NUCLEAR POWER – A PART OF THE EUROPEAN GREEN DEAL

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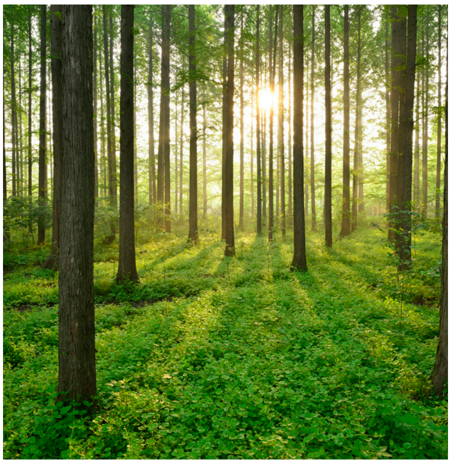

NUCLEAR POWER – OUTLOOK AND TECHNOLOGY DEVELOPMENT

Energiforsk

Nuclear Power – A Part of the European Green Deal

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Foreword

One mission of the Energiforsk Nuclear portfolio is to follow the developments in the nuclear field, to create understanding of the various opportunities and consequences of nuclear power.

The EU taxonomy is a classification system aiming to facilitate environmentally sustainable investment. The decision of the European Commission to include nuclear power in this taxonomy will have an impact on the future of nuclear power in the European energy system.

This study summarizes the report from the Joint Research Center that formed the basis for the decision of the Commission, and puts its conclusions in a Nordic context. The aim of the study is to better understand the opportunities that the taxonomy brings for Nordic nuclear.

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Sammanfattning

Kärnkraft kan bidra till EUs gröna omställning och inkluderas därför i EUs Taxonomi för hållbara investeringar. EU-kommissionen bygger denna slutsats på en rapport framtagen av Joint Research Centre (JRC), vilket är EUs egen vetenskapliga organisation. I denna rapport från Energiforsk sammanfattas JRCs konstateranden avseende kärnkraftens hållbarhet i relation till andra kraftslag och sätter även slutsatserna i en nordisk kontext.

Som en del i arbetet med att utvärdera möjligheten att inkludera kärnkraften i EUs Taxonomi för hållbara investeringar har JRC ombetts ta fram en rapport [1] där kärnkraftens påverkan på miljön och människors hälsa utvärderas vetenskapligt. Villkoret för att en verksamhet ska inkluderas i EUs Taxonomi är att den ska bidra till ett miljömål utan att orsaka signifikant skada på övriga miljömål (Eng: Do No Significant Harm, förkortat DNSH). Kärnkraft bidrar genom låga utsläpp av växthusgaser till målet att begränsa klimatförändringar, vilket gör att JRC-rapportens fokus är att undersöka påverkan på övriga miljömål. Hela kärnkraftens livscykel, från uranbrytning till slutförvar av avfall, beaktas i rapporten.

Slutsatsen är att kärnkraften står sig väl i förhållande till både förnybar och fossil elproduktion och därför kan inkluderas i EUs Taxonomi. Inkluderingen förutsätter att ett antal villkor uppfylls, så kallade Tekniska Acceptanskriterier. Dessa omfattar exempelvis krav på finansiering och att planer för omhändertagande av avfall finns.

JRC-rapporten visar att utsläppen av växthusgaser är mycket låga, landanvändningen och resursförbrukningen begränsad, den relativa olycksrisken, uttryckt som antal dödsfall per producerad energienhet, tillhör de lägsta bland samtliga kraftslag och vägen mot cirkulär ekonomi finns på sikt genom fjärde generationens kärnkraft. Dessutom visar rapporten att kärnkraften tar ansvar för sitt avfall på ett säkert och hållbart sätt. Men samtidigt finns det delar som kan göras bättre. Utsläppen från uranbrytningen kan reduceras, liksom de från byggnation och drift av anläggningarna. Förbättringarna består till stora delar i att göra transporter och byggnader fossilfria, vilket uppnås med just elektrifiering.

Beaktat uppfyllande av ställda villkor kan kärnkraft, via dess inkludering i EUs Taxonomi, bidra till EUs gröna omställning utan att skada människors hälsa eller miljön.

Summary

Nuclear power can contribute to the European green deal and is therefore included in the EU Taxonomy for sustainable economic activities. The European Commission bases this conclusion on a report prepared by the Joint Research Centre (JRC), which is the EU's own scientific organization. This report from Energiforsk summarizes JRC's findings regarding the sustainability of nuclear power in relation to other types of energy sources and puts the conclusions in a Nordic context.

As part of the work to evaluate the possibility of including nuclear power in the EU Taxonomy for sustainable economic activities, the JRC has produced a report [1] in which the impact from nuclear power on the environment and human health is evaluated with scientific methods. The terms for an activity to be included in the EU Taxonomy is that it must contribute positive to an environmental objective without causing significant harm to other environmental objectives. This is referred to as the Do No Significant Harm criteria (DNSH). Since nuclear power has low emissions of greenhouse gases, it has a positive contribution to climate change mitigation objective. The focus of the JRC report is therefore to examine the impact on other environmental objectives throughout the entire life cycle of nuclear power, from uranium mining to final disposal of nuclear waste.

The conclusion is that nuclear power performs well in relation to both renewable and fossil electricity production and can therefore be included in the EU Taxonomy. Thus, provided that special terms, so-called Technical Acceptance Criteria, are met, which for example include financing and plans for a final waste repository.

The JRC report shows that greenhouse gas emissions are very low, it has limited impact on land use and resources, the relative accident risk-is among the lowest of all types of energy sources expressed as number of deaths per unit of energy produced. The report also shows that the road to a circular economy can be found in the long term through the fourth generation of nuclear power. In addition, the report shows that nuclear power takes responsibility for its waste in a safe and sustainable way. But at the same time, there are areas that can be improved. Emissions from uranium mining can be reduced, as well as those from the construction and operation of the plants. Nevertheless, the improvements largely consist of making transport and buildings fossil-free, which could be achieved by electrification.

