal to 2 years of global energy-related CO_2 emissions. Of this total, 22.4 Gt of CO_2 were avoided by the EU nuclear fleet (IEA 2019).

4.3.5. IAEA Nuclear Energy for Sustainable Development

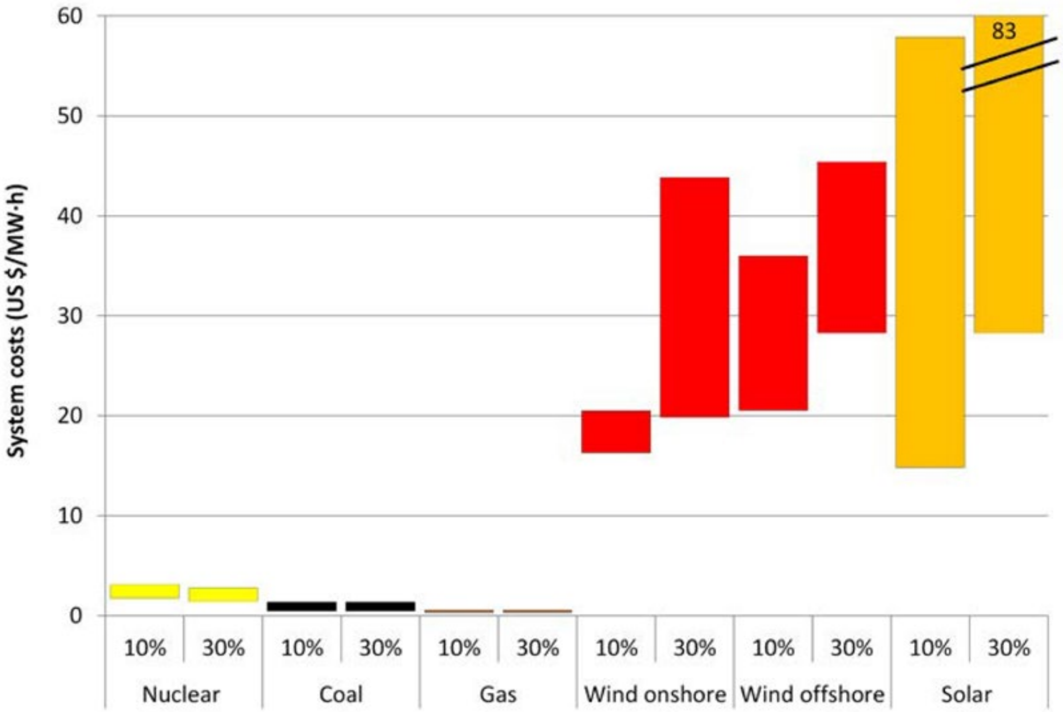
In 2016, IAEA released a report which was also endorsed by the UN General Assembly. The foreword states for example that:

"*Countries choosing nuclear power as part of their sustainable energy strategies note that it broadens the resource base, expands electricity supplies, is ahead of other energy technologies in internalizing externalities, increases the world's stock of technological and human capital, and avoids air pollution and greenhouse gas emissions. Nuclear power has a place among other solutions and needs to be accessible to countries interested in making it part of their sustainable energy strategies. Nuclear power is a choice that rests with sovereign countries together with the responsibility to use it safely and securely*." And that: "*Since there is no technology without risk, waste generation or interaction with the environment, the role of every energy technology needs to be assessed on an equal footing*."

From the introduction:

"*The publication also addresses some misconceptions and misleading statements regularly associated with the development and operation of nuclear power plants (NPPs). These perceptions often result from a combination of exaggerations and statements that are demonstrably false. Examples include the misconceptions that nuclear power costs more than other electricity generation options, it is impossible to finance new nuclear power stations, there is no solution for storing and disposing of radioactive waste, the costs of managing radioactive waste is prohibitive, the remaining uranium resources will run out in a few years and that nuclear power poses substantial radiation risks to the public, consumes too much water, takes up too much land or contributes to air pollution*."

Figure 2: Ranges of system costs (backup, balancing, grid connection, reinforcement and extension) of selected technologies at their 10% and 30% shares in the grid in selected countries (Finland, France, Germany, Republic of Korea, United Kingdom and the USA).[44]



The above figure from the IAEA report shows the ranges of system costs of selected technologies at 10 % and 30 % shares in the grid. While these costs should come down with technological innovation in demand flexibility and energy storage, these levels of low-carbon energy penetration are nowhere near enough to reach zero-carbon electricity – and even less so zero-carbon energy – supply by 2050. Further, as the share of variable production increases, these costs likely increase in an exponential manner. These costs can be great mitigated with nuclear both in baseload and flexible roles, as well as hydro (which is hard to expand in developed markets such as the EU).

The report concludes:
"*In the light of the wide range of indicators compiled in this publication and supporting these conclusions, nuclear power can be seen as a reliable source of power that can play a role in energy supply diversification and foster a more resilient sustainable power supply*."

4.3.6. OECD-NEA: Decarbonizing Electricity with Nuclear is more cost-effective

OECD-NEA published a study "The Costs of Decarbonization: System Costs with High Shares of Nuclear and Renewables[45]" in 2019. In it, they model the full cost of electricity provision, including all the system cost, with different shares of variable renewable energy (VRE, mainly wind and solar PV) in the system. Due to their properties, the larger their share, the higher the system costs will be relatively, and the lower the market-value of VRE production will be (making further investments less and less profitable and therefore unlikely).

44 Nuclear Power and Sustainable Development, figure 15 on page 37, 2016, IAEA.

45 https://www.oecd-nea.org/ndd/webinars/2019/system-costs/.

It is clear that while a system based completely on variable energy sources and limited amount of hydro plus other flexibility and storage technologies is possible, it is neither cost-effective, optimal nor likely to happen fast enough. When a source of baseload clean energy such as nuclear is used optimally to do its share, the total costs become lower, the decarbonization faster and the climate targets more likely to be reached in time.

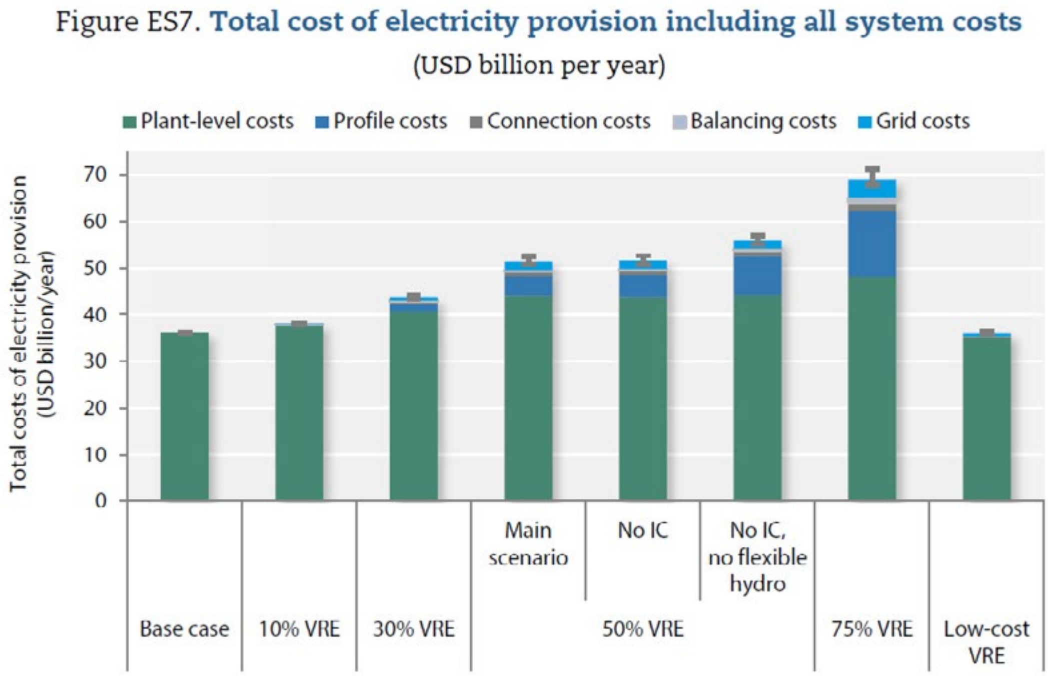


Figure 3: Figure from the OECD-NEA report on how different scenarios affect the total cost of electricity provision, while all scenarios also assume <50 gCO2 / kWh.

4.3.7. Top Climate Scientists Call for More Nuclear

In 2015 Paris COP21, four of the most famous and well-regarded climate scientists, **Dr. James Hansen**, **Dr. Tom Wigley**, **Dr. Ken Caldeira and Dr. Kerry Emanuel** made a case for inclusive and technology neutral climate and energy policy, carbon fee & dividend system, while stressing especially the case for nuclear energy to be a bigger part of the solution[46].

4.3.8. Global Conservationist community supports nuclear for nature conservation?

In 2014, 75 conservation scientists and biologists signed an open letter for the "Environmentalist community" of the world on nuclear energy. The open letter was based on a peer reviewed article "Key role for nuclear energy in global biodiversity conservation[47]." They urged for nuclear to be included in the energy mixes precisely from the "do no significant harm" perspective for biodiversity, as nuclear energy is, together with wind, among the least harmful ways

46 The Guardian wrote about the event, for example here: https://www.theguardian.com/environment/2015/dec/03/nuclear-power-paves-the-only-viable-path-forward-on-climate-change

47 Letter was published here: https://bravenewclimate.com/2014/12/15/an-open-letter-to-environmentalists-on-nuclear-energy/ and it is based on the conclusions of the peer-reviewed article "Key role for nuclear energy in global biodiversity conservation", by professors Brook, B. and Bradshaw, C., which was published in Conservation Biology (2014). https://doi.org/10.1111/cobi.12433

to produce low-carbon energy for society.

