Life cycle assessment of electricity from Sizewell B nuclear power plant development

EDF

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Glossary

Abbreviations	Definition
AD	Associated Development
AGR	Advanced Gas-cooled Reactor
ALARP	As Low as Reasonably Possible
AONB	Area of Natural Beauty
AP	Acidification Potential
AWARE	Available WAter REmaining
BAP	Biodiversity Action Plan
BDP	Baseline Decommissioning Plan
BEIS	Department for Business, Energy and Industrial Strategy
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CEGB	Central Electricity Generation Board
CH_4	Methane
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
EA	Environment Agency
EMF	Electromagnetic Field
EMS	Environmental Management System
EP	Eutrophication Potential
EPD	Environmental Product Declaration
EPR	European Pressurised Reactor
ESA	Environmentally Sensitive Area
FES	Future Energy Scenarios
GDF	Geological Disposal Facility
GHG	Greenhouse Gas
GPA	Generic Performance Assessment
GSP	Grid Supply Point
GWP	Global Warming Potential
HAZOP	Hazard and Operability
HLW	High Level (radioactive) Waste
HPC	Hinkley Point C
HVAC	Heating, ventilation, and air conditioning
ICE	Institution of Civil Engineers
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IES	International EPD System
ILMP	Integrated Land Management Plan
ILW	Intermediate Level (radioactive) Waste
ISL	Insitu Leaching
LC	Life Cycle
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LLW	Low Level (radioactive) Waste
LLWR	Low Level (radioactive) Waste Repository
luluc	Land Use and Land Use Change

Abbreviations	Definition
mSv	MilliSievert
N_2O	Nitrous oxide
NDA	Nuclear Decommissioning Authority
NMVOC	Non-Methane Volatile Organic Compounds
NRVB	NDA Reference Vault Backfill
ONR	Office for Nuclear Regulation
PCR	Product Category Rules
PM2.5	Fine Particulate Matter
POCP	Photochemical Oxidation Creation Potential
PSA	Probabilistic Safety Assessment
PWR	Pressurised Water Reactor
Ricardo	Ricardo Energy and Environment
RSR	Radioactive Substances Regulation
RWM	Radioactive Waste Management
SAC	Special Area of Conservation
SF	Spent Fuel
SF_6	Sulphur hexafluoride
SKB	Swedish Nuclear Fuel and Waste Management Company
SO_2	Sulphur dioxide
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SZA	Sizewell A
SZB	Sizewell B
SZC	Sizewell C
T&D	Transmission & Distribution
U_3O_8	Uranium oxide
UF6	Uranium hexafluoride
VLLW	Very Low Level (radioactive) Waste
VOC	Volatile Organic Compound
WMC	Waste Management Centre
WSF	Water Scarcity Footprint

1 Preface

Producer: EDF is the operating company for the Sizewell B (SZB) nuclear power plant project. EDF's registered address is: 90 Whitfield Street, London, W1T 4EZ, UK.
https://www.edfenergy.com/energy/power-stations/sizewell-b

EDF is a major electricity generator, operating several nuclear sites in the UK as well as developing Hinkley Point C (HPC), the first new nuclear build in decades, and bringing forward proposals for Sizewell C (SZC), which has an application currently with the Secretary of State for review.

Product: Electricity from the Sizewell B nuclear power plant. Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy.

This declaration was prepared by Ricardo Energy and Environment (Ricardo) on behalf of EDF.

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The purpose of this document is to communicate the life cycle environmental impacts associated with the construction, operation and decommissioning of the SZB nuclear power plant, as well as impacts associated with distributing SZB's electricity. It summarises the findings of the full Life Cycle Assessment (LCA) report that provides a detailed presentation of the SZB LCA study. The full LCA report and this document have undergone third party review by WSP USA Inc.

The function of SZB is to generate electricity to be delivered via the grid to consumers. Therefore, a functional unit of 1kWh delivered has been chosen for this study. This aligns with the requirements of the Product Category Rule (PCR)[1] for 'Electricity, Steam and Hot Water Generation and Distribution PCR2007:08, version 4' (Electricity PCR) , which has been used as a guide for this study. Please note this document is not an Environmental Product Declaration (EPD) as it does not fully comply with the PCR.

2 Introduction

EDF owns and operates the nuclear power station, known as SZB in Sizewell, East Suffolk. In 2020, EDF estimates that SZB generated enough low carbon electricity to supply 2.3 million homes, helping

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[1] PCRs lay out category-specific requirements for conducting LCAs and reporting results in Environmental Product Declarations (EPDs)

to support the UK's decarbonisation ambitions and meet its legal obligation to achieve 'net zero' economy wide carbon emissions by 2050. In order to support its low carbon claims in relation to nuclear energy generation, EDF commissioned Ricardo to prepare a LCA for SZB, the results of which it wishes to communicate publicly.

Ricardo has performed this LCA study along the guidelines of the core international LCA standards; ISO 14040 (Environmental management – Life cycle assessment – Principles and framework) [1] and ISO 14044 (Environmental management – Life cycle assessment – Requirements and guidelines) [2]. This resulting public facing document summarises the work done and alongside the methodology followed, has been reviewed against these core ISO standards by a third-party, WSP USA Inc.

The LCA study assesses SZB's impacts across its life cycle, considering:

- The activities 'upstream' of generation, such as the procurement of raw materials and fuel fabrication
- The 'core' activities associated with constructing, operating and decommissioning SZB
- The 'downstream' activities associated with distributing electricity to customers

The assessment considers a selection of key environmental indicators, including Global Warming Potential (GWP) and Acidification Potential (AP). It also reports on a number of resource use and waste output indicators.

In addition to the core ISO standards, the study has referred to the framework established in the Electricity PCR. However, it should be noted that this is not an Environmental Product Declaration (EPD) as has not sought to cover all of the requirements of the Electricity PCR (see Appendix A1 for deviations).

This document summarises the work undertaken to assess SZB's life cycle environmental impacts and the results of the study. The GWP value associated with generating 1kWh of net electricity at SZB has been calculated as 10.14g CO_2 eq., whilst that associated with a downstream user receiving 1kWh of electricity generated by SZB has been calculated as 16.13g CO_2 eq once the impacts of the transmission and distribution (T&D) networks are taken into account.

As mentioned, appendix A1 lists the key areas where the study and this communication document do not fully align with the Electricity PCR. Other appendices of SZB confidential data have been shared in the full LCA report but are not publicly available in this communication document. It is important to note that this communication document provides a condensed description of the methodology. Full details can be found in the full LCA report "Life Cycle Assessment of Sizewell B nuclear power plant" dated 21/12/2021.

3 LCA

3.1 Goal and scope

3.1.1 Goal

The goal of this study is to assess the life cycle impacts of the 1.2GWe (gross) SZB nuclear power station currently operational in Sizewell, Suffolk, UK. This is assessed in terms of the electricity to be generated and delivered to a downstream user.