If terms and requirements are met, nuclear power, via its inclusion in the EU Taxonomy, can contribute to the European green deal without harming human health or the environment.

List of content

1 Background

1.1 THE EU TAXONOMY – A BRIEF INTRODUCTION

Within the EU, climate and environmental objectives have been broken down into specific economic criteria to provide investors with guidance on which activities that have the potential to be environmentally sustainable. This is called the EU Taxonomy and one of the comprehensive sectors where the activities are included in the Taxonomy is the energy sector. The work of identifying the activities that can be included in the Taxonomy, i.e. which activities are considered to have the potential to meet the climate and environmental objectives, is based on scientific methodologies according to the following steps:

- Reports from the EU's Technical Expert Group (TEG).
- Research carried out by the EU's Joint Research Centre (JRC).
- Statements from the European Commission's advisory body on "Sustainable Finance", consisting of researchers and experts in various fields.

When an activity is included in the EU Taxonomy, it means that it, based on a scientific assessment, meets the EU's overall climate and environmental objectives and can be an important part of achieving a climate-neutral EU by 2050.

The Taxonomy Regulation has been approved by the Parliament and the Council, with the addition related to nuclear power entering into force on 1 January 2023. Thus, it has been established within the EU that nuclear power is included in the Taxonomy and the regulations are now applied by the Member States within the EU.

1.2 THE JRC REPORT AND THIS REPORT

To include nuclear power in the EU Taxonomy for Sustainable Investments, the Joint Research Center (JRC) has produced a report to identify the impact of nuclear power on the environment and human health.

The JRC report [1] describes the radiological and non-radiological emissions of nuclear power and its impact on land use, water consumption and natural resources in a life-cycle perspective. The assessment in [1] is based on the EU Taxonomy's methodology that an economic activity (nuclear power in this case) must contribute significantly to an environmental objective, while at the same time it shall “Do No Significant Harm" (DNSH) to the remaining environmental objectives. The methodology thus defines the European Commission's view of sustainability.

The environmental objectives are as follows:

1. Climate change mitigation.
2. Climate change adaptation.
3. Sustainable use and protection of water and marine resources.
4. Transition to a circular economy, waste prevention and recycling.
5. Pollution prevention and control.
6. Protection of healthy ecosystems (protection and restoration of biodiversity and ecosystems).

Based on this, Energiforsk has produced this report that summarizes the conclusions in [1] and comments on them from a Swedish and Finnish context. The aim is to show in a comprehensive way what impact nuclear power has on the environment and human health compared to other energy production methods, especially those that already were included in the Taxonomy. The summary is made for each step of a nuclear power plant's life cycle and follows the layout in [1].

The JRC report [1] is divided into two parts, Part A and B, where the first one (Part A) presents the impact of nuclear power from a life cycle perspective (LCA analysis), in which all parts of the life cycle are reviewed. Part B describes the radioactive waste management and focuses on the final disposal of spent nuclear fuel.

1.3 MAIN FINDINGS OF THE JRC REPORT

The main findings of the report [1] are summarized below:

- Average lifecycle GHG emissions determined for electricity production from nuclear energy are comparable to the values characteristic to hydropower and wind.
- Nuclear energy has very low NOx (nitrous oxides), SO2 (sulphur dioxide), PM (particulate matter) and NMVOC (non-methane volatile organic compounds) emissions. The values are comparable to or better than the corresponding emissions from the solar PV and wind energy chains.
- With regard to acidification and eutrophication potentials, nuclear energy is also comparable to or better than solar PV and wind.
- Land occupation of nuclear energy generation is about the same as for an equivalent capacity gas-fired power plant, but significantly smaller than wind or solar PV.
- The total impact on human health of both the radiological and non-radiological emissions from the nuclear energy chain are comparable with the human health impact from offshore wind energy.
- Severe accidents can cause serious consequences but have a very low probability of occurring. All in all, this means that the risk, expressed in terms of the number of deaths per produced GWh, for older nuclear power plants (Gen II) is comparable to hydropower and wind. For new plants (Gen III), they are significantly lower.
- The operation of nuclear power plants can cause environmental impacts related to the heating of cooling water in lakes and rivers and the consumption of fresh water through evaporation in cooling towers. This is mainly a problem for inland facilities, which do not use seawater for cooling1.
- Available methods exist for the safe disposal of radioactive waste from nuclear power plants.

[1] Nuclear power plants in Sweden and Finland are situated along the coastline and use seawater for cooling.

2 The Life Cycles of Nuclear Power in Relation to the six Environmental Objectives

The JRC report [1] provides a review of life cycle assessments (LCAs) of the impact of nuclear power on the six environmental objectives, described in Chapter 1, based on the concept DNSH.

For environmental objective 1, the EU Taxonomy's Technical Expert Group (TEG) has previously concluded that nuclear power can significantly contribute to climate change mitigation. The technical expert group, which developed the criteria in the EU Taxonomy, considered that an energy source can meet this objective if its emissions are below 100 g of carbon dioxide equivalents per kWh.

The JRC report confirms what TEG has already concluded: nuclear power makes a significant contribution to environmental objective 1 since its emissions are around 28[2] g CO_2 equivalents per kWh, see **Figure 1** below, which is comparable to wind and hydropower.