4.4. Nuclear Energy Activities

Nuclear energy is used to produce heat, which is usually used to make steam which is then used to run a turbine generator to make electricity. Nuclear energy is therefore well suited to also make heat/steam for different purposes, from district heating to industrial processes to hydrogen manufacturing with steam electrolysis or even thermolysis.

Nuclear energy should therefore be added to the taxonomy as three activities:

- Production of Electricity from Nuclear Energy
- Cogeneration of Heat/Cool and Power from Nuclear Energy
- Production of Heat/Cool from Nuclear Energy

Further, there are at least three major economic categories within the nuclear energy field that warrant inclusion, as all of them can be used to contribute to climate change mitigation in slightly different ways:

1) Long term operation (LTO) and capacity uprates of existing nuclear fleet, which currently provides almost half of Europe's low-carbon energy (830 TWh in 2018). Unnecessary shutdowns will greatly hamper the reaching of Europe's climate goals. Of the 126 reactors in the EU today, 89 are to be decommissioned by 2030 without further extensions, and by 2040, there would be only 15 reactors remaining (IEA 2019)[48].
2) Construction of Generation 3/3+ large power reactors (EPR, AP1000 and others) to further decarbonize electricity production in the European Union, and to replace the dispatchable and reliable production that will eventually be lost due to older plants shutting down and being decommissioned.
3) Research, development and deployment of small and/or advanced nuclear reactors (SMRs) that can be used to decarbonize local heat use, industrial process heat and manufacturing of hydrogen and/or synthetic fuels and chemicals. These technologies can greatly help decarbonize many other sectors besides electricity, including the chemical industry, forestry and biofuels/transportation sectors.

4.4.1. Long Term Operations (LTO) and Capacity Uprates

In many cases, carrying out the investment required to obtain authorisation from the regulatory authorities to extend the operating lifetime of a nuclear reactor is an economically and financially attractive option compared with building other low-carbon technologies. IEA 2019

Most nuclear power plants were initially licenced to operate for 40 years. This was largely an estimate based on lifetimes of coal plants, as nobody had extensive experience with nuclear long-term operations. Most of the European and global nuclear fleet is approaching, or has already passed, that 40-year lifespan. With experience, and by keeping the plants in good condition, we have learned that their safe operational lifetime can be significantly extended. Indeed, this can be the most cost-effective way to increase (not lose) low-carbon energy production, according to IEA (2019). A refurbished nuclear plant will have a levelized cost in the range of USD 40-55 per MWh[49], or roughly

48 Nuclear Power in a Clean Energy System, IEA, 2019. https://www.iea.org/publications/nuclear/

49 LCOE is based on an 8% weighted-average cost of capital (WACC), 85% annual capacity factor, two year refurbishment period and USD 170 per kW annual O&M costs. LCOE is the average total cost to build and operate a power plant over its lifetime divided by the total

35-50 € per MWh. The estimated average cost is roughly USD 650-700 million for 1 GW plant, according to a European Commission Communication (2016[50]).

In IEA's (IEA 2019) "Nuclear Fade Scenario", where no further investments or extensions are made, two thirds of nuclear capacity in the advanced economies will be lost, with Europe seeing largest decline in absolute terms.

Figure 19. Operational nuclear power capacity in advanced economies in the Nuclear Fade Case

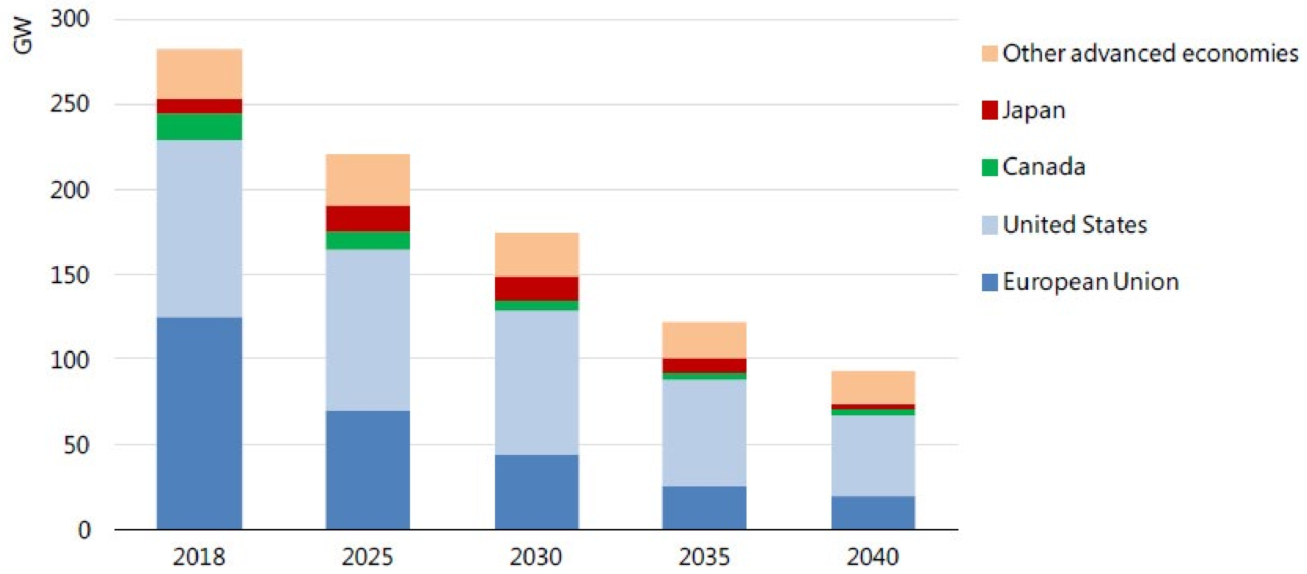


Figure 4: Operational nuclear power capacity in advanced economies in the Nuclear Fade Case. Graph from IEA 2019.

Of the 126 reactors in the EU today, 89 are to be decommissioned by 2030 without further extensions, and by 2040, there would be only 15 reactors remaining (IEA 2019)[51]. Compared to IEA New Policies Scenario, most of this lost generation would be replaced by natural gas and renewables and some coal. Even the added renewables would have little overall effect, as they would be replacing another low-carbon energy source instead of coal or other fossil fuel combustion.

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energy output of the plant over the same period. IEA 2019.

50 https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v10.pdf

51 Nuclear Power in a Clean Energy System, IEA, 2019. https://www.iea.org/publications/nuclear/

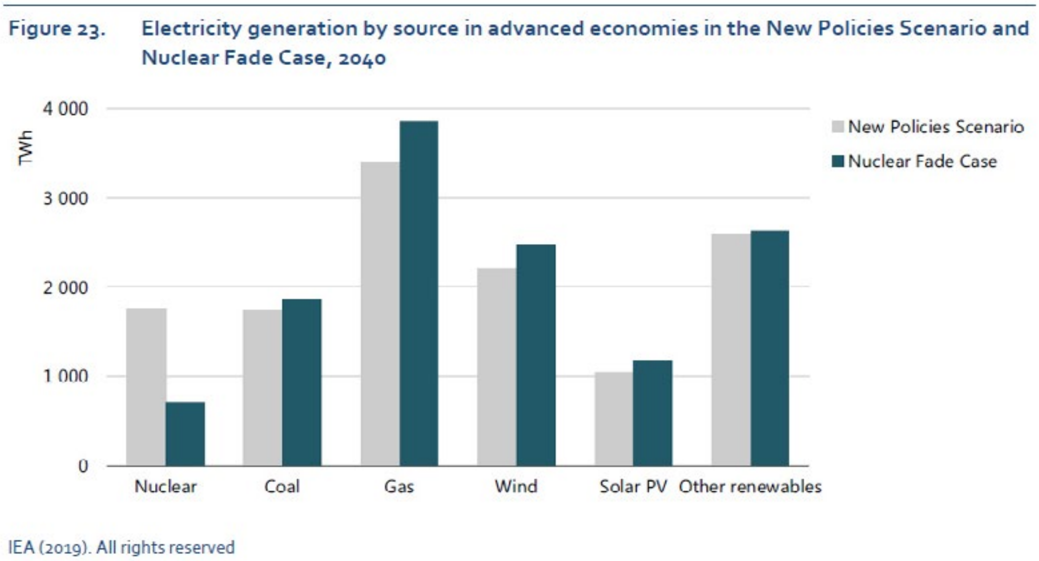

Figure 5: Electricity generation by source in advanced economies in the New Policies Scenario and Nuclear Fade Case, 2040. Graph from IEA 2019.

In order to more fully facilitate LTO and capacity uprates, proper policies and funding opportunities need to be in place. Including nuclear in the Taxonomy would – directly and indirectly – aid with both of these.

4.4.2. Constructing Large Gen 3+ Reactors

Many European grids – such as those of Poland, Germany and Czech Republic – still rely on significant amounts of fossil fuels-based baseload electricity. While some of these countries have chosen to politically prevent nuclear from being used or built, many of them have not. Much of this baseload production can be decarbonized effectively by constructing modern nuclear power plants.

The IPCC 1.5 degree report four main scenarios (P1, P2, P3 and P4) all called for significant increases in nuclear generation. Already by 2030, the global fleet should increase 1.6 to 2 times from current, and by 2050, by 2 to 6 six times. As many European nations already have an established nuclear energy sector, the necessary institutions and engineering know-how in place, they can (and should) move more quickly with new-build projects compared to newcomer countries – and then export that knowhow and institutions to newcomer countries and help them decar-bonize more effectively.

Ample real-world evidence[52] shows that restarting nuclear constructions after decades of inactivity, when all the supply chains, subcontractors, nuclear project management, skilled labour and regulatory routine have been atro-phied, is slow and expensive[53]. This should be avoided, and a serious effort made to facilitate continuous learning by doing.