The study is being undertaken to understand SZB's environmental impact and communicate this to the public and other key stakeholders. Consequently, third-party review of the study against the core international standards for LCA - ISO 14040 and ISO 14044 - has been undertaken to provide assurance of the findings and methodology employed to derive them.

3.1.2 Scope

3.1.2.1 Product system

SZB comprises one Pressurised Water Reactor (PWR) with an electrical output of 1.2GWe (gross). PWR are a type of nuclear power plant which pump pressurised water into the reactor core. This water is heated by nuclear fission of the uranium within the fuel assembly which generates steam in a secondary circuit that then passes through turbines to generate electricity.

Construction of SZB began in 1988 with generation commencing in 1995. It has been designed for an operational period of 40 years so decommissioning is estimated to begin in 2035. Although the plant may be subject to further life extension, if the relevant approvals can be gained, it should be noted that this LCA has assumed that decommissioning will begin in 2035. In addition to the main reactor, other buildings and associated developments (ADs) were constructed and some will be built during operation and decommissioning, in order to manage and store waste in the short term.

The plant runs all day, every day, except during planned maintenance periods, assumed to occur every 18 months.

Table 1 below summarises the project's key characteristics.

Table 1: Overview of SZB details

Characteristic	Assumption
Reactor type	PWR
No. of reactors	1
Fuel	Enriched uranium oxide fuel (currently assumed to by EDF to be of maximum enrichment level of 4.6%)
Start of construction	1988
Start of generation	1995
Start of decommissioning	2035
Designed service life	40 years
Fuel cycle	Designed to operate at full power for a "fuel cycle" of 18 months per reactor (including a few weeks for refuelling outage)
Location	Sizewell, Suffolk, UK
Gross generated	circa 1.2GWe
Transmission	Electricity will be transmitted at 400kV and subsequently distributed to the majority of customers through lower voltage distribution networks

3.1.2.2 Functional Unit

The function of SZB is to supply electrical energy to consumers. A functional unit of 1kWh net electricity generated and thereafter distributed to the customer has been selected, hereafter referred to as 1kWh delivered. This value is inclusive of losses within the T&D network. For every kWh of SZB electricity delivered to a customer, ~1.12kWh had to be generated (net) at SZB to account for these losses. It is assumed for this LCA that the customer receives medium voltage electricity

Table 2 below compares SZB's lifetime gross generation and net generation (assuming a 40-year operational life), as well as the amount of SZB electricity delivered after T&D losses over the grid have been taken into account.

Table 2: Comparison of SZB energy outputs under different accounting boundaries

Gross generated	Net generated	Delivered
384,193GWh	364,104GWh	319,403GWh

Operational data for a recent reference period of 18 months has been used and scaled to cover the 40-year operational period. All impacts associated with construction and decommissioning of SZB have been linked to the net generated lifetime value, which has been calculated by extrapolating the recorded operational electricity output for the reference period up to 40 years.

As described above, for every 1.12kWh generated (net) 1kWh is delivered to a customer. When presenting the results per kWh delivered, the upstream and core impacts associated with generating the 0.12kWh that is lost, are included in the downstream stage, not the upstream and core stages.

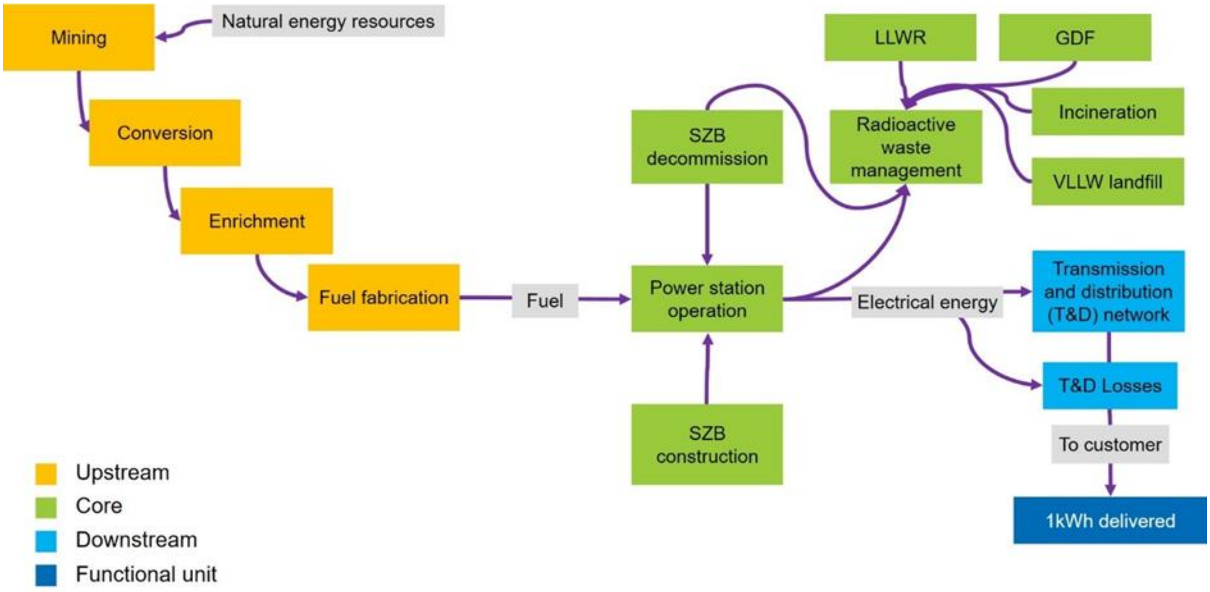
To provide greater transparency the impacts per kWh generated (net) are used to supplement the results per the functional unit of 1kWh delivered.

3.1.2.3 System boundary

The scope of this LCA is cradle-to-grave, excluding the impacts from use of electricity (i.e., after delivery). As such, the LCA model and the results are divided into three different life cycle stages:

- **Upstream**: activities that occur ‘before’ the SZB facility, capturing processes associated with the mining, conversion, enrichment and fabrication of nuclear fuel which the plant uses.
- **Core**: capturing the infrastructure and operations associated with energy generation by the plant over its life cycle as well as those facilities associated with the treatment and disposal of radioactive waste either in the future Geological Disposal Facility (GDF), or as currently, at the at the Low-Level Waste Repository (LLWR), via incineration, metal recycling and/or via Very Low Level Waste (VLLW) landfill.
- **Downstream**: capturing processes associated with the operation and infrastructure of the electricity network through which electricity generated at the power plant site is transmitted to customers. This includes accounting for transmission and distribution losses through the network.