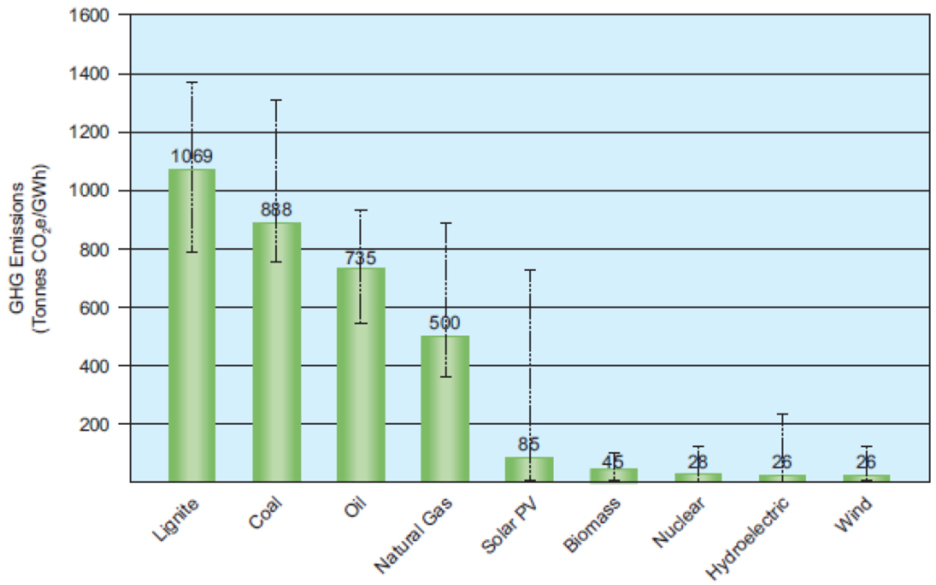


Figure 1. *Comparison of greenhouse gas emissions in tonnes of CO_2 equivalents per GWh between different types of energy sources. The values are directly transferable to grams of CO_2 equivalents per kWh. From [1].*

[2] As shown in Figure 1, there are large variations in the results of emitted CO_2 equivalents for all types of energy sources. In [1], values of about 5 g CO_2 eq/kWh are presented for nuclear power plants in Sweden and France.

The JRC report then describes how nuclear power as an energy source affects the other five environmental objectives, as well as the criteria that need to be met in order for nuclear power to be assumed to do no significant harm (DNSH) to each environmental objective. Written below is a walkthrough of the different phases of a nuclear power plant's life cycle and how each phase contributes to the total impact on the environment and human health.

2.1 URANIUM MINING

Uranium mining takes place in three main ways: open-pit mining, deep-pit mining and in-situ leaching (ISL). The mining method, but also the uranium ore grade, is important for the impact uranium mining has on the environmental objectives.

For open pits and underground mining, emissions to water and air take place via tailings, which mainly consist of leftover minerals after the uranium has been separated and extracted from the ore, waste rock and runoff water.

In the case of chemical leaching, ISL, the impact is mainly through the use of chemicals, which need to be properly disposed. Furthermore, groundwater in the areas where the mineral is extracted may be adversely affected. Partly through groundwater reduction, partly through chemical pollution.

All aspects mentioned above can be managed/mitigated through containment, monitoring/measurement and the transition to fossil-free electricity production in the mining process.

Of the three mining methods (open pit, deep pit and ISL), ISL has the lowest environmental impact.

From a life-cycle perspective, uranium mining contributes to about one third of the total greenhouse gas emissions of a nuclear power plant and to 99% of the potential impact of ecotoxicity and toxicity to humans. Furthermore, uranium mining contributes to about 55% of the total share of radioactive gases emitted from nuclear power in a life cycle perspective, see **Figures 4 and 5** further down in the report. At the same time, the affected land area per produced MWh, which also includes the land use of uranium mining, is low for nuclear power. See **Figure 2**.

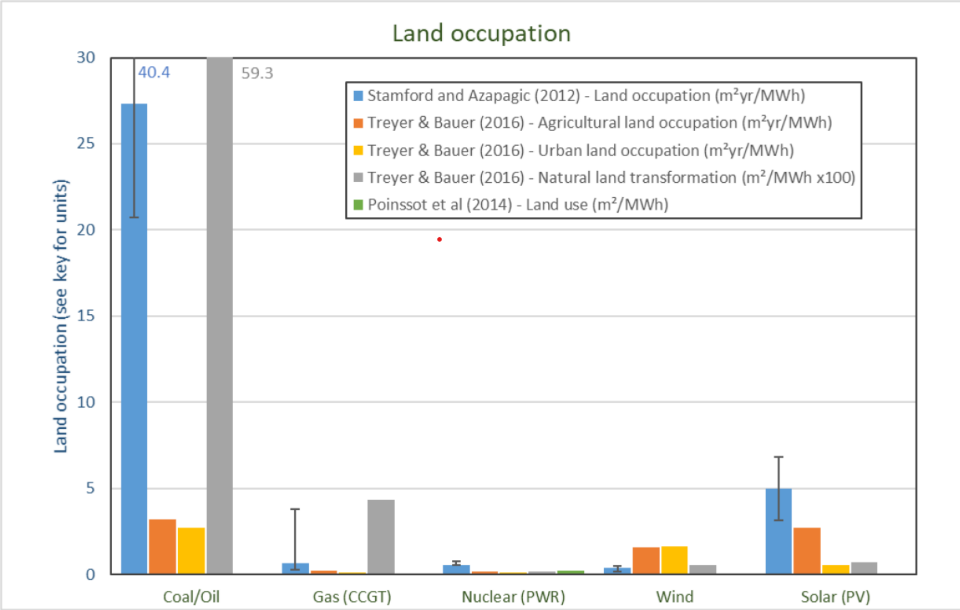


Figure 2. *Comparison of land occupation per produced MWh between different types of energy sources. From [1].*

Since uranium mining is the part of the nuclear life cycle that has the largest emissions, it is desirable to minimize this activity as much as possible. One way to do this is to switch to a closed fuel cycle. A closed fuel cycle is explained in more detail in section 2.3 below.