52 EPR projects in Finland and France, AP1000 projects in the United States done after 20+ years of not building nuclear proved to be very problematic, slow and expensive.

53 A recent study found out that "First-of-a-kind" and "First-in-a-country", which also includes countries that have had a long hiatus of not building new nuclear, cases face much higher costs than countries with recent and ongoing experience. The ETI Nuclear Cost Drivers Project: Summary Report (2018). https://www.eti.co.uk/library/the-eti-nuclear-cost-drivers-project-summary-report

Further, even with lifetime extensions, the aging fleet of over one hundred nuclear plants needs to be replaced at some point during the next 2 – 3 decades. Having clean baseload energy production makes it much easier, faster and less expensive to also add variable energy production such as wind and solar, as the need to load-follow or curtail production is much smaller (OECD-NEA 2019). Still further, by 2050, the current European capacity of both wind and solar PV will need to be also replaced, some of it twice, to not lose their production – in addition to the needed additional capacity for wind and solar.

4.4.3. Deployment of Advanced and/or Small Reactors

Advanced and/or small nuclear reactors (ASMRs) of less than 300 MWe (~900 MWt) will become commercially available in the 2020s, with consequent opportunities for mass-production and significant decarbonization impact happening in the 2030s and beyond. Regulatory and policy work to enable the utilization of these technologies needs to start today (and has been starting in select countries), and the addition of nuclear into the taxonomy can help create a push for this work.

There are multiple good reasons to develop and deploy small and/or advanced nuclear reactors, as they can help us decarbonize not just electricity, but also heating, industrial processes and feedstocks and even transportation through more affordable clean hydrogen and synfuels. These reactors are also often designed to be very flexible, which can enable higher penetrations of VRE production at lower system cost and lower total emissions.

Share of electricity of our end-energy use has been growing steadily and is today just under 20 per cent. This electrification has historically progressed at roughly two percentage points per decade. IEA (WEO 2018[54]) New Policies scenario sees this share increase to 24 % by 2040, while their Future is Electric Scenario manages to push electrification to over 30 % by 2040.

Many of the ASMRs are being developed with cogeneration of power and heat in mind, enabling them to decarbonize industrial processes directly by replacing fossil fuels combustion for process energy. Cogeneration also enables effective production of clean, reliable district heating and cooling. Europe uses around 6,000 TWhs of heat today, with roughly half going to space heating, a third going to industrial processes and the rest used for hot water and other uses[55].

5. Nuclear Energy Lifecycle Activities

In this chapter, each of the three nuclear lifecycle activities is described in more detail and a short summary of the DNSH findings (which are assessed in more detail in the following chapter) is given.

To summarize the findings, none of the nuclear activities cause any significant harm to any of the sustainability criteria. Any potential for harm is mitigated through strict enforcement of tight regulations, legislation, international guidelines and best practices at all levels. The Nuclear energy sector is one of the most responsible industries out there, according to evidence provided in this document.

54 https://www.iea.org/weo2018/electricity/

55 Heat Roadmap Europe – A low-carbon heating and cooling strategy (2017).

5.1. Front End – Uranium production, enriching and fuel fabrication

Uranium production includes mining, milling and transportation activities. Uranium has roughly two million times the energy density of the best chemical fuels (oil, coal), although the current reactor-fleet only uses around a one percent of this energy[56]. Due to the extremely high energy content of uranium, the mining activities are tiny relative to the amount of energy produced (taxonomy sustainability objective 4 and 5).

Globally, uranium is produced in several ways. Roughly half is done with in-situ leeching, which involves minimal mining activity, as the uranium is leeched directly from the rock, underground. Roughly 46 % is produced through open pit or underground mining. The rest is produced as a side product of other mining activities[57]. Uranium production today is tightly regulated (objective 3, 4, 5 and 6).

Enriching of uranium increases the content of fissile U-235 in the fuel from 0.7 % to 3-5 %, to make it suitable for current reactor fleet. Practically all the commercial uranium enriching today is done with centrifuges, which are roughly 50 times more energy efficient than the previous technology, gaseous diffusion (objective 4). The activity is very tightly regulated, controlled and safeguarded at all levels, as is the fuel fabrication activity (objective 3, 4, 5 and 6).

In summary: Uranium production, enriching and nuclear fuel fabrication are tightly regulated and controlled activities in the EU, and in most other locations. They do not cause significant harm to any of the Taxonomy objective. See more detailed analysis in chapter 6 on DNSH.

5.2. Middle-end – Nuclear power plant construction and operation

Construction of a nuclear power plant is strictly regulated, and its environmental impacts are assessed with an EIA before construction permit is given (taxonomy sustainability objective 3 and 6). In some countries, such as Finland, Sweden and UK, the future operator also needs a (funded) plan for the long-term storage of the waste already before construction permit is given (objective 5). In France, there is a public establishment ANDRA that manages the waste independently from the radioactive waste producers (also other than nuclear energy industry). Nuclear plant operators usually collect and put aside funds from their electricity sales that will be used to decommission and manage the long-term waste storage (objective 5)

Nuclear power offers reliable and comparably weather-resistant energy production, which helps with climate change adaptation (objective 2). Compared to most other clean energy production, nuclear power plants use much less materials (concrete, steel, glass etc) per unit of energy produced[58], which helps to prevent waste (objective 4).

56 Current fleet of reactors use mainly the rarer fissile uranium isotope U-235 for energy production, as it is readily fissile. The more common (<99% or all uranium) fertile isotope U-238 can and is also being used as fuel in reactors indirectly by turning it into fissile plutonium, but to do this to a greater extent requires a different reactor type, often called a Fast Breeder Reactor, such as the BN600 and BN800 operated in Russia or the Super Phenix that operated in France for a number of years.

57 According to World Nuclear Association data. https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx. Read 31st July 2019.

58 Quadrennial Technology Review, US Department of Energy, 2015. https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter10.pdf

Nuclear power plants use much less land-area per energy/power produced compared to other low-carbon technologies; often two to three orders of magnitude less, depending on the case and technology[59]. As less land is used to produce energy, it is easier to protect healthy ecosystems (objective 6)[60].

During operation, releases from nuclear power plants include mainly low-quality heat and some radioactive isotopes such as tritium. Both are regulated and released in a way that they do not pose significant harm to people or the environment (objective 3, 5 and 6).

In summary: The construction and operation of nuclear power plants does not do significant harm to any of the sustainability criteria. See more detailed analysis in chapter 6 on DNSH.

5.3. Back end – Nuclear power plant decommissioning and waste management

The back end of nuclear energy includes nuclear power plant decommissioning and the management of waste and especially high-level radioactive waste (HLW). In most countries, the utility company that operates the nuclear power plant collect funds – as required by law – from electricity sales to manage both these tasks. In some other countries, the government has taken this responsibility (and perhaps the collected funds) for one reason or the other.

Decommissioning of a commercial nuclear power station can be done in multiple ways. When a nuclear power plant is shut down permanently, it is not causing significant harm to any of the criteria, as long as it is managed responsibly according to regulations and legislation. The ultimate cost of the decommissioning activity depends significantly on two things: First, how soon after shut-down does the decommissioning start. Letting the facility cool down properly and letting the shorter-lived radioactive isotopes present in some of the structures decay away makes the decommissioning much less expensive. Another aspect is the state into which the facility is to be returned; will it be returned to “brown-field” or “green-field” status.

The long-term management of nuclear waste, especially HLW, was the concern specifically identified by the TEG in their report regarding DNSH objective 5, Pollution prevention and control. In fact, it is clear that HLW is being managed responsibly, the needed legislation and regulations are in place and they are being enforced and followed strictly at all levels. Further, the basis for these regulations is Do No Significant Harm, with a wide margin of error included (taxonomy sustainability objective 3, 5 and 6). This task of waste management is made more manageable thanks to the extreme energy density of nuclear fuel, which means that there is very little of the waste per unit of energy produced (objective 4).

As evidenced, the current status, where HLW is being stored and cooled often on-site or in a central interim facility, has already been proven to cause no significant harm with decades of experience. The US nuclear safety regulator NRC has stated that current dry cask storage solution can be used for up to a century, or even longer, as long as proper monitoring is done, and their safety is ensured for example by changing the casks when needed[61]. There is no

59 V. Smil: “Power Density – A key to Understanding Energy Sources and Uses”, MIT Press, 2015

60 Brook, B. and Bradshaw, C., Key role for nuclear energy in global biodiversity conservation, Conservation Biology (2014). https://doi.org/10.1111/cobi.12433

61 Continued Storage of Spent Nuclear Fuel, NRC 2014. https://www.nrc.gov/docs/ML1417/ML14177A477.pdf

reported harm done by civilian nuclear waste up until today (objective 3, 5 and 6).

Further, at least 25,400 shipments of spent nuclear fuel have been made worldwide by 2016, according to a DOE study[62]. To quote: "*Review of the data sources shows that all of these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported.*" (objective 5 and 6).

As part of its responsible operation, the nuclear energy sector seeks a more passive long-term solution for the waste – both to increase the level of safety even further and to manage costs from their waste-management. Often this is also required by law as part of the operational mandate of a nuclear utility. The regulatory requirements for the safety of a final geological repository – which is the option closest to be implemented – are very strict (objective 3, 4, 5 and 6).

Geological Disposal is currently identified by a number of countries as the preferred option for long term disposal of Higher Activity Wastes and Spent Fuel. The likelihood that Geological Disposal Facility will not be developed for the long-term storage of Higher Activity Wastes is unlikely. Finland and Sweden both have operating geological repositories for Intermediate Level Waste which have been operating for over 20 years. In addition, in the USA, since 1999, a Deep Geological Disposal Facility has received long lived radioactive wastes which contain uranium and plutonium. As such there is considerable operating experience of operating geological repositories for Higher Activity Wastes, which shows that they are effectively managed and do not cause significant environmental harm.