Figure 1: System boundary overview schematic



The studied life cycle begins at the extraction point of raw materials and energy carriers from nature, and the final stages include waste generation and delivering of electricity energy to the customer.

3.1.2.4 Representativeness

Temporal

ISO 14044 requires LCA studies to consider the impact of temporal differences within the data modelled. As noted in Table 1 above, the construction of SZB began in the 1980s, and the plant began generating electricity in the mid-1990s and is set to continue until 2035.

Data has been estimated on the basis of certain assessment periods, such as 18 months of operation for the in-operation inventory (from February 2018 to August 2019). Data for construction and decommissioning has been considered as ‘units’ of activity that occur once in the life cycle of SZB and as such, no upscaling has been required.

This assessment has modelled a contemporary grid mix for electricity consumption during construction and operation and has not sought to forecast or back-cast modelling. This will affect the results. It is worth noting that electricity consumption during construction is responsible for 3% of the GWP of delivered electricity, while electricity consumed during operation is responsible for 6% so it is considered that this assumption will make only a minor difference. In addition to electricity consumption, it is important to note that no adjustments have been made to the underlying material input datasets to reflect how their carbon intensity may have also changed during this time period.

The model does however estimate potential changes to the electricity grid mix which will have occurred in 2035 onwards, when the decommissioning of SZB will begin as well as use of a future UK GDF (2040). As with construction and operation, it is expected that electricity use during decommissioning will only account for 3% of the total GWP of delivered electricity so this is a relatively minor assumption.

This study assesses GWP using a 100-year horizon.

Geographic

In terms of geography, a number of geographies were considered. Downstream, core activities and enrichment have been modelled as occurring in the UK, whilst fuel conversion and fabrication are assumed to take place in France. Mining operations have been assumed, for the purposes of this study, to take place in Canada, Kazakhstan and Namibia. Where possible, suitable datasets to reflect these assumed geographies, were applied.

Secondary data has been sourced from ecoinvent -a globally recognised life cycle inventory database- to model individual inventory flows. Wherever possible, the most relevant geography has been selected when choosing data. It is understood that the ecoinvent datasets represent technological averages for the given geographies and reflect recent time frames.

3.1.2.5 Allocation procedures

Allocation has been carried out where necessary in accordance with the requirements of ISO 14044. For uranium mining, allocation between the differently mined sources of uranium has been done on a physical basis, based on the global sourcing of uranium by mass. For the enrichment process, 100% of the impacts of the enrichment process have been allocated to the enriched uranium product. For waste treatment only a portion of the offsite radioactive waste facility operation and infrastructure impacts have been allocated to SZB on a physical basis (i.e., by the mass or volume depending on the dataset), according to the flow of the ecoinvent dataset used to represent these facilities and their respective treatment processes. The handling/treatment/transportation of operational waste and residues is included according to the polluter pays principle.

3.1.2.6 Data sources and quality

LCA studies require two kinds of information: data regarding the environmental aspects of the product system such as its material and energy flows; and data regarding these flows’ life cycle impacts. The former has been supplied by EDF specifically for SZB for the core life cycle stages of operation and decommissioning. As EDF was not the owner of SZB at the time of construction in the 1980s, minimal data is available for the construction stage. However, EDF provided two specific values for SZB (concrete and a steel), which it had derived from a reference document from the Proceedings of the Institute of Civil Engineers [4]. From the concrete quantity provided, an extensive range of construction stage flows have been extrapolated from detailed SZC construction data on a per tonne of concrete basis. As SZB is a PWR and SZC is a European Pressurised Reactor (EPR), which is a type of PWR, the data for SZC was considered to be the most applicable data available.

Secondary flow data has been collected from the LCI database ecoinvent, v3.7 cut-off database as implemented in SimaPro v9.1.

Data and values for SZB's operation were based on an 18-month operational reference period of data from SZB, whilst decommissioning data was based on SZB's Baseline Decommissioning Plans (BDP).

Specific data obtained from SZC's potential future fuel fabricator and uranium enricher was used, supplemented with data from fuel fabrication and enrichment ecoinvent datasets to ensure that no 'key' input or output flows are unaccounted for.

Specific data for the UK future GDF derived from the most conservative of the three scenarios currently scoped was also used.

Generic datasets have been used to represent the life cycle stages substages for conversion, milling and mining, downstream infrastructure, and offsite waste treatment, as specific data was not available. Generic data (ecoinvent datasets) was also used to represent all upstream infrastructure.

3.1.2.7 Data assumptions

3.1.2.7.1 Electricity assumptions

For the majority of life cycle stages, which are known to occur in the UK, a national production mix process has been selected from ecoinvent. For upstream processes of mining and milling, conversion, enrichment and fuel fabrication, the most applicable region was selected.

For the decommissioning stage, that is estimated to begin in 2035, it has been considered necessary to make assumptions regarding the electricity type that SZB (or activities associated with SZB) will consume at this point in time. For these, estimates of the future UK electricity grid mix were derived. These mixes were based on BEIS 2019 Updated Energy & Emissions Projections, v1.0 11-12-2020, for Net Zero Lower Demand Projection of electricity generation by source [5] and supplemented with data from the National Grid's Future Energy Scenarios (FES) 2020 Data Workbook data [6]. Full details are given in the LCA report.

3.1.2.7.2 Cut-offs and exclusions

In terms of cut-off and exclusions, the study has used the system boundary detailed in the Electricity PCR as guidance and excluded certain processes in line with that document. These include business travel, commuter travel, R&D activities and downstream electricity usage.

For all four upstream stages (fuel fabrication, enrichment, conversion and mining and milling), infrastructure was included as part of the generic ecoinvent datasets which have been used as a basis for each. For core operation, no known inflows, other than mass enriched boric acid, for which EDF were unable to provide a value, have been excluded. Based on the relative impact that this material had on the SZC LCA, less than <0.1% of the total GWP impact, this can be considered negligible and therefore, the life cycle inventory (LCI) data for core operation can be considered to meet the cut-off criteria detailed in the Electricity PCR. In terms of core infrastructure, limited data (concrete and rebar quantities) was available. Remaining quantities were extrapolated from the data provided by SZC Co for SZC's main site using the two existing construction material quantities for SZB. Whilst some infrastructure for SZB ADs ***may*** have been covered within these two SZB specific values, it should be generally assumed, that only the SZB main site has been included and that ADs are excluded.

3.1.2.7.3 Limitations

It should be noted that as with any LCA and modelling, this study only considers potential impacts and does not reveal actual impacts on the state of the environment. The quality and uncertainties of the results are based on the quality and accuracy of the primary data provided, and also the secondary data and datasets selected, and any assumptions made.