However, although uranium mining is responsible for a significant part of the environmental impact of nuclear power, the JRC report [1] states that this can be managed/mitigated with existing technologies and methods. Thus, the DNSH criterion is fulfilled for the uranium mining phase even without the application of a closed fuel cycle.

2.1.1 Uranium Mining in Sweden and Finland

Uranium mining does not currently take place in Finland or Sweden, but the Finnish company Terrafame will start extracting uranium in the Sotkamo mine in eastern Finland during the summer of 2024. The extraction takes place as a by-product of the mine's main production of nickel and zinc and, when full capacity is reached, is expected to be able to extract 200 tonnes of uranium per year [3].

In Sweden, uranium mining is prohibited by law, but there is a legislation bill proposal to change this [4]. It is estimated that about 27% of Europe's uranium deposits are found in Swedish bedrock, where specifically the counties of Skåne, Östergötland, Närke, Öland, Billingen and parts of the mountain range have relatively high concentrations (70–300 g/tonne ore). However, this is still below the limit for what is considered as uranium ore, where a concentration of at least 1000 g/tonne is required [3]. Any extraction of uranium in Sweden will therefore probably take place in the same way as at the Sotkamo mine in Finland, i.e. as a by-product of other mining activities. Historically, uranium mining in Sweden has taken place at the Ranstad site, in the county of Västergötland, between 1965 and 1969.

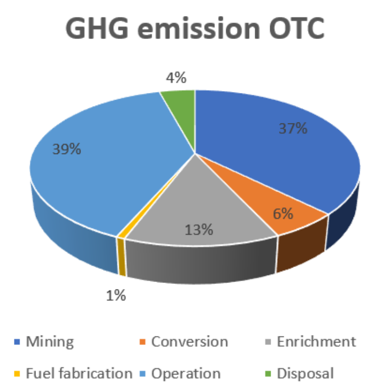
2.2 NUCLEAR FUEL MANUFACTURING AND REPROCESSING

Uranium Conversion and Enrichment

For uranium to be used as nuclear fuel, it needs to be converted and enriched. Uranium mines and associated uranium plants produce uranium concentrate, a powder containing 70–85% uranium. However, this concentrate is neither pure enough nor in the right chemical form to enter the enrichment and fuel production process. The uranium concentrate therefore needs to undergo conversion and then enrichment. When converted, the chemical form of the uranium changes to uranium hexafluoride, UF_6. This chemical compound is used in the production of enriched uranium, i.e. the increase in the proportion of fissile uranium isotopes. In natural uranium, the fissile isotope U-235 is about 0.7%, but for the fission process to maintain in a light water reactor, the ratio needs to be increased to between 3 and 5%. The process of increasing the share of the fissile isotope is called enrichment and currently takes place in centrifuges. The impact on the environmental objectives is low for the conversion and enrichment process, see **Figures 4 and 5** below.

Open and Partially Closed Fuel Cycle

Nuclear power plants in Sweden and Finland, for example, apply a so-called once through cycle (OTC) for its nuclear fuel. This means that the nuclear fuel is used once in the reactor before it is extracted and placed in a final repository. To reduce the amount of uranium that needs to be mined, a partially closed fuel cycle can be applied instead. In this case, the spent nuclear fuel is taken to a reprocessing plant where fissile material is separated from other substances. This recycled material is then used to produce new nuclear fuel that can be placed in ordinary light water reactors, so-called MOX fuel. Globally, MOX accounts for about 30% of the fuel in all nuclear power plants.



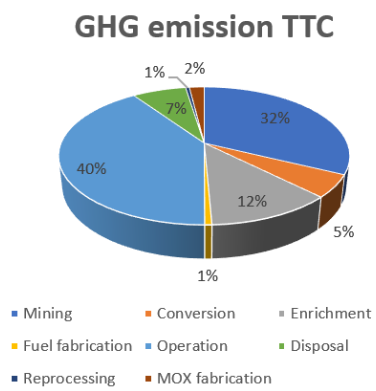


Figure 3. *Greenhouse gas emissions from an open (OTC) and partially closed (TTC) fuel cycle. The impact from reprocessing and production of MOX fuel accounts for about 10% of the total emissions. OTC has a total emission of 5.45 g CO_2 equivalents/kWh, while TTC has a total emission of 5.29. Data taken from [1].*

In France, a partially closed fuel cycle (twice through cycle, TTC) is applied, i.e. the fuel is reprocessed once after use in the reactor and then disposed to a final repository. The need of new uranium in a TTC is about 20-30% lower than in an OTC, thereby also reducing the environmental impact of the uranium mining process. A partially closed fuel cycle also has a positive effect on the amount of high-level waste that needs to be disposed to a final repository.

Figure 3 shows the greenhouse gas emissions for an open (OTC) and a partially closed (TTC) fuel cycle.

Reprocessing and MOX Fuel Fabrication

Reprocessing of spent nuclear fuel and the production of MOX fuel have a low impact on the environmental objectives as both radioactive and non-radioactive emissions are low. A comparison with the other steps in the Life Cycle Assessment is made in **Figures 4 and 5** below. In general, TTC results in lower emissions than OTC for all indicators, where the differences are between 0-20% compared to the TTC values in **Figures 4 and 5**.