The maximum dose of radiation allowed for people living atop a final repository is commonly less than one percent of the dose people on average get from natural background radiation and other activities (such as medical treatments and flying)[63]. Given that the natural background doses can vary by more than an order of magnitude depending on the place, diet and lifestyle of the person, the health impacts of the maximum additional dose allowed from a final geological repository is statistically irrelevant. Both the Finnish and Swedish repository-projects have been thoroughly studied and modelled and found to stay well-under this maximum dose limit even with catastrophic failures modelled in. See image below for more information of the average sources of radiation to humans[64]. The complete nuclear fuel cycle causes a dose of 0.0002 mSv per year, while the total average dose is around 3 mSv.

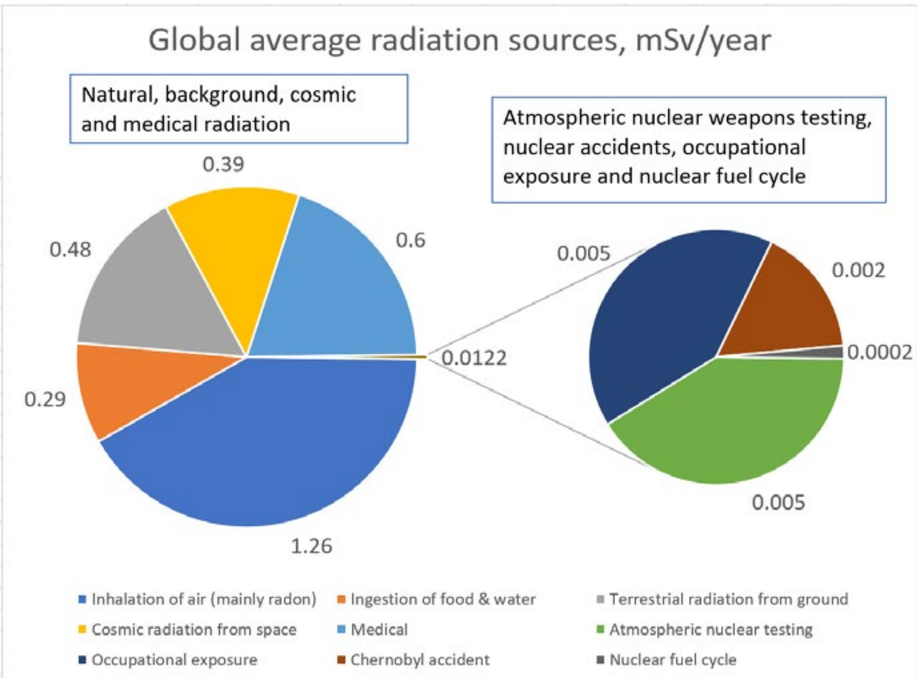

Figure 6: Global average radiation sources, mSv/year. Source: UNSCEAR 2008.

62 A Historical Review of the Safe Transport of Spent Nuclear Fuel, US Department of Energy, 2016.

63 Source Swedish

64 Data from **Sources and effects of ionizing radiation, UNSCEAR, 2008**

Different countries approach HLW management in different ways. In some countries, such as Finland[65] and Sweden, the nuclear operators have been mandated (and allowed) to build a solution. After decades of careful study and analysis, the first one is now under construction in Finland, with Sweden not far behind. Some other countries have a similar legislation in place, but they have so far failed to make the necessary political decisions to enable the siting and construction of necessary facilities. In France, a public organization ANDRA manages and keeps stock of radioactive waste, and they are currently preparing to leave an application for constructing a storage centre (Cigéo) with the ANS (Nuclear Safety Authority).

In some countries, the government has taken the responsibility (and funds) to find, design and build the final repository (such as Germany and the United States), with various degrees of political success. The obstacles are not technical, economical or public health related, but political, and therefore they can be mitigated through politics, as has been done in multiple countries such as Finland, Sweden and France.

In summary: Nuclear power plant decommissioning and radioactive/hazardous waste management are tightly regulated activities and do not cause significant harm to any of the criteria.
See more detailed analysis in chapter 6 on DNSH.

6. Do No Significant Harm

In this chapter, each nuclear activity is assessed against each of the DNSH criteria in more detail, and evidence/citations are provided for each claim.

DNSH is evaluated through TEG specification:

Objectives 3-6	Conditions for causing 'significant harm'
Sustainable use and protection of water and marine resources	The activity is detrimental to a significant extent to good status of Union waters, including freshwater, transitional waters and coastal waters, or to good environmental status of marine waters of the Union.
Transition to a circular economy, waste prevention and recycling	The activity leads to significant inefficiencies in the use of materials in one or more stages of the life-cycle of products, including in terms of durability, reparability, upgradability, reusability or recyclability of products; or where that activity leads to a significant increase in the generation, incineration or disposal of waste.
Pollution prevention and control	The activity has relative high emissions to air, water and land compared to a level of environmental performance that is based on BAT principles.
Protection of healthy eco-systems	The activity is detrimental to a significant extent to the good condition of ecosystems.

65 The original plan was to wait for some big nuclear nation to develop and build a solution and buy the know-how from them, but as that never happened, Finland went on ahead and became the world leader in this.

And by asking and answering: **What would generate significant harm during the life cycle of the activity? And can this risk be addressed by complying with EU legislation and best practices, international standards or guidelines?**

6.1. Climate Change Adaptation

Summary

None of the nuclear activities – Uranium production, enriching and fuel fabrication, power plant construction and operation and power plant decommissioning and waste management – causes any harm to climate change adaptation. **Nuclear energy as a whole contributes to climate change adaptation by providing a resilient and reliable source of low-carbon energy.**

6.2. Sustainable use and protection of water and marine resources

Objective 3	Conditions for causing 'significant harm'
Sustainable use and protection of water and marine resources	The activity is detrimental to a significant extent to good status of Union waters, including freshwater, transitional waters and coastal waters, or to good environmental status of marine waters of the Union.

Summary

All activities of the nuclear energy cycle are tightly regulated. All relevant activities that could cause significant harm to water and marine resources are regulated and should require a sufficient Environmental Impact Assessment to be made prior to the activity.

What would generate significant harm during the life cycle of the activity? And can this risk be addressed by complying with EU legislation and best practices, international standards or guidelines?

6.2.1. Uranium production, enriching and nuclear fuel fabrication

Potential harm: In uranium production, enriching and nuclear fuel fabrication, the potential for significant harm is due to hazardous waste streams entering the water or marine systems.

Mitigation of potential harm: These activities are tightly regulated and controlled to prevent waste streams from entering local water and marine systems. Environmental Impact Assessments are required prior to starting the activity.

6.2.2. Construction and operation of nuclear power plants

Potential harm: Construction and operation of nuclear power plants in an area that has vulnerable and valuable water and marine resources in an unregulated manner could cause harm to these resources. Operating nuclear power plant releases low-quality heat into the environment, which can affect local water resources.

Mitigation of potential harm: Harm from construction is mitigated through Environmental Impact Assessment prior to construction of nuclear power plants. The waste heat that nuclear power plants release as part of their normal operations is tightly regulated to ensure it does not cause significant harm to the water or marine resources. These regulations are one of the main reasons why, during the hot summer weeks of 2019, some reactors were shut down and some operated at lower capacity in Europe.

6.2.3. Decommissioning of nuclear power plants and managing waste

Potential harm: Hazardous nuclear waste could contaminate water resources if it is not managed during decommissioning.

Mitigation of potential harm: Nuclear waste is well managed and controlled, and the management of waste is tightly regulated to prevent any contamination of water and marine systems.

6.3. Transition to a circular economy, waste prevention and recycling

Objective 4	Conditions for causing 'significant harm'
Transition to a circular economy, waste prevention and recycling	The activity leads to significant inefficiencies in the use of materials in one or more stages of the life-cycle of products, including in terms of durability, reparability, upgradability, reusability or recyclability of products; or where that activity leads to a significant increase in the generation, incineration or disposal of waste.

Summary

Nuclear energy lifecycle uses comparable small amount of materials per unit of energy produced. The extremely high energy-density of uranium fuel means that also the mining requirements are comparably small.

Modern nuclear power plants are designed and constructed in a way that practically all the parts and components can be replaced if need be, within economic limits. This guarantees a very long technical lifetime for the valuable power plants. According to recent IEA study[66], refurbishing and uprating current fleet of nuclear power plants is one of the most cost-effective ways to add (not lose) low-carbon energy production. The plants also use comparably small amounts of materials, as can be seen on the image below[67]. NOTE that those materials do not include the fossil/biofuels used to produce the electricity. For coal, the amount is roughly 120,000 tons per TWh of electricity, more than 100 times the other materials combined. For biomass, it is even more.