LCA also cannot directly consider future changes to technology or demand although some attempt at representing the influence of future UK electricity grid mix has been made for the decommissioning and GDF stages. However, this has not been undertaken for the construction and operation of SZB. The construction of SZB and much of its operational life has occurred in years prior to 2021, but no 'backdating' of electricity mixes has been undertaken, likewise no forecasting has been applied to the remaining 14 years of operation.

A large limitation for SZB is the lack of site-specific construction data. Data has been extrapolated from SZC but it is important to note that this is only assumptive and therefore this should be taken into consideration when considering the results. There is no way to test how these results would deviate from the those which would have been based on full SZB specific data.

Likewise, for the UK GDF, data for one specific assumed scenario of its future construction is used. While this is the most available data at this point in time, this will undoubtably change as site location and designs for the GDF evolve.

For certain processes (largely those representing the upstream stage for mining and conversion, the core stage for offsite waste repositories and disposal facilities, and for infrastructure and operation of the downstream stage for T&D networks), no specific data was available. Therefore, ecoinvent datasets have been used as proxies.

Additionally, as with all modelling, the estimated impact results are only relative statements which do not indicate the end points of the impact categories, exceeding threshold values, safety margins or risks.

3.2 Life Cycle Inventory Analysis

The LCA model includes a series of life cycle inventories (LCIs), which describe the cradle-to-grave generation of electricity at SZB, excluding the impacts from use of the electricity downstream (i.e., after delivery). Each inventory is interconnected, with mining inventories feeding into conversion, which feeds into enrichment, and so on all the way through the life cycle up to the reference unit of lifetime net electricity generation over the planned 40-year operation of SZB.

Table 3 summarises the processes covered by the inventory of the key stages of the SZB LCA model.

Table 3: Processes included in the key life cycle inventories

Stage	Included processes
Upstream*	Upstream production of materials, fuel and electricity consumption, emissions, production of materials required, infrastructure, wastes, transport of uranium from previous upstream stage.
Core operation	Upstream production of materials required for operation (including radioactive waste packaging), transport of materials and fuel to site, fuel and electricity consumption (including reserve power), water requirements, emissions, transportation of wastes (both radioactive and non-radioactive), treatment and disposal of wastes. Note that for offsite radioactive waste facilities, processes were included to the extent that they are in the ecoinvent datasets used for modelling.
Core infrastructure: construction	Upstream production of materials required for construction of the SZB facilities including reactors and other infrastructure, reinvestment of construction materials, transport of materials to site, fuel and electricity consumption, water consumption, transport of wastes from site, treatment/disposal of wastes generated.
Core infrastructure: decommission	Upstream production of radioactive waste packaging materials, fuel, electricity and water needed for decommissioning, transport of packaging materials to site, transport of wastes (both radioactive and non-radioactive), treatment/disposal of wastes generated.
Downstream	SF_6 switchgear inputs, SF_6 emissions, T&D infrastructure processes or flows related to land use, digging, construction, transformer stations, cables and poles, and waste treatment processes. Maintenance and dismantling of the T&D networks does not appear to be included in the ecoinvent datasets so should be considered to be excluded.

* Note that the processes included were based on those available in the ecoinvent datasets used to represent each stage

The following section discuss these stages in more detail.

3.2.1 Upstream

Upstream processes relate to the production of the nuclear fuel used at SZB. For the purposes of this study, it is assumed that SZB purchases uranium fuel assemblies from Framatome (the fuel assembler), and that enriched uranium sources are from a Urenco enrichment facility in the UK. As the of uranium mining and conversion services to SZB are not confirmed, assumptions of possible suppliers have been made as listed in Table 4.

Table 4: Assumed percentage split and location for the four key upstream fuel stages†

Upstream production	Split by mass	Company	Location
Underground mining, milling	21.4%	Orano/Cameco	Cigar Lake and McClean Mill, Saskatchewan, Canada
In situ leaching (ISL)	61.4%	Orano	Muyunkum and Torkuduk, Kazakhstan
Open pit mining, milling	17.2%	CNNC Rossing Uranium	Rossing, near Swakopmund, Namibia
Mining (total)	**100%**	**See above**	**See above**
Conversion	**100%**	**Orano**	**Pierrelatte & Malvési, France**
Enrichment	**100%**	**Urenco UK**	**Capenhurst, UK**
Fuel fabrication	**100%**	**Framatome**	**Romans-sur-Isère, France**

† Note that as EDF were not able to share the specific companies and locations of SZB's uranium supply chain, the listed companies and specific locations have been used as assumptions for this project.

All upstream data has been linked to the lifetime mass (1,040 tonnes) of enriched uranium needed for 40 years of operation, during which the plant is expected to generate 364,103,833MWh of electricity (net). Table 5 shows the reference flow mass from each upstream stage in relation to the required total life operational enriched uranium.

Table 5: Masses of uranium material related to the total life requirement of enriched uranium

Upstream fuel	Mass (t)
Underground sourced milled uranium*	1,870
ISL sourced uranium	5,108
Open pit sourced milled uranium*	1,503
Converted uranium	8,320
Enriched uranium	1,040
Fuel assemblies (total mass including enriched uranium)	1,534

* Includes a 5% uplift of impacts to account for milling losses as per the milling ecoinvent datasets

Transportation impacts from the uranium being transported between the upstream stages and assumed providers is included.

3.2.2 Core

3.2.2.1 Core operation

In line with the system boundary contained in the Electricity PCR, processes modelled for core operation covered:

- Energy conversion process of the plant
- Maintenance (but not reinvestment of components)
- Reserve power including test operation
- Transportation of waste
- Handling/treatment/deposition of spent nuclear fuel and other radioactive waste
- Handling/treatment/deposition of other operational waste

Current plans assume that SZB will continue to generate electricity for up to 40 years and site-specific data has been supplied by EDF for a representative reference period of 18 months.

The commissioning stage of the plant is the period between construction and operation and is where various components and systems are tested before full service begins. It includes activities such as pipe flushing. As this period occurred decades ago and when SZB was under different ownership, very little data is available for this substage, so a number of assumptions have been applied including that it takes 18 months (which is the same amount of time that the commissioning period of SZC was assumed to take). For this model, commissioning has been assigned to broader the core operation stage.

In relation to operational data for off-site facilities for the treatment/deposition of radioactive and non-radioactive wastes generated during operation of SZB, specific data for most facilities was not available. Therefore, this has been included to the extent that the ecoinvent datasets used to represent these treatments have covered operational impacts.

For the future UK GDF, more specific data (supplied by SZC Co and used for the SZC LCA study) was used to represent its operation, based on data extracted from a generic carbon footprint analysis. Due to the early concept of the GDF, this itself is underpinned by a number of assumptions made by Radioactive Waste Management (RWM) Ltd [7] and following discussions between EDF and RWM.