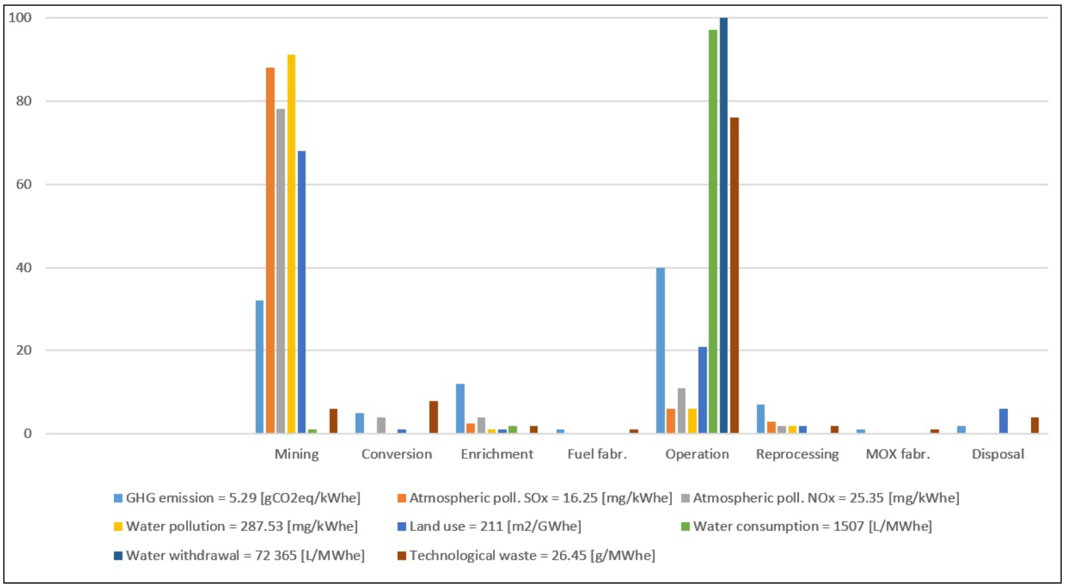


Figure 4. *Non-radioactive emissions from a life cycle perspective. The largest impact is related to the uranium mining and operation of nuclear power plant activities. From [1].*

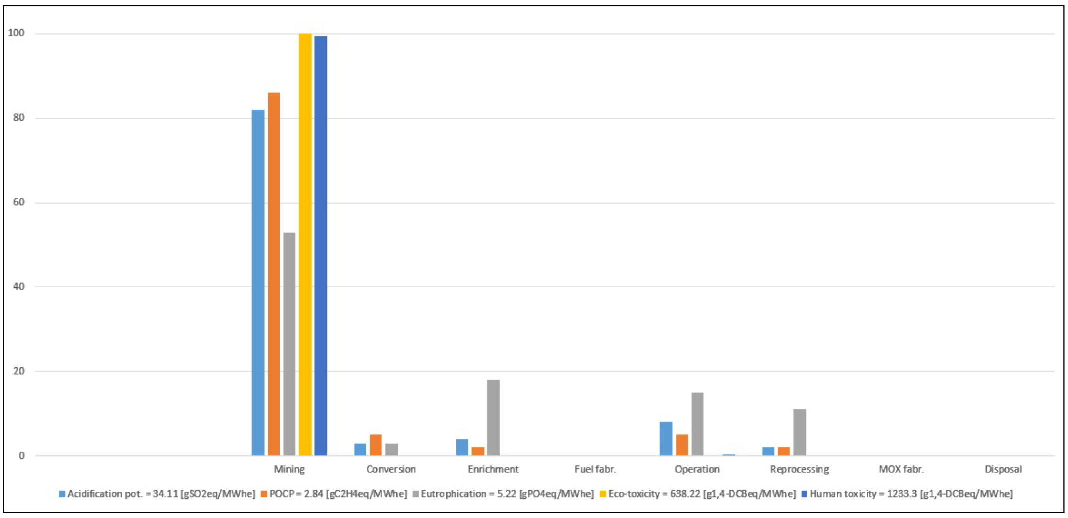


Figure 5. *Radioactive emissions from a life cycle perspective. The largest impact is related to the uranium mining activity. From [1].*

2.2.1 Nuclear Fuel Manufacturing and Reprocessing in Sweden and Finland

Nuclear fuel for both boiling and pressurized water reactors (BWR and PWR), as well as for the Russian-designed VVER, is manufactured at Westinghouse's factory in Västerås, Sweden.

Sweden and Finland do not have their own reprocessing plants, nor has any form of reprocessing taken place historically.

2.3 TRANSITION TO A FULLY CLOSED FUEL CYCLE

A fully closed cycle (FCC) is also known as the generation four nuclear reactors or Gen IV. More information on generation four nuclear reactors can be found in [2].

The conclusion in [1] is that the reprocessing of spent nuclear fuel generally causes a lower environmental impact than an open fuel cycle, mainly due to the reduced need for uranium mining. A fully developed FCC can bring savings in the requirements for fresh natural uranium by up to 100% and thus significantly contribute to both environmental goals 1 "Climate change mitigation " and 4 "Transition to a circular economy, waste prevention and recycling ", while meeting the DNSH concept for other environmental goals.

2.3.1 Transition to a Fully Closed Fuel Cycle in Sweden and Finland

In Sweden, studies are ongoing on the introduction of generation four nuclear reactors in the form of lead-cooled small modular reactors (SMR). It is a step towards a fully closed cycle, but to enable this, facilities and processes associated to Gen IV need to be added, either in each country or as a joint venture within the EU.

Generation four nuclear reactors can also be used in an open fuel cycle and enable applications that are difficult to achieve with conventional reactor technology, such as high temperature steam and the production of hydrogen gas.

2.4 DESIGN, CONSTRUCTION AND OPERATION OF NUCLEAR POWER PLANTS

Design and Construction

The environmental impact during the design and construction phase of a nuclear power plant is no different from that of a conventional construction project. The main impact is from the building materials used, transport to and within the construction site, as well as electricity and fuel consumption for machines and system tests. See also **Figure 4**, where design and construction are described under the activity "Operation". A comparison in the use of natural resources such as metals, minerals and fossil energy, so-called abiotic resources, between different types of energy sources is made in **Figure 6**. Nuclear power has a low impact, which states that resource utilization per GWh is high.