66 Nuclear Power in a Clean Energy System, IEA, 2019

67 Quadrennial Technology Review, US Department of Energy, 2015. https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter10.pdf

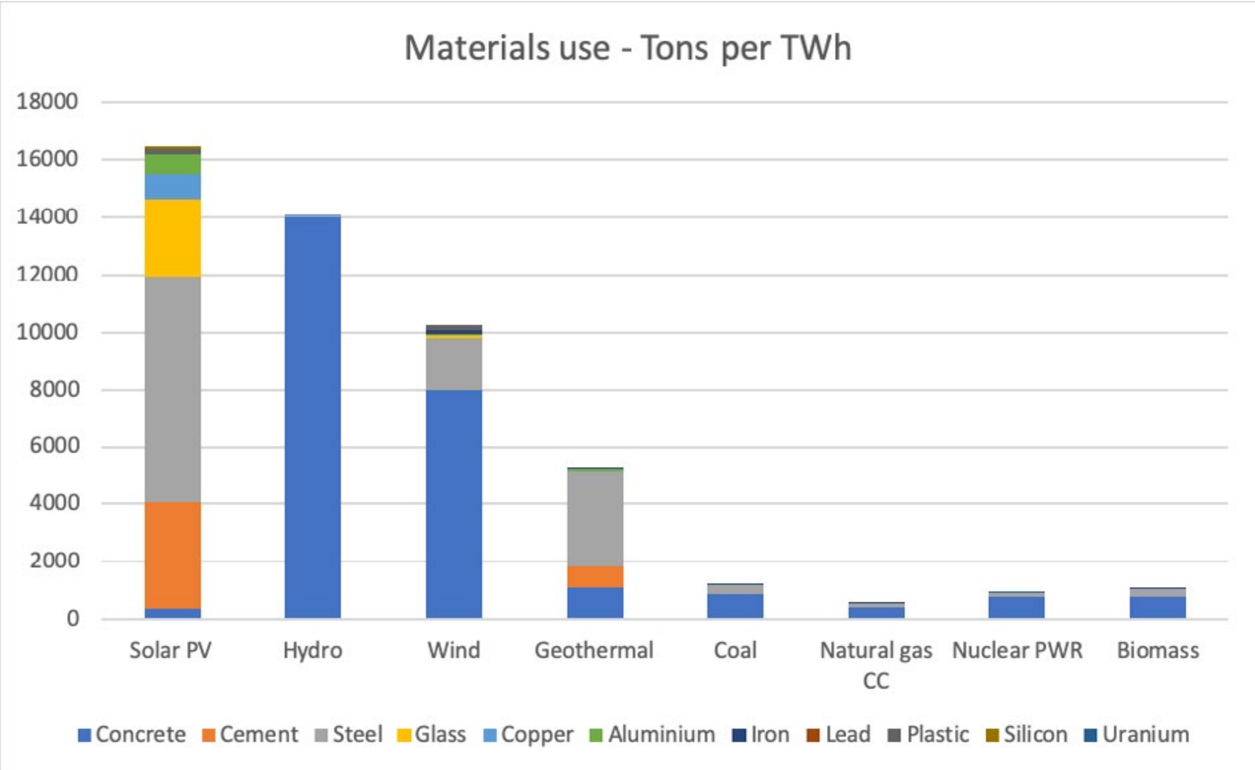

Figure 7: Materials use of energy production facilities - tons per TWh. Source: US DoE 2015. Uranium amount, 25 tons, added by authors.

As the amount of materials and fuel used is small with nuclear, so is the amount of hazardous high-level waste produced. Even this waste, or "partially spent fuel" can be reprocessed and recycled to be used as new fuel in different types of reactors[68].

What would generate significant harm during the life cycle of the activity? And can this risk be addressed by complying with EU legislation and best practices, international standards or guidelines?

None of the nuclear lifecycle activities cause significant harm to Transition to a circular economy, waste prevention and recycling. Due to the properties of nuclear lifecycle mentioned above, nuclear energy strongly contributes to this objective. It has very little waste, and most of that waste can be recycled and/or reused.

6.4. Pollution prevention and control

Objective 5	Conditions for causing 'significant harm'
Pollution prevention and control	The activity has relative high emissions to air, water and land compared to a level of environmental performance that is based on BAT principles.

Summary

68 Plutonium can be separated and mixed into MOX fuel to be used in current light water reactors. Depleted uranium (mostly U-238) can be used to make new fuel (plutonium) in breeder-type reactors.

Uranium production, enriching and nuclear fuel fabrication are tightly regulated and controlled activities in the EU and elsewhere, to prevent pollution from getting released.

Operating nuclear power plants limit and manage their pollution releases according to strict regulations. They do not cause significant harm. According to studies and statistics cited elsewhere in this assessment, nuclear energy is the least harmful way of producing reliable energy, pollution and waste products included. In fact, according to the best available research on this topic in a major study by the European Commission, nuclear energy results in 442 times fewer deaths relative to brown coal per unit of energy. These figures also account for estimated cancer-related deaths as a result of radioactive exposure from nuclear energy production across the whole life cycle, including accidents.

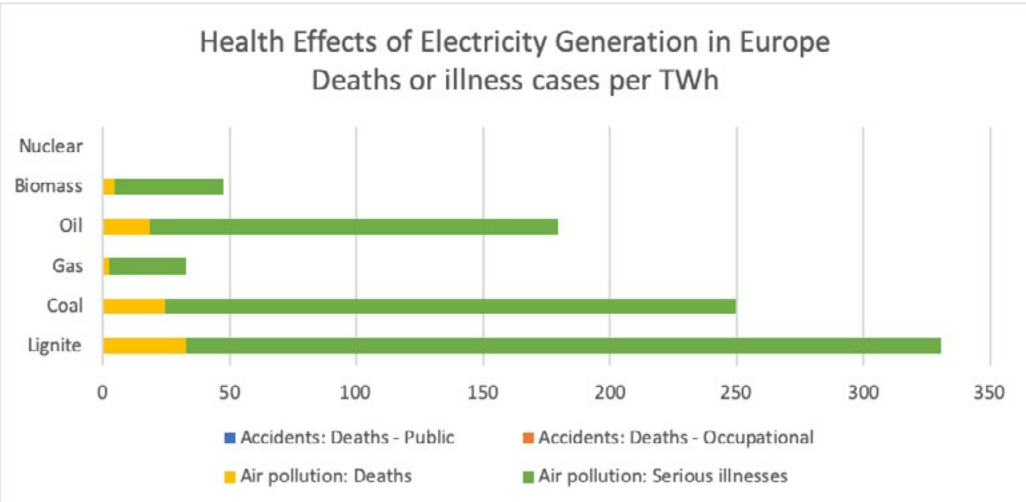

Figure 8: Deaths or illnesses per terawatt hours of electricity generation in Europe. Source: Lancet 2007[69]

In addition to the ExternE-study and the article form The Lancet (2007, from which the data on the graph 8 is taken from), a more recent paper "External Costs of Energy: How Much is Clean Energy Worth?" was published in Journal of Solar Energy Engineering in 2016. The paper uses the ExternE-methodology with some notable updates (for example, the statistical value of a fatality has been almost doubled to 3M$, to match the value now commonly used in the EU and recommended by the OECD). The paper puts a monetary value for the externalized cost/harm as cents per kWh. Below is a chart from the study.

It should be noted that much of the external costs for nuclear operations come from the fact that it is assumed that average EU mix of electricity is used for enriching the uranium, and that causes particulate pollution (Solar PV manufacturing also assumes this same mix). This means that as the EU grid moves to electricity generation not based on combustion of fuels, these external costs also shrink. Also, these kinds of indirect effects are not considered in DNSH for the taxonomy, and additional clean energy generation will help mitigate these issues. Regarding nuclear, the study concludes that:

> *Nuclear also has low damage costs. Even if the cost of catastrophic accidents is included, with a pessimistic assessment based on the historical record, its damage cost for baseload production is lower than for the least expensive renewable alternative (wind with natural gas combined cycle as backup) in the usual situation of insufficient storage capacity.*

69 Markandaya, A., Wilkinson, P., 2007, Electricity generation and health, The Lancet. DOI:10.1016/S0140-6736(07)61253-7

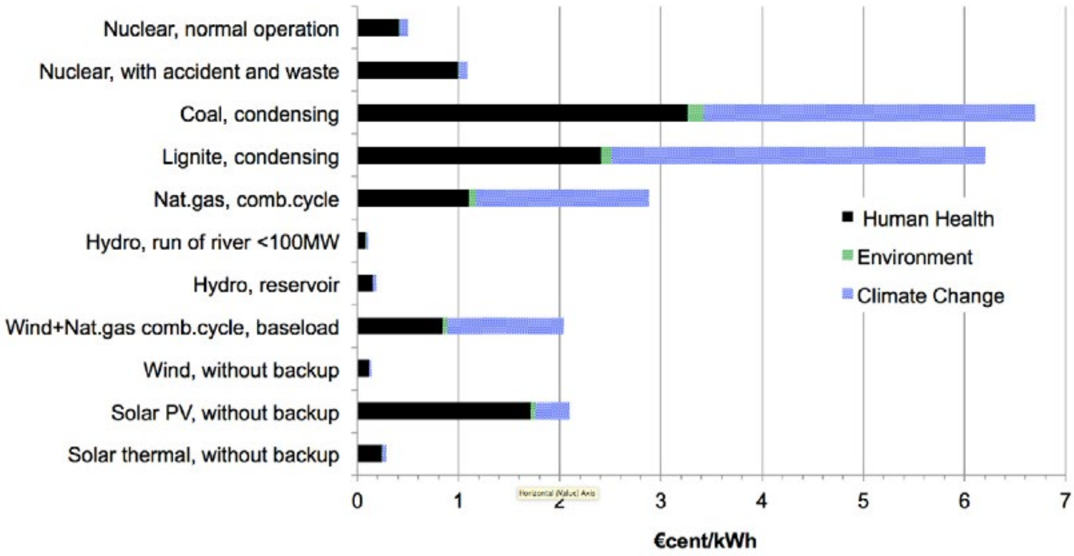

Figure 9: External costs of energy[70].

While the cost increases slightly with "accident and waste" included, even this can be considered somewhat debatable. The paper uses *linear exposure-response functions without threshold* in the modelling, while the global radiation expert organizations (such as UNSCEAR[71] and ICRP[72]) have specifically stated that Linear no threshold (LNT) should not be used for epidemiological purposes, as it overestimates the effects of low dose and low dose rate (LDDR, such doses that are within natural background variation of radiation doses humans get). The study also illustrates the nuclear fuel cycle radiation effects and puts them in context clearly (emphasis added):

> *To illustrate how small the radiological doses from normal operation are, Rabl, Spadaro and Holland[73] look at the dose per person that would result if the nuclear technology of France of the nineteen nineties were used to provide electricity* ***at a rate equal to the entire electricity production of the world in 2010 (20,000 TWh/***

70 Rabl, A., External Costs of Energy: How Much Is Clean Energy Worth?, 2016, Solar Energy Engineering. doi: 10.1115/1.4033596

71 "In general, increases in the incidence of health effects in populations cannot be attributed reliably to chronic exposure to radiation at levels that are typical of the global average background levels of radiation....the Scientific Committee does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels." UNSCEAR. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation Fifty-ninth Session (21-25 May 2012). New York, NY: UNSCEAR; 2012: Report No. A/67/46.