3.2.2.2 Core infrastructure: construction and decommission

As per the Electricity PCR, processes modelled for core infrastructure covered:

- Reactor building and other infrastructure including digging, foundations, roads etc within the site, and respective construction processes
- Reactor, machinery, cables, tubes and other equipment for the conversion process and reserve power
- Power plant transformer
- Connection to the power network
- Transportation of inputs and outputs
- Facilities for handling of radioactive waste (on site and elsewhere) and facilities on site for handling of waste, residues and wastewater
- Reinvestments of material and components during the estimated technical service life

Minimal construction inventory data for SZB is available to EDF as SZB construction started in 1988 prior to EDF ownership. For this reason, extrapolation of estimates of SZC data has been applied. As data provided for SZC covered all of the above Electricity PCR requirements in terms of construction, asides from some offsite waste facilities, it is likely that the extrapolated data also covers most of the required aspects, albeit by estimates. It should be noted that SZB data did not extrapolate any of the SZC construction data for associated developments (ADs) so this should be considered to be largely excluded. However, these are not explicitly required to be included by the Electricity PCR beyond roads.

In relation to infrastructure data for off-site facilities for the treatment/deposition of radioactive and non-radioactive wastes generated during the operation of SZB, specific data for most facilities was not available. Therefore, this has been included to the extent that the ecoinvent datasets used to represent these treatments have covered construction and deconstruction impacts.

EDF has estimated quantities of key materials, utility consumption, and waste generated during decommissioning from its baseline decommissioning plan (BDC) and anticipated Advanced Gas-Cooled Reactor (AGR) Waste Management Centre (WMC) operation for gap filling.

3.2.3 Downstream

The downstream life cycle stage refers to the distribution of electricity from the site of generation to the downstream electricity users.

Figure 2: Overview of where losses can occur during electricity delivery to the user

The transmission network is a high voltage network which transports electricity from its source of generation (such as from the nuclear power plant ‘gate’) to the distribution network (or to large electrical users directly connected to the transmission network). Losses occur over both networks as well as when stepping up the electricity from its source to the transmission network. These losses and their impacts are covered by the model.

T&D losses effectively mean that more electricity needs to be generated in order to ensure that the customer receives the required amount of electricity. This increased electricity transmitted also infers an uplifting of the impacts associated with the grid itself as it is being ‘used’ more. These losses affect all forms of power generation that are connected to the electricity network.

The Electricity PCR requires that T&D losses be accounted for in the downstream life cycle stage. To model the downstream impacts associated with the nuclear power plant, generic ecoinvent datasets were used, as specific data representing the infrastructure and operation of the UK electricity network was not available to EDF. Therefore, a generic ecoinvent dataset for medium voltage electricity was used, into which the SZB electricity model was fed, and T&D losses applied accordingly as per Table 6.

Table 6: Parameter values modelled to represent T&D losses in the downstream module

Loss type	Loss modelled	Source
Transmission loss	1.7%	National Grid document 2019 [7]
Distribution loss	8%*	National Grid document 2019 [7]
Step up loss	3%	ecoinvent dataset

*The highest value in the range was used for conservatism

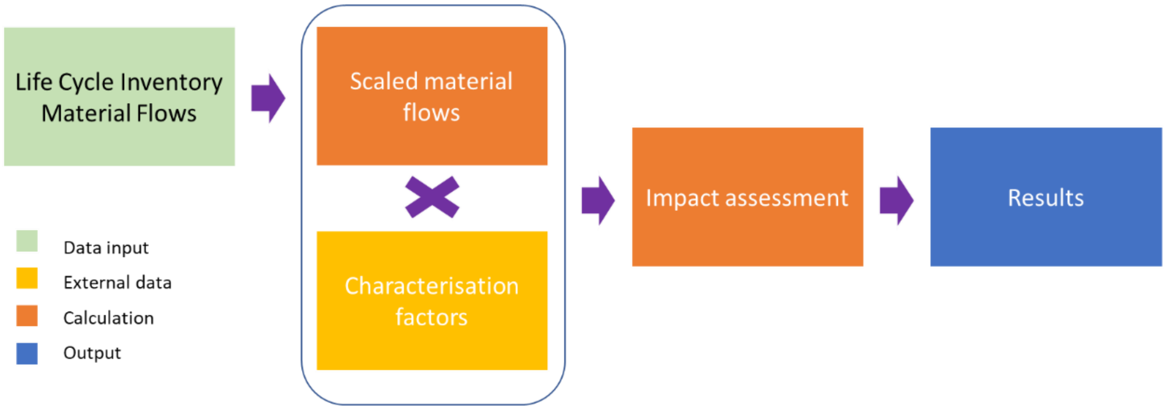
The model representing the generation of electricity at SZB was then fed into this copied dataset.

As mentioned, T&D losses over the grid, will result in a reduction in the quantity of electricity reaching the final user. While 1.12kWh is generated at SZB, these losses mean that the customer ultimately receives 1kWh. The additional upstream and core impacts of generating 1.12kWh versus 1kWh have been assigned to the downstream stage of the model, alongside impacts of the infrastructure and operation of the grid. In order to calculate these impacts, the impacts of generating 1kWh at SZB must first be subtracted from those of delivering 1kWh to the user. This difference will be the downstream impacts related to both the infrastructure and operation of the network ***plus*** impacts from the additional generation by SZB due to losses on the network. Subtracting the infrastructure and operation impacts of the grid will give the T&D loss impacts.

3.3 Life Cycle Impact Assessment

Within the SimaPro® software v9.1, the life cycle impact assessment uses the life cycle inventories to calculate results for each of the assessed environmental indicators. First, each inventory is scaled to deliver the correct amount per functional unit (1kWh of SZB electricity delivered to a medium voltage downstream user). The inventories are built in a cascading hierarchy, where each inventory reads how much ‘primary product’ the next inventory needs, thereby scaling the inventory and related processes accordingly to meet that requirement. Once the inventories are scaled, characterisation factors (which are factors that link process flows with environmental impact) are applied to the scaled material flows. The resulting impact is then summed per life cycle stage. The model flow is illustrated in Figure 3 below.

Figure 3: Model flow diagram



As specified by the PCR, results are reported at a minimum granularity of life cycle stage (i.e., upstream, core, downstream).

3.3.1 Environmental impacts

The results of the SZB LCA are shown below in terms of the core environmental impacts as described in Table 7. Results are reported per life cycle stage in terms of the indicated unit per unit of 1kWh generated and the functional unit of 1kWh delivered to a hypothetical customer.

Results have been analysed further in section 3.4 with a focus on carbon.

3.3.2 Resource use

The input of resources for the LCA, per functional unit, are shown in Table 8. This data was extracted from the results inventory.