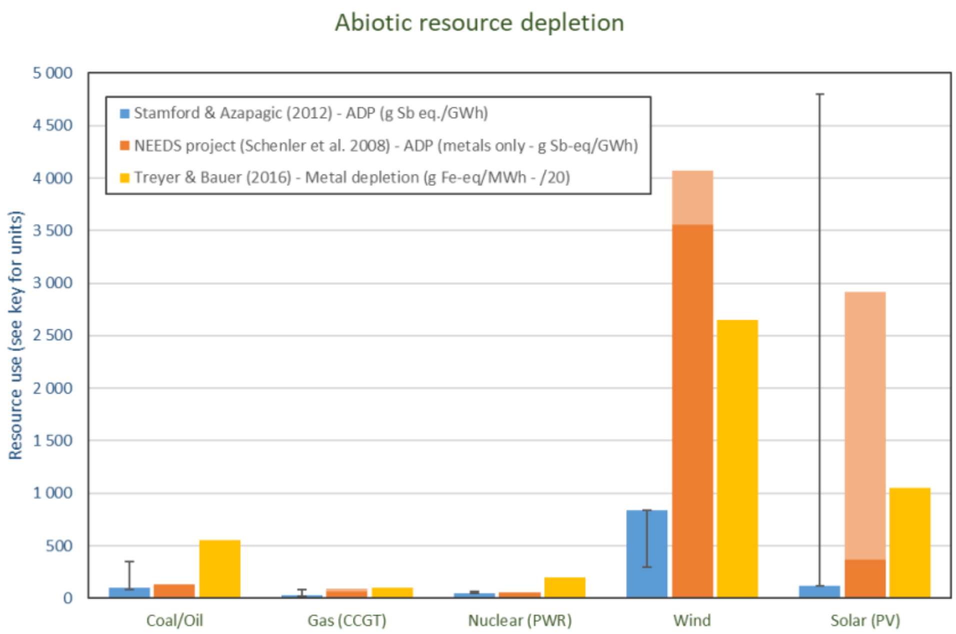


Figure 6. *Comparison in the use of abiotic resources between different types of energy sources. From [1].*

Operation

During operation of nuclear power plants, emissions of greenhouse gases, NOx, SOx and particulates occur when the plants' backup power diesel generators are tested. But the largest emissions are obtained during commuting to and from the power plant. The local marine life is affected via the plants cooling water system, partly by the heated water released to the recipient and partly by fish and other aquatic animals getting stuck in intake grids, cleaning facilities and pumps. For plants that do not use seawater as a coolant the heating of cooling water in lakes and rivers and the consumption of fresh water by evaporation in cooling towers can have an impact on the environment. Other potentially environmentally related impacts include wastewater and the handling of various chemicals and hazardous waste at the power plant. See **Figure 4**.

Radioactive emissions from nuclear power plants during normal operation are low and a member of the public receives an average radiation dose of 0.0002 mSv per year originating from nuclear power plants. This can be compared to the natural background radiation, which is between 1 and 2 mSv per person per year, i.e. in the order of 10,000 times greater. From a life cycle perspective, radioactive discharges during operation are small, see **Figure 5**.

A lifetime extension of operating nuclear power plants, i. e. long-term operation (LTO), lowers the environmental footprint per GWh. From an environmental perspective, this option requires less material and resources compared to building a new nuclear power plant. The resulting waste from the replacement of components has a negligible impact in this context. Lifetime extensions are therefore positive provided that the safety level of the plant is maintained.

2.4.1 Design, Construction and Operation of Nuclear Power Plants in Sweden and Finland

There are several mitigating measures to reduce the environmental impact of the construction of nuclear power plants.

One factor that contributes to the environmental impact during the construction and operation phase is the consumption of electricity and energy use for machines and vehicles. Electricity production in Sweden has a low contribution to carbon dioxide emissions and Finland is on its way to reach the same levels, hence carbon dioxide emissions from electricity use during the construction phase become less relevant.

Heating of lakes and rivers through cooling water discharges, as well as the consumption of fresh water via evaporation in cooling towers, is not a problem in Sweden and Finland since their nuclear power plants are situated along the shoreline and use seawater for cooling. For this reason, cooling towers do not exist at Swedish and Finnish nuclear power plants.

Lifetime extensions have been made to the Swedish and Finnish nuclear fleets, which is the most effective way to contribute to reduced environmental impact, and new nuclear power plants are being constructed for a lifetime of between 60-100 years. From this perspective, the environmental impact of the design, construction and operation of nuclear power plants in Sweden and Finland is therefore low.

2.5 DECOMMISSIONING AND DISMANTLING OF NUCLEAR FACILITIES

Large-scale decommissioning and dismantling of closed nuclear power plants is an activity that has started in the last 10-20 years. This means that new technology can be used to decontaminate contaminated systems and thus reduce the amount of waste that needs to be disposed in a repository. Up to 90% of the material in a nuclear power plant can then be cleared and either reused or used as filling material in, for example, road construction. Most of the waste that needs to be disposed of is in the categories of Short Level Waste – Short Lived and Very Low Level Waste, see **Figure 7** below.