72 "Collective effective dose is an instrument for optimisation, for comparing radiological technologies and protection procedures. Collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections. This is because the assumptions implicit in the calculation of collective effective dose (e.g., when applying the LNT model) conceal large biological and statistical uncertainties. Specifically, the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided. Such computations based on collective effective dose were never intended, are biologically and statistically very uncertain, presuppose a number of caveats that tend not to be repeated when estimates are quoted out of context, and are an incorrect use of this protection quantity." ICRP. ICRP Publication 103: the 2007 recommendations of the International Commission on Radiological Protection. Ann ICRP. 2007;37(2-4):1–332.

73 Rabl A, J. V. Spadaro, M. Holland. 2014. How Much is Clean Air Worth: Calculating the Benefits of Pollution Control. Cambridge University Press. ISBN 978-1-10-704313-8.

***yr) for the next 100 years. Such a scenario would increase the dose rate by only about 0.15% beyond the background**, which is generally around 2.5 mSv/yr, almost entirely due to natural sources (radon, and cosmic radiation) and medical xrays. **New nuclear plants have significantly lower emissions than what we assumed for this scenario**, and in any case uranium based fission reactors are only a stop gap until cleaner technologies come on line.*

The “back end” of the nuclear lifecycle – decommissioning of facilities and especially managing high level and long-lived radioactive waste products – is often one that causes the most concern for people. The activities are well managed under strict regulations, legislation and international guidelines. The nuclear power industry has a very good track record of operating within those regulations. The best evidence and real-world statistics tell us that **nuclear waste from and decommissioning of civilian nuclear power does not cause significant harm to pollution prevention and control**.

Nuclear waste and plant decommissioning are things that the nuclear industry and academia have spent decades studying and preparing for. As is often mandated in legislation, the civilian nuclear industry has also collected funding for decommissioning of facilities and for managing their waste products long term – a feat that that is truly rare among energy producing industries in general.

Mainstream expert studies – including those commissioned by the European commission (ExternE -study[74]) and those done by United Nations expert organizations (United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR[75]) – agree that the whole nuclear lifecycle, including waste management, causes only a tiny share of our radiation dose and comparably little harm or external costs to humans or the environment.The regulations on final repositories – which all planned facilities must meet to be constructed and operated – are extremely strict when it comes to radiation doses caused to the public over short and long timelines. As an example from Sweden: Even an unrealistic catastrophic scenario in a deep geological facility – multiplied by a thousand times – would be unlikely to cause significant harm, as the added radioactive doses would still be well within normal variation people get from background radiation due to where they live[76].

Final repositories are being constructed, with Onkalo in Olkiluoto Finland likely being the first one in Europe to start operations in the 2020s, built by Posiva. It has been studied extensively and can be constructed to be safe, according to Finland’s independent nuclear and radiation safety regulator STUK.

Posiva has been doing decades worth of research on Onkalo, including different leakage scenarios and the worst effects they could have for humans in the future. Amongst the 40 scenarios, the worst case for people

74 http://www.externe.info/externe_d7/

75 For example: Sources, effects and risks of ionizing radiation UNSCEAR 2016 Report and Sources and effects of ionizing radiation UNSCEAR 2008 Report.

76 Technical Report TR-19-15, Supplementary information on canister integrity issues, SKB, 2019.

10,000 years in the future includes the following assumptions[77]:

1. Waste storage canister would corrode through in 1,000 years, 100 times faster than assumed), AND
2. The bentonite-shielding around the canister would disappear suddenly, AND
3. Groundwater would move upwards, AND
4. A city would be built on top of the repository, AND
5. A person would live her whole life on the most contaminated square meter of land, AND
6. She would eat only food grown on that most contaminated square meter of land, AND
7. She would only drink the most contaminated water.

The radioactive contamination would top at roughly the year 12,000 AD. The person fulfilling all the criteria above would receive an annual extra dose of 0.00018 mSv. This is almost two orders of magnitude below the regulatory maximum limit (0.01 mSv in Finland), which in turn is a thousand times less than what nuclear workers are (safely) allowed as occupational dose.

By no objective measure can it be claimed that nuclear power plant decommissioning or nuclear waste management, done under national and international regulations and recommendations, would "have relative high emissions to air, water and land compared to a level of environmental performance that is based on BAT principles" as is stated in the TEG report as a condition for causing 'significant harm'.

What would generate significant harm during the life cycle of the activity? And can this risk be addressed by complying with EU legislation and best practices, international standards or guidelines?

6.4.1. Uranium production, enriching and nuclear fuel fabrication

Potential harm: Uranium production, enriching and nuclear fuel fabrication could release hazardous pollution to the environment.

Mitigation of potential harm: Uranium production, enriching and nuclear fuel fabrication are tightly regulated and controlled activities in the EU and elsewhere. This prevents pollution from getting released.

6.4.2. Construction and operation of nuclear power plants

Potential harm: Harmful amounts of radiation released from the operating nuclear power plant.

Mitigation of potential harm: Nuclear power plants operate under strict regulation on how much radioactive materials they can release to the environment. Plants are also mandated to measure and report these releases. The maximum limit of radiation releases – 0.1 mSv for a person spending all their time at the perimeter fence of a nuclear

77 http://www.posiva.fi/files/3195/Posiva_2012-10.pdf

facility – do not cause significant harmful effects either to the population or the environment.

6.4.3. Decommissioning of nuclear power plants and managing waste

TEG report specifically mentions nuclear waste as an issue of complexity and for which it requires more information on, so it will be discussed more extensively below.

Potential harm: Failure to decommission and manage facilities that have been shut down can release harmful substances to the environment.

Failure to manage high-level radioactive waste (HLW) products of the nuclear lifecycle, especially used nuclear fuel, could harm surrounding society and ecosystems if radioactivity and/or radioactive materials get spread around in amounts that are harmful.

Mitigation of potential harm: European nuclear energy industry follows very strict regulations, guidelines and legislation (Euratom Treaty) that are designed to address these risks, and it has done so very successfully for decades.

Nuclear operators collect funds – often as mandated by legislation – during the lifetime of their facilities that are used to both decommission facilities at their end-of-life and to manage their waste products. The operators are also responsible to take care of the decommissioning of shut down facilities.

Safe management of HLW is extremely tightly regulated and controlled on many levels, from the plant/corporate level to national regulations and legislation, to EU directives and international guidelines and controls.

We have decades of experience on the performance of interim storage of HLW and the civilian nuclear fuel cycle up to it. No significant harm has been caused by it.

6.4.3.1. Interim HLW storage and back-end of nuclear fuel-cycle today

Ionizing radiation is caused by radioactive decay of certain unstable isotopes of certain atoms. Each unstable isotope decays at a certain rate (which is measured as a half-life, which is time it takes for half of the isotope atoms to decay), and when it does, various types of radiation are released. With each half-life, only half of any given isotope remains, so with passage of time, radiation decreases, faster at first, and then slower. Often the most harmful isotopes are those with short half-lives and which emit strong gamma radiation[78], but they also disappear fastest.

78 Gamma radiation travels for longer distances and can penetrate clothes and skin, so it can enter the body and cause harm. Beta and alpha radiation travel shorter distances and can be stopped by clothing and even skin, which makes them much less harmful externally.

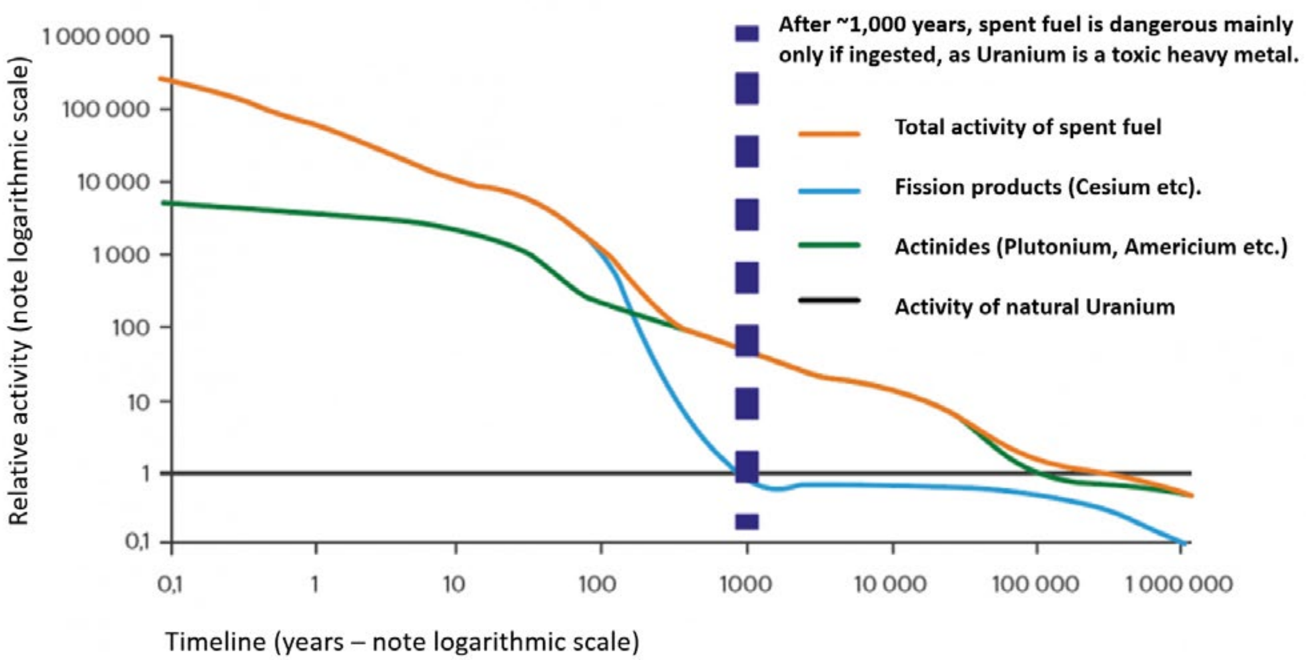

Figure 10: The development of spent nuclear fuel radioactive dose over time.