Note that only data from secondary sources was available for non-SZB controlled stages, for which details of reuse and recycled material were not known. Therefore, it was not possible to disaggregate raw material secondary inputs. In order give a rough overview, the top tier values of steel and aluminium inputs were extracted from these non-SZB specific stages. Assumptions of the average recycled content of the steel and aluminium, as based on the underpinning ecoinvent datasets, were applied to give an approximate value for recycled content. This was only applied for steels and aluminium. Offsite infrastructure was not included and hence no value is declared for total generated so as to not give a false impression. Consequently, no value has been declared for downstream T&D losses. For downstream infrastructure, Table 8 shows no values for secondary resource inputs. This is not necessarily because no secondary materials are used in the construction and operation of the grid, but because no steel or aluminium datasets were displayed in the top tier datasets.

These estimates have not been further analysed as they are a facet of reporting the inventory as opposed to an actual calculation of impacts.

3.3.3 Waste and material outputs

The waste and material outputs for the LCA, per functional unit are shown in Table 9.

In order to sum the materials or wastes going to reuse or recycling for the SZB core stages, a custom waste flow was made. This allowed for custom created datasets in the model to report recycled/reused material inputs in the SimaPro resource inventory list. However, due to the use of secondary data for the non-SZB stages, it has not been possible to provide a suitable estimate for materials or wastes to reuse or recycling for the other stages. These have therefore not been declared and will be described as ‘ND’ in the waste outputs table.

These estimates have not been further analysed as they are a facet of reporting the inventory as opposed to an actual calculation of impacts.

Table 7: Key environmental indicator results per functional unit of 1kWh of generated and delivered electricity

Environmental indicator	Upstream	Core construction	Core operation	Core decommission	**Total generated**	Downstream T&D losses	Downstream other	**Total delivered**
GWP total (g CO$_2$ eq.)	3.48	2.76	2.33	1.58	**10.14**	1.26	4.73	**16.13**
GWP total (kg CO$_2$ eq.)	3.48E-03	2.76E-03	2.33E-03	1.58E-03	**1.01E-02**	1.26E-03	4.73E-03	**1.61E-02**
GWP fossil (kg CO$_2$ eq.)	3.47E-03	2.71E-03	2.32E-03	1.56E-03	**1.01E-02**	1.25E-03	4.72E-03	**1.60E-02**
GWP biogenic (kg CO$_2$ eq.)	4.80E-06	4.70E-05	6.75E-06	3.86E-06	**6.25E-05**	7.78E-06	2.94E-06	**7.32E-05**
GWP luluc (kg CO$_2$ eq.)	1.66E-06	3.00E-06	1.84E-06	1.10E-05	**1.75E-05**	2.18E-06	2.58E-06	**2.23E-05**
AP (kg SO$_2$ eq.)	3.21E-05	2.06E-05	1.12E-05	4.65E-06	**6.86E-05**	8.54E-06	2.68E-05	**1.04E-04**
EP (kg PO$_4^{3-}$ eq.)	4.51E-05	6.61E-06	3.59E-06	2.03E-06	**5.73E-05**	7.14E-06	1.27E-05	**7.72E-05**
POCP (kg NMVOC eq.)	3.53E-05	1.68E-05	1.13E-05	4.03E-06	**6.74E-05**	8.40E-06	9.47E-06	**8.53E-05**
Particulate matter emissions (kg PM2.5 eq.)	1.65E-05	8.83E-06	3.96E-06	1.93E-06	**3.12E-05**	3.88E-06	8.54E-06	**4.36E-05**
WSF (m^3 world eq. deprived)	2.51E-03	3.69E-04	6.89E-04	2.85E-04	**3.86E-03**	4.80E-04	4.47E-04	**4.78E-03**

Table 8: Inventory of resource inputs per functional unit of 1kWh of generated and delivered electricity

Resource use per stage	Unit/kWh	Upstream	Core: operation	Core: infra	Total generated	Downstream: T&D	Downstream: other	Total delivered
Non-renewable material resources								
Aluminium	g	4.55E-03	1.16E-03	6.41E-03	1.21E-02	1.51E-03	3.31E-02	4.68E-02
Clay, bentonite	g	9.19E-04	7.45E-04	5.77E-01	5.79E-01	7.21E-02	2.06E-03	6.53E-01
Basalt	g	2.01E-04	1.05E-04	3.94E-04	7.00E-04	8.71E-05	3.66E-04	1.15E-03
Chromium	g	5.31E-03	1.23E-02	2.41E-02	4.17E-02	5.20E-03	1.59E-03	4.85E-02
Copper	g	2.15E-03	7.27E-04	1.33E-02	1.62E-02	2.01E-03	3.99E-02	5.81E-02
Dolomite	g	1.11E-03	7.30E-04	3.87E-03	5.71E-03	7.11E-04	2.32E-03	8.74E-03
Feldspar	g	7.15E-10	3.15E-10	2.29E-07	2.30E-07	2.86E-08	8.20E-10	2.59E-07
Fluorspar	g	2.96E-02	3.87E-04	1.15E-03	3.12E-02	3.88E-03	1.33E-03	3.64E-02
Gravel	g	5.86E-01	4.84E-01	6.02E+00	7.09E+00	8.82E-01	2.44E+00	1.04E+01
Sand	g	8.59E-02	1.50E-02	6.86E-02	1.70E-01	2.11E-02	5.85E-01	7.76E-01
Rock	g	1.58E-02	5.08E-03	4.78E-01	4.99E-01	6.21E-02	4.26E-02	6.03E-01
Gypsum	g	3.77E-03	1.19E-03	1.49E-02	1.99E-02	2.47E-03	1.23E-02	3.47E-02
Iron	g	7.32E-02	7.82E-02	3.19E-01	4.70E-01	5.85E-02	1.79E-01	7.07E-01
Lead	g	4.61E-04	2.38E-05	2.05E-04	6.90E-04	8.59E-05	8.04E-04	1.58E-03
Calcite	g	1.52E-01	7.85E-02	7.68E-01	9.99E-01	1.24E-01	3.85E-01	1.51E+00
Magnesium	g	3.84E-04	1.88E-05	1.58E-04	5.60E-04	6.97E-05	1.18E-03	1.81E-03
Manganese	g	5.64E-04	2.62E-04	7.16E-04	1.54E-03	1.92E-04	1.13E-04	1.85E-03
Nickel	g	2.48E-03	7.06E-03	1.43E-02	2.38E-02	2.96E-03	1.34E-03	2.81E-02