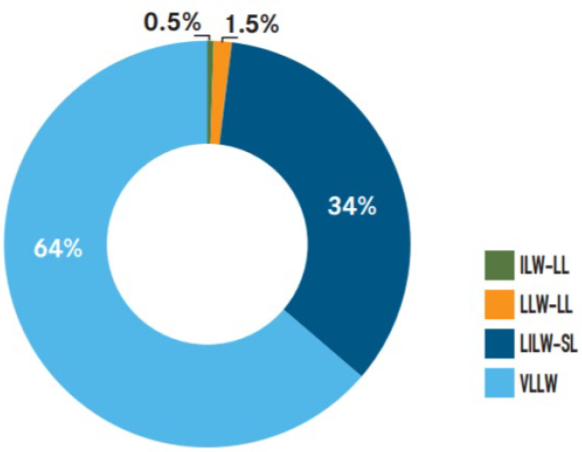


Figure 7. *Waste fractions categorized according to their level of radioactivity. According to the IAEA classification, the entire dark blue sector is LLW-SL, but according to the French classification, it also contains ILW-SL (intermediate-level short-lived waste). From [1].*

The risks associated with decommissioning and dismantling are mainly related to occupational health for the employees who carry out the actual dismantling work. Contaminated systems can spread radioactive dust when they are demolished, but since the reactor building is decommissioned last, this barrier remains to prevent contamination from spreading outside the building. Targeted ventilation also ensures that the monitoring of radioactive releases can continue to be carried out during the dismantling phase. Water used in the decommission and dismantling process is also monitored and purified if necessary.

The report [1] states that if nuclear power plants are built, operated, decommissioned and dismantled in accordance with existing regulations, these activities fulfil the DNSH criteria.

2.5.1 Decommissioning and Dismantling in Sweden and Finland

Sweden has acquired practical knowledge on how decommission and dismantling of nuclear power plants can be carried out in an efficient and radiologically safe manner. The reactors in Barsebäck and two in Oskarshamn are currently being dismantled, while two at Ringhals are awaiting decommissioning. In addition, two test and experimental reactors at Studsvik have been dismantled and the dismantling of the heavy water reactor in Ågesta outside of Stockholm has begun. Working methods for decommission and dismantling are constantly being developed and experiences are being utilized. Air and water emissions are monitored, as well as the waste leaving the facilities so that it can be properly disposed. Low-level waste is often stored in the vicinity of the facility that is being decommissioned, while intermediate-level waste is taken care of by the Swedish Nuclear Fuel and Waste Management Company (SKB) and placed in a final repository. The high-level waste consists of spent nuclear fuel and is not handled within the decommissioning process since all nuclear fuel, including control rods, has already been removed from the plant in this stage.

The decommissioning of the Swedish nuclear power plants is financed through the Nuclear Waste Fund, which in turn is financed by the Swedish nuclear power operators. The decommissioning and nuclear waste management funding in Finland is carried out in a similar way as in Sweden.

2.6 MANAGEMENT OF RADIOACTIVE WASTE

The methods available for the management of intermediate-level (ILW) and high-level (HLW) nuclear waste, referred to in [1], are mainly based on data from facilities in Sweden and Finland. High-level waste in the form of spent nuclear fuel needs to be temporarily stored and cooled for 30–40 years before it can be disposed in a final repository. Interim storage takes place either at the respective nuclear power plant or, as in Sweden's case, in a facility specially designed for this purpose.

Final disposal of spent nuclear fuel will take place in a geological repository, i.e. in the bedrock, as there is a broad consensus that this method is the safest from a long-term perspective. The method used in Finland and Sweden is based on placing the spent nuclear fuel in copper canisters that are lowered into boreholes 400–500 meters below ground and surrounded by bentonite clay. See **Figure 8**.

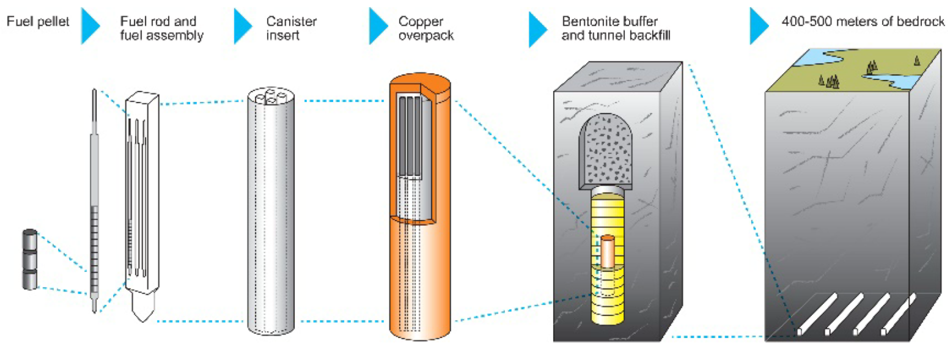


Figure 8. *The design of a geological repository for spent nuclear fuel (HLW). From [1].*

The process for managing spent nuclear fuel is based on an open fuel cycle, but the method can also be used for a partially or fully closed fuel cycle.

Intermediate-level waste, mainly consisting of operational waste, is stored in different types of containers and canisters, adapted for each waste type, and is placed 50–100 meters underground. However, long-lived radioactive waste, such as control rods and internal components from the reactor, will be disposed of deeper into the bedrock according to methods similar to the final repository of spent nuclear fuel.

The report [1] concludes that the final disposal of radioactive waste has little or very little impact on the six environmental objectives and therefore comply with the DNSH criteria.

2.6.1 Management of Radioactive Waste in Sweden and Finland

The management of spent nuclear fuel in Sweden and Finland is carried out in accordance with the process described in section 2.6 and **Figure 8**. Data in [1] on the management of radioactive waste in general, and spent nuclear fuel in particular, are largely taken from Swedish and Finnish conditions. Thus, the conclusions in [1] can be applied to Swedish and Finnish facilities and it can be concluded that this part of the nuclear power life cycle has little or very little impact on the environment in Sweden and Finland.

3 Severe Accidents

Severe accidents at nuclear power plants are very unlikely to occur. Two accidents involving Western designed plants, Three Mile Island (TMI) and Fukushima Daiichi, have resulted in partially or completely melted reactor cores. However, no obvious radiological health effects have been determined from these events.