While HLW is often considered to be dangerous over very long time periods, this is somewhat of an empty statement without context. To assess whether it causes significant harm, we need to ask "How dangerous is it and how is it dangerous, and for how long? Compared to what? Can it be managed?"

The graph above shows how the radioactive dose[79] of spent nuclear fuel develops over time (note the logarithmic scales). From that, several observations can be made:

1. Fresh spent fuel is very hot and radioactive due to radioactive decay of the different fission products in the fuel. It is therefore cooled down in a pool of water (which also stops radioactivity effectively) for several years.
2. In a decade, the relative activity has dropped by roughly two orders of magnitude.
3. Most fission products – the main source of hazardous radiation in spent fuel – have half-lives of several decades. This means that they all but disappear in a couple centuries.
4. After a thousand years, the dose from spent fuel is roughly 100 times higher than dose from natural uranium. It is still hazardous, but mainly only when ingested, and even then, mainly because uranium is a somewhat toxic heavy metal, not so much because of the radioactivity. This is due to the fact that the isotopes remaining at this point are mainly "alpha emitters", which is a type of radioactivity that is stopped by couple centimeters of air, a light cloth or even skin, so it needs to get inside the body (and stay there) to cause harm.

Given the nature of radioactivity – it decreases with time – it is useful to get perspective on the current health effects of high-level waste and how it is managed. It is useful also to keep in mind that as the waste ages, the radioactivity (and hazardousness) of it decreases. The by far most hazardous part of the lifecycle of nuclear waste is already being managed all around the world with half a century of experience, and there are regulations and safety measures already in place.

The procedures leading from the safe temporary storage of spent nuclear fuel on site and the transportation to

79 Dose measures the estimated health impact of radiation.

centralized interim storage facilities, such as Clab in Sweden, have been designed to prevent pollution and to ensure strict accounting and control throughout the transport chain. The same now goes for solutions leading up to final storage, from encapsulation to transport and disposal into final repositories**.** The nuclear material is strictly contained and accounted for in all stages of the process.

The maximum allowed dose a person should get from any operational nuclear facilities, such as nuclear power plants or interim storage facilities that are often near them, is often 1 mSv / year. The dose limit at the perimeter fence of such facilities is set at 0.1 mSv/year maximum[80]. For nuclear workers, occupational limits apply. It is clear that the regulatory limits, if and when complied to, prevent significant harm from pollution from the interim waste facilities.

As the pie chart on page 39 showed us, the “nuclear industry related activities”, without nuclear weapons testing as it’s not a part of the civilian nuclear industry today, represent less than half a percent (0.0072 mSv/year) of our total average dose (~3 mSv/year/person).

The current nuclear fuel cycle, which also handles the spent fuel at its most hazardous and radioactive stage, causes less than 0.01 % of the total dose humans get on average.

Of course, there is variation at local level. Near nuclear fuel cycle related sites, the dose can be up to 100 times larger (0.02 mSv/year, UNSCEAR 2008). But it is still insignificant from a public health perspective and causes no significant harm, and is well below regulatory limits. In Finland, a worker in a nuclear facility is allowed an annual dose of around 20 mSv per year for five consecutive years or a maximum dose of 50 mSv in a single year (these limits vary slightly between countries). The doses of nuclear workers are actively monitored, and excess doses are prevented.

After cooling for several decades, spent fuel can be moved to a long-term storage, or a “final repository”. While there is currently no operating final repository facility for civilian high-level waste, and therefore no empirical evidence on its performance, we do have a wealth of information, studies and knowledge to get a broad estimate of the potential harmfulness of such a facility to the environment or humanity in general. As discussed below, one final repository is currently under construction in Finland.

The United States nuclear regulator NRC, often considered as the gold standard when it comes to rigorous nuclear and radiation regulation, has also stated that the current dry-cask storage facilities, as long as they are monitored and licensed according to regulations, can be safely used to store HLW for a century, or even longer[81].

6.4.3.2. Long term HLW repositories

Similar strict regulations and limits apply to long term storage of HLW as do for interim storage and management. The regulations need to be met with extensive studies and evaluations to even get a construction license for the final repository, and the regulations have more than enough safety-margin to ensure that no harm is done even if something was not taken into account in the studies and scenarios.

The nuclear industry also has decades of experience in geological repositories for low and medium level radioactive waste.

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80 The example is from Sweden, but other countries have similar limits. The doses of surrounding population can’t practically be measured, so the limit is set at the perimeter fence, which can be measured. In reality, neighbouring population gets a much smaller dose as nobody spends their entire time near the perimeter fence.

81 Continued Storage of Spent Nuclear Fuel, NRC 2014. https://www.nrc.gov/docs/ML1417/ML14177A477.pdf

6.4.3.2.1. Studies of final repositories

The validation of the long-term safety of final repositories for HLW is important. Their safety case is unique in the way it considers very long-time climate change and its impact on the safety of a final repository, in the case of Sweden over a period of a million years meaning that the technology implemented must withstand multiple periods of glaciation. No other infrastructure project assumes such standards of long-term risk assessments. The main scenario for the final repository included studies of more than 100 different thermal, hydrological, mechanical and chemical processes concerning the encapsulation, bentonite buffer, bedrock and the environment[82]. Obviously, these vary depending on where the repository is located. Different member states also work on different repository concepts but the principles for proving the safety case are similar.

The scope of site investigations when it comes to the protection of healthy ecosystems and pollution prevention is far-reaching and has been publicly documented and successively presented over the years to the general public in the concerned communities. Worst-case scenarios, which should always be included with such conservative decision-making as is called for in this case, include for example major earthquakes over a timescale of up to a million years following periods of glaciation.

The methodology behind the safety cases for the repositories are developed through extensive international co-operation. In the case of the safety case SKB has presented, this includes the OECD Nuclear Energy Agency, NEA, and international scientific expertise. Research projects at universities and final repository companies' (such as SKB and Posiva in Sweden and Finland, respectively) own laboratories have contributed to the establishment of leading-edge technical know-how of how to construct a safe and pollution-free final repository for spent nuclear fuel. This includes, for instance, the Greenland Analogue Project involving implementor organizations in Finland, Sweden and Canada together with some 20 universities with field studies from 2008 to 2013. The initiative confirmed the expected conditions in a final repository during a glaciation period.

6.4.3.2.2. Regulations

Nuclear waste repositories are regulated by strict criteria from the national regulatory bodies. These vary somewhat between different countries, but all are designed so that the repository will not pose any significant risk to people or the environment today or in the future. As an example, the Swedish regulator Strålsäkerhetsmyndighen allows the maximum radiation dose increase for a person that lives on top of a final repository to be 0.014 mSv (14 μSv) per year. To put that in context, this is:

- The equivalent of what a person receives when flying in an aeroplane for about three hours.
- A bit over one percent the average person globally gets from naturally occurring radon (1,4 mSv / year).
- Less than half a percent of the average radiation dose we get from all sources.
- Less than the dose from one chest X-ray (0.02 mSv).

The Finnish regulator STUK states that "**According to the general principles of nuclear waste management, the final disposal may not cause radiation damage that is hazardous to human health or otherwise damaging to the envi-**

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82 According to 2017 SKB presentation "Säkerhet efter forslutning" before the Land and Environmental court in the process on the spent fuel repository. http://www.skb.se/wp-content/uploads/2017/09/1579365-21-Sakerhet-efter-forslutning.pdf (In Swedish).

ronment or to property[83]." STUK will only approve final repository projects that can prove that these principles are adhered to and no significant harm is done. The limit of annual maximum radiation dose from a normally operating repository in Finland is 0.01 mSv a year[84].

Any proposed repository site is studied extensively through different scenarios beforehand. If the extremely strict limit is exceeded, the repository will not receive a construction licence, unless further actions are taken to improve the performance. In practice, even the practically impossible scenarios fall well below the regulator limits. As an example, to test the robustness of the safety case, Swedish SKB has modelled a scenario where all canisters are postulated to be defect (4 mm holes) when deposited. In reality, this scenario could be excluded since defects on all canisters would never pass quality control. Even in this scenario, the regulatory dose limit was not breached.