Resource use per stage	Unit/kWh	Upstream	Core: operation	Core: infra	Total generated	Downstream: T&D	Downstream: other	Total delivered
Olivine	g	9.23E-09	8.11E-07	3.42E-08	8.54E-07	1.06E-07	1.33E-08	9.74E-07
Sodium chloride	g	4.24E-02	1.50E-01	7.23E-02	2.65E-01	3.30E-02	8.05E-03	3.06E-01
Soil	g	0.00E+00	0.00E+00	3.45E+00	3.45E+00	4.30E-01	0.00E+00	3.88E+00
Sulphur	g	2.56E-05	2.35E-05	3.48E-05	8.39E-05	1.05E-05	3.94E-05	1.34E-04
Tin	g	1.93E-06	1.30E-06	5.10E-06	8.33E-06	1.04E-06	1.31E-06	1.07E-05
Titanium	g	3.38E-04	7.18E-05	4.32E-04	8.41E-04	1.05E-04	3.14E-04	1.26E-03
Zinc	g	2.08E-03	1.05E-04	8.88E-04	3.07E-03	3.82E-04	3.33E-03	6.78E-03
Zirconium	g	4.94E-05	1.19E-05	6.86E-05	1.30E-04	1.62E-05	5.01E-05	1.96E-04
Renewable material resources								
Wood	g	8.70E-11	1.38E-10	2.62E-10	4.87E-10	6.06E-11	4.58E-11	5.93E-10
Non-renewable energy resources								
Crude oil	g	5.32E-01	5.32E-01	3.29E-01	6.14E-01	1.47E+00	1.84E-01	1.06E-01
Hard coal	g	2.94E-01	2.94E-01	3.28E-01	5.61E-01	1.18E+00	1.47E-01	3.60E-01
Lignite	g	6.41E-02	6.41E-02	6.37E-02	8.50E-02	2.13E-01	2.65E-02	4.85E-02
Natural gas	g	3.90E-01	3.90E-01	4.24E-01	3.30E-01	1.14E+00	1.42E-01	4.63E-02
Uranium in ore	g	2.81E-02	2.02E-05	4.42E-05	2.82E-02	3.51E-03	1.13E-06	3.17E-02
Uranium in ore, primary energy	MJ	1.57E-02	1.13E-05	2.47E-05	1.57E-02	1.96E-03	6.30E-07	1.77E-02
Peat	g	1.02E-03	1.81E-03	1.56E-03	4.40E-03	5.47E-04	1.24E-04	5.07E-03
Renewable energy resources								
Energy, in biomass	MJ	1.71E-03	2.73E-03	5.15E-03	9.59E-03	1.19E-03	9.50E-04	1.17E-02

Resource use per stage	Unit/kWh	Upstream	Core: operation	Core: infra	Total generated	Downstream: T&D	Downstream: other	Total delivered
Energy, potential (in hydropower reservoir), converted	MJ	2.90E-03	1.07E-03	3.36E-03	7.33E-03	9.13E-04	1.26E-03	9.51E-03
Energy, solar, converted	MJ	7.49E-07	4.23E-06	1.71E-03	1.72E-03	2.14E-04	4.50E-07	1.93E-03
Energy, kinetic (in wind), converted	MJ	6.89E-04	1.25E-03	1.62E-02	1.82E-02	2.26E-03	5.17E-05	2.05E-02
Water resources								
Ground water	m3	1.67E-06	1.05E-06	8.36E-06	1.11E-05	1.38E-06	4.93E-06	1.74E-05
River water	m3	1.52E-04	4.15E-05	3.68E-05	2.30E-04	2.87E-05	9.38E-06	2.69E-04
Sea/salt water	m3	6.89E-07	3.42E-07	7.21E-07	1.75E-06	2.18E-07	1.27E-06	3.24E-06
Water, specified natural origin	m3	4.83E-08	3.34E-08	2.35E-06	2.44E-06	3.03E-07	8.84E-08	2.83E-06
Water, unspecified natural origin	m3	2.23E-02	1.08E-02	3.84E-02	7.15E-02	8.91E-03	1.04E-02	9.09E-02
Use of secondary material								
Aluminium	g	2.66E-03	0	4.87E-03	ND	ND	0	ND
Steel	g	1.26E-03	1.36E-02	3.64E-01	ND	ND	0	ND

Table 9: Inventory of waste and material outputs per functional unit of 1kWh of generated and delivered electricity

Waste and material outputs	Unit/kWh	Upstream	Core operation	Core infrastructure	Total generated	Downstream T&D	Downstream other	Total delivered
All hazardous (non-radioactive) wastes disposed	g	1.18E-07	4.76E-08	4.10E-07	5.76E-07	7.17E-08	9.88E-08	7.46E-07
Total radioactive wastes generated	g	ND	1.00E-02	6.76E-02	ND	ND	ND	ND
HLW generated	g	ND	0	0	ND	ND	ND	ND
ILW and LLW generated	g	ND	6.53E-03	6.76E-02	ND	ND	ND	ND
Depleted uranium, spent UF_6	g	ND	2.86E-03	ND	ND	ND	ND	ND
Total volume of repository needed for radioactive wastes as disposed, including SF	m^3	2.01E-08	7.78E-09	1.19E-07	1.47E-07	1.83E-08	1.62E-11	1.65E-07
Volume of repository needed for radioactive wastes as disposed, HLW*/ILW	m^3	6.83E-12	4.32E-09	3.76E-08	4.20E-08	5.22E-09	5.00E-13	4.72E-08
Volume of repository needed for radioactive wastes as disposed, LLW	m^3	2.01E-08	3.47E-09	8.15E-08	1.05E-07	1.31E-08	1.57E-11	1.18E-07
Waste (radioactive and non-radioactive) to recycling	g	ND	1.54E-01	3.93E-01	ND	ND	ND	ND
Materials for reuse (only relevant to SZB non-radioactive waste)	g	ND	0.00E+00	3.35E+00	ND	ND	ND	ND
Inert waste disposed of	g	2.13E-04	1.54E-04	8.90E-03	9.27E-03	1.15E-03	6.79E-03	1.72E-02
Other non-hazardous (non-radioactive) waste disposed of	g	2.62E-04	3.10E-04	7.89E-04	1.36E-03	1.70E-04	1.91E-04	1.72E-03

* Note that SZB does not generate HLW

It should be noted that for core operation, for waste to recycling and materials for reuse, results relate purely to the SZB core operation as it was not possible to assess this for the operation of offsite core facilities as largely generic datasets were used.

3.4 Life Cycle Interpretation

This section presents a high-level summary of the assessed environmental potential impacts. Note that a more detailed analysis is given in terms of GWP in a later section. Throughout the analysis, the colours indicate the core stages: yellow is upstream, green is core and blue is downstream.

3.4.1 Global Warming Potential (GWP) by LC stage

GWP-total is made up of three sub-indicators. Table 10 shows the contribution by life cycle (LC) stage to the total GWP-total value and to each of the GWP sub-indicators, per delivered kWh. The percentages have been RAG (Red-Amber-Green) rated in order to easily identify the highest contributing stage for each of the sub-indicators.