The Chernobyl accident, which took place in a Soviet RBMK reactor that has a completely different design from Western nuclear power plants, led to extensive radioactive releases with subsequent mortalities. It is difficult to estimate the fatalities caused by the Chernobyl accident, but in [1] an upper limit for current and future deaths is assumed to be 30,000 people. Other studies from the World Health Organization [5] estimates that up to 4,000 fatalities in total can emerge related to the incident. This includes both occurred and possible future mortalities. At the same time, [5] states that up to the year 2005 fewer than 50 deaths have been confirmed directly caused by the accident.

All electricity production is associated with risks. In [1], the risks for different types of energy sources are represented as the mortality rate per produced GWh and the estimated maximum number of fatalities in the event of a severe accident. The figures should not be interpreted as exact values of the mortalities for each energy source. Rather, they are intended as a comparison between different types of energy sources. The second-generation nuclear power plants (Gen II) from Western countries have a mortality rate per GWh on a par with hydro and wind power. Third-generation nuclear power (Gen III), which includes the EPR reactor type, is significantly lower than all other types of energy sources. This is illustrated in **Figure 9**.

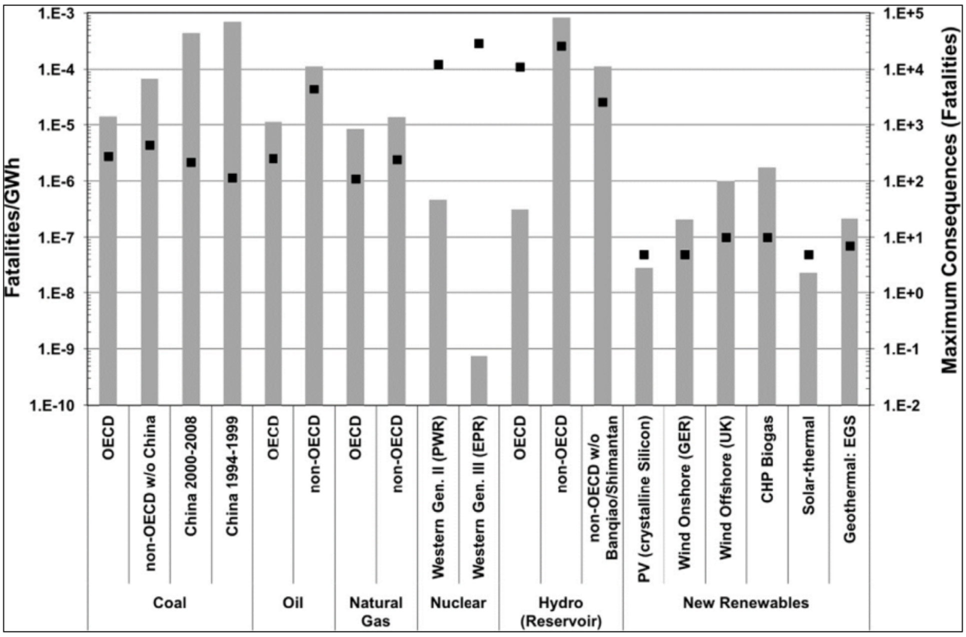


Figure 9. *The number of fatalities per GWh (grey bars) and the maximum number of fatalities in a severe accident (black squares) for different types of energy sources. Note that the scale is logarithmic. From [1].*

By comparison, [1] estimates a prematurely fatality rate caused by air pollution to approximately 400,000 people per year in the EU.

3.1 SEVERE ACCIDENTS IN A SWEDISH AND FINNISH CONTEXT

The safety of Swedish and Finnish nuclear power plants has been continuously uprated in line with new knowledge and experiences. The events mentioned in Chapter 3 above have all led to measures, such as the introduction of severe accident mitigation systems, i. e. filters aimed at reducing the environmental and health consequences after a very unlikely event. It can therefore be assumed that Finnish and Swedish plants rank somewhere between the values for second and third generation nuclear power (Gen II and Gen III) in **Figure 9** above. Finland's newest reactor, Olkiluoto 3, is an EPR (Gen III) and thus has the lowest values of all compared energy sources in **Figure 9**.

It should also be pointed out that fatalities related to nuclear accidents or radiation incidents has not occurred at Finnish or Swedish nuclear power plants.

4 Conclusions

Chapter 2 above shows that nuclear power has the potential to make a significant contribution to reducing greenhouse gas emissions. At the same time, it fulfils the requirements for Do No Significant Harm (DNSH) on the remaining environmental objectives, which has been the basis for nuclear power to be included in the EU Taxonomy as an environmentally sustainable energy source in the same way as, for example, wind, solar and hydropower.

However, there are some additional requirements specific to nuclear power that needs to be fulfilled to include it in the Taxonomy. These are set out in full in [6] and include, among others, conditions for the construction of new nuclear power plants, conditions for lifetime extensions of existing plants and pre-commercial stages of fourth generation nuclear power (Gen IV).

To qualify as environmentally sustainable, an energy source must also meet basic requirements for human rights and working conditions, during construction, operation and decommission and dismantling. This is presented in the Taxonomy as "Compliance with minimum safeguards". For more information about minimum safeguards, see [7].

If the requirements above are met, nuclear power, via its inclusion in the EU Taxonomy, can contribute to the European green deal without harming human health or the environment.

5 References

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[7] A USER GUIDE TO NAVIGATE THE EU TAXONOMY FOR SUSTAINABLE ACTIVITIES, European Commission, ISBN 987-92-76-40678-5

NUCLEAR POWER – A PART OF THE EUROPEAN GREEN DEAL

Nuclear power can contribute to the European green deal and is therefore included in the EU Taxonomy for sustainable economic activities. The European Commission bases this conclusion on a report prepared by the Joint Research Centre (JRC), which is the EU's own scientific organization. This report from Energiforsk summarizes JRC's findings regarding the sustainability of nuclear power in relation to other types of energy sources and puts the conclusions in a Nordic context.