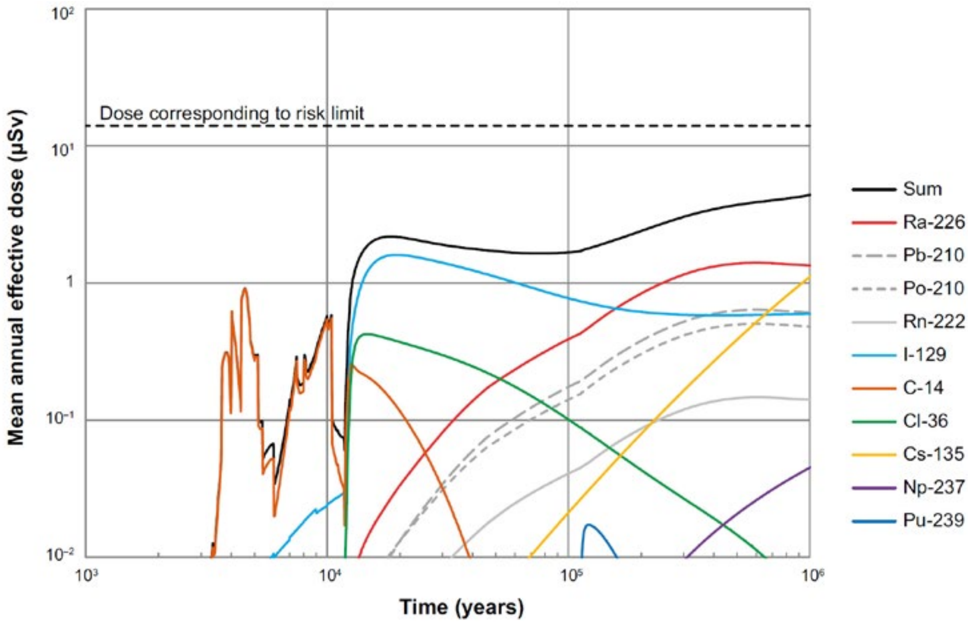

Figure 12: Consequences of "what-if" case. All waste canisters have a 4 mm hole through, and the buffer is gradually lost in the deposition holes with the highest groundwater flow rates. The maximum dose stays at around half of that allowed by regulations[85].

In addition to being carefully studied and needing approval from the regulator before construction licence, the construction of the repository is supervised carefully. Once finished, the performance of the repository can be monitored to ensure it meets expectations. If, for some reason, it does not, the waste can be retrieved as needed and either the problems fixed, or another solution used.

6.4.3.2.3. Lack of empirical Evidence?

The TEG report (June 2019) cited a report by Blue Ribbon Commission as evidence of no final repository being in operation. The authors of this assessment asked for a comment from a representative of the Blue Ribbon Commission, and got the following statement:

83 https://www.stuk.fi/en/web/en/topics/nuclear-waste

84 YEA 161/1988 22 d §. (19.12.2017/1001)

85 Technical Report TR-19-15, Supplementary information on canister integrity issues, SKB, 2019, page 120.

The European Union *Technical Expert Group on Sustainable Finance* ("TEG") has in its "Taxonomy Technical Report" from June 2019 not recommended the inclusion of nuclear energy in its list of sustainable technologies. The specific example provided as a basis for this position in the report is uncertainty regarding the long-term management of high-level waste and whether the present situation regarding waste management is in harmony with the principles of "do no significant harm" (DNSH):

> *"Yet nowhere in the world has a viable, safe and long-term underground repository been established*[270,271]*. It was therefore infeasible for the TEG to undertake a robust DNSH assessment as no permanent, operational disposal site for HLW exists yet from which long-term empirical, in-situ data and evidence to inform such an evaluation for nuclear energy.*
>
> *"Given these limitations, it was not possible for TEG, nor its members, to conclude that the nuclear energy value chain does not cause significant harm to other environmental objectives on the time scales in question. The TEG has not therefore recommended the inclusion of nuclear energy in the Taxonomy at this stage.*
>
> *"Further, the TEG recommends that more extensive technical work is undertaken on the DNSH aspects of nuclear energy in future and by a group with in-depth technical expertise on nuclear life cycle technologies and the existing and potential environmental impacts across all objectives."*

Of the two external citations provided in the assessment, reference 270 is a non-peer-reviewed report co-authored by long-time anti-nuclear activists and commissioned by an outspoken anti-nuclear political group (the Greens/EFA group). In contrast, reference 271 refers to the politically neutral expert-led United States *Blue Ribbon Commission on America's Nuclear Future*, which provides one of the most comprehensive assessments on options for management of high-level nuclear waste to date.

Professor Per Peterson of the University of California Berkeley, one of the members of the Blue Ribbon Commission (BRC) states that the international historic experience and future plans for management of nuclear waste shows with exceptional clarity that nuclear energy indeed does successfully adhere to the principles of "do no significant harm":

> "The Blue Ribbon Commission, appointed by President Barack Obama and composed of fifteen members, conducted a very extensive two-year study of nuclear waste disposal. During the research, the Commission visited Finland, France, Japan, Russia, Sweden, and the UK to assess current and future plans for high level nuclear waste disposal. In the more than 60 years of civilian nuclear power operation in over 30 countries, high level nuclear waste has without exception been stored safely and has not caused harm.
>
> "Both Finland and Sweden have successfully sited final geologic repositories for nuclear waste. Finland's final waste repository has been licensed by the independent regulatory agency STUK and is currently under construction. The Swedish repository solution has been approved by the independent Radiation Safety Authority (Strålsäkerhetsmyndigheten) and is awaiting final approval by one local court. The method to be employed in the near future in the Nordic countries is the result of over 40 years of very extensive research. The fact that these facilities are not currently in operation is almost entirely academic. Prototype facilities have been in operation for many years in both Sweden and Finland, and after 40 years of development and in-depth independent expert safety assessments by the relevant government safety authorities of two European Union

member states, there does not exist any uncertainty with regards to their safe operation, which is why they have been licensed to enter operation in the next few years. Further improvement and expanded availability of deep geologic disposal can also be expected. A particularly exciting emerging technology is horizontal boreholes.

"To conclude: Nothing in the Blue Ribbon Commission report, nor in the international historic experience and very near-term future plans for storage of civilian high level nuclear waste storage within the European Union, offers any justification for exclusion of nuclear energy in the Technical Expert Group taxonomy. On the contrary, the exceptional record of storage of civilian high level nuclear waste is an excellent example of an industry successfully meeting the criteria of 'do no significant harm'."

Signed: Per F. Peterson, Professor, University of California Berkeley

Commissioner of the *Blue Ribbon Commission of on America's Nuclear Future*

6.4.3.3. Onkalo repository

Onkalo, the first final repository for HLW being built in Europe, is currently under construction in Finland by Posiva. As such, and by being approved by the regulator, the project shows that **constructing a safe, long-term repository for high-level nuclear waste (HLW) is technically feasible.**

STUK, the independent Finnish radiation and nuclear safety authority has made a statement[86] regarding Finnish final repository construction license for the Finnish Parliament. The STUK statement says for example:

"The planned disposal of spent nuclear fuel will be passively safe after closure. Ensuring the safety of the facility will not require monitoring of the disposal site or other maintenance activities." (page 7)

"The encapsulation plant and disposal facility for spent nuclear fuel proposed by Posiva can be constructed to be safe." (page 13)

The STUK statement was supportive, and Posiva got the construction license and political Decision-in-Principle from the Parliament and has now started construction of the Onkalo final repository, and HLW will start to be deposited there in the 2020s, according to current plans.

6.5. Protection of healthy ecosystems

Objective 5	Conditions for causing 'significant harm'
Protection of healthy ecosystems	The activity is detrimental to a significant extent to the good condition of ecosystems.

86 STUK's statement and safety assessment on the construction of the Olkiluoto encapsulation plant and disposal facility for spent nuclear fuel (2015). https://www.julkari.fi/bitstream/handle/10024/127133/stuk-b196.pdf

Summary

Uranium mines and nuclear fuel related-facilities, nuclear power plants and final repositories all need to prepare Environmental Impact Assessments to get construction permit. The assessment, combined with following regulations, legislation and international guidelines, ensures that these activities do not cause significant harm to protection of healthy ecosystems. They also take up comparably little land area.

What would generate significant harm during the life cycle of the activity? And can this risk be addressed by complying with EU legislation and best practices, international standards or guidelines?

6.5.1. Uranium production, enriching and nuclear fuel fabrication

Uranium mining can cause harm to ecosystems through direct mining activity or if significant amounts of waste products are released to the ecosystem.

Uranium mining is tightly regulated, and due to the energy density of uranium, relatively small amount of mining is required per energy produced. To avoid further significant harm, uranium mines need to do proper Environmental Impact Assessments before production can start, and open-pit or otherwise environmentally destructive mining should not be done in fragile or protected (NATURA etc.) areas or ecosystems. Production and waste-streams from mining and other activities need to be monitored and managed as per regulations.

6.5.2. Construction and operation of nuclear power plants

Nuclear power releases low-quality heat as part of its operations into the environment, which can have effects (both positive and negative) for local ecosystems. Nuclear power plants also release radioactive materials, such as tritium, to the environment.

Both the release of waste heat release and the release of radioactive materials are tightly regulated to safe limits as part of normal operations.

Nuclear power plants take comparably little land-area, and an environmental impact assessment is done to ensure they have a limited impact on the ecosystems before they can be built. Studies show that nuclear energy has a relatively small impact to the ecosystems, and recommend a greater role for it for that reason[87].

6.5.3. Decommissioning of nuclear power plants and managing waste

Decommissioning of nuclear power plants is done within the national regulations and legislation, and funds for that have been collected in the price of electricity. Waste management and long-term storage pose little risk for the ecosystems and constructing waste facilities requires thorough analysis and environmental impact assessments to be made.

87 Brook, B. and Bradshaw, C., Key role for nuclear energy in global biodiversity conservation, Conservation Biology (2014). https://doi.org/10.1111/cobi.12433

7. Afterword

The state of public and political discussion around nuclear energy rarely reflects the factual state of things. Emotions like fear take hold, even though from a statistical and scientific point of view, there is less to fear from nuclear energy than from practically any other energy source. The civilian nuclear energy sector has managed its risks and waste products well. Accidents and radioactive waste are often talked about, but they are rarely put in context: the coal combustion around the world causes more premature fatalities every single day than the nuclear energy industry, accidents and waste included, has caused in the 60+ years of its existence.

Climate change is a defining challenge for humans in the coming decades. It will require us to challenge many of our beliefs, life choices and preferences, our views on nuclear energy included. This assessment of nuclear sustainability was compiled to help us do that. We need powerful tools to address our climate challenge, and in this report we demonstrate that nuclear energy can play a safe and effective role in mitigating climate change.