While each of the GWP sub-indicators contributes to GWP-total, they consider different sources. Therefore, while GWP-total may show a hotspot in one life cycle stage there will not necessarily be a matching hotspot within each of the sub-indicators in Table 10.

Table 10: Contribution to GWP indicators by LC stage to the value per delivered kWh

Environmental indicator	Upstream	Core construction	Core operation	Core decommission	Downstream T&D losses	Downstream other
GWP total	22%	17%	14%	10%	8%	29%
GWP fossil	22%	17%	15%	10%	8%	30%
GWP biogenic	0%	64%	9%	5%	0%	4%
GWP luluc	7%	13%	8%	49%	10%	12%

The percentage contributions from each LC stage for the GWP total and the GWP fossil indicators are extremely similar as are their absolute results shown earlier in Table 7. This is because over 98% of the GWP-total values for all SZB electricity life cycle stages are driven by the GWP-fossil impacts, from the combustion of fossil fuels during upstream energy usage in the production of materials for example.

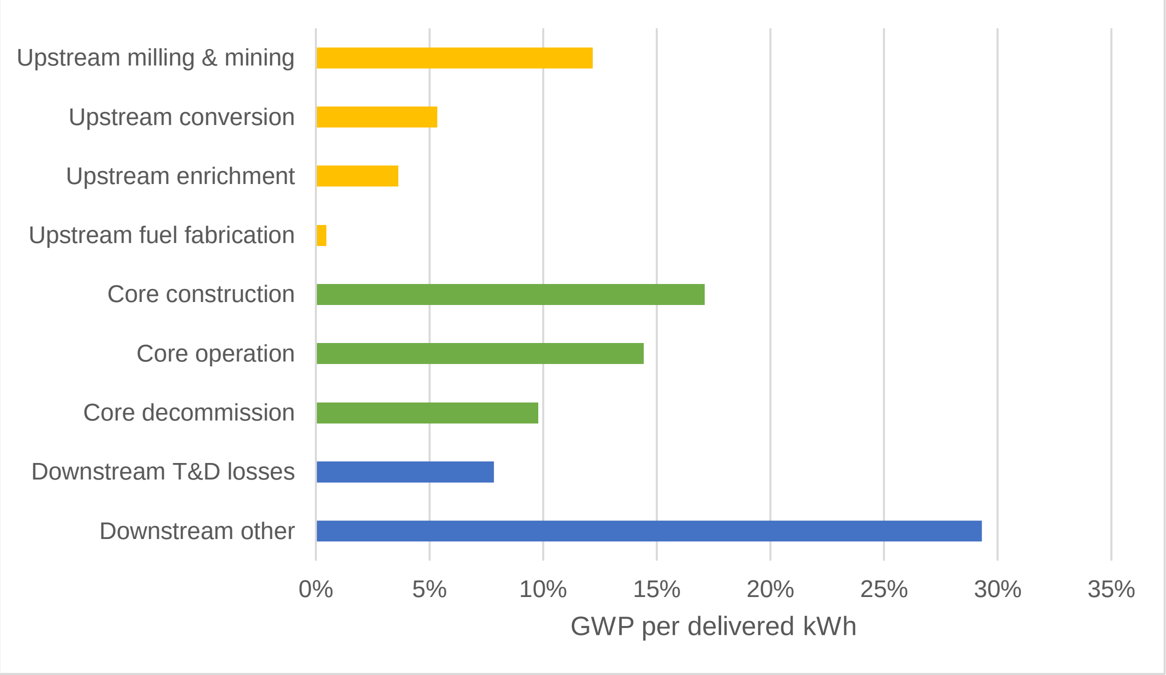
Table 10 shows that for the GWP-fossil results, the highest contributing stage is downstream other, followed by upstream, core construction and core operation. The reasons for this will be covered later in this section and in later sections by focusing on GWP-total. It is important to note that the hotspots for GWP-fossil largely align with the hotspots for GWP-total. Generally speaking, this is largely because the contributing sources for GWP-fossil can be found throughout the supply chain, connected with the combustion of fossil fuels in transport, material production, material/waste processing, as well as from the decomposition from certain heavily used materials, such as limestone (for cement production). Conversely, the contributing sources for GWP-biogenic and GWP-luluc, tend to be clustered around specific activities that are not as prevalent at each life cycle stage (in general).

For the GWP-biogenic indicator results, at 64%, the core construction stage is overwhelmingly the largest contributor (although this is only 1.7% of the GWP-total value for this stage). The majority of this, 99%, arises from fugitive biogenic methane emissions associated with the treatment of construction stage waste types sent to landfill, in particular from anaerobic decomposition of biodegradable waste fractions. GWP-biogenic results for the other stages are much lower contributors, with contributions of less than 0.05% coming from the upstream and the downstream T&D loss stages. In terms of the GWP-total value for each of these stages, the contribution from the GWP-biogenic related emissions, is less than 1%. This is because key sources, such as methane from biogas combustion and decomposition of biogenic materials, are less prevalent in these life cycle stages.

For the GWP-luluc indicator results, almost half of the total emissions per delivered kWh arise from the decommissioning stage although it should be noted that this contributes only 0.7% of the GWP-total value for this stage. 94% of this GWP-luluc value is associated with the electricity dataset applied, which represents the potential GB grid mix in 2035. More specifically, the emission sources are associated with the hydroelectricity portion of the grid mix used in the decommissioning LC stage, which is higher than the portion in that used to represent the operational stage reference period. GHG emissions generated by changing the use of the land to facilitate pumped storage hydroelectric infrastructure, are responsible for these GWP-luluc emissions.

The rest of the analysis on GWP in this document refers to the GWP-total results as opposed to any of the three GWP sub-indicator results. GWP-total is of most interest to EDF and hence this level of analysis was considered sufficient for the purposes of this LCA. It is important to note that the results per the GWP sub-indicators should not be communicated without context Figure 4 below therefore shows how each LC stage contributes to the total GWP-total value associated with generating and delivering 1kWh of SZB electricity to a customer.

Figure 4: Contribution by LC stage to total GWP value per delivered kWh



The collective downstream stage is responsible for 37% of the total GWP-total value and 29% arises from the substage ‘downstream other’. This element of the downstream stage encompasses both the infrastructure and operational requirements of the grid itself. Emission leakages of SF_6 insulation (a powerful greenhouse gas) is the largest contributor within 'downstream other'. SF_6 emissions in the ‘downstream other’ stage area responsible for 98% of all the SF_6 emissions and over 99% of the downstream SF_6 emissions. They also account for one third of all downstream GWP-total related emissions.

Some N_2O emissions may also arise due to ionisation of air due to proximity to electromagnetic fields and high voltage lines. These values are taken from the generic ecoinvent datasets used to model the downstream impacts.

The remaining third of the total downstream GWP value comes from CO_2 emissions from additional generation required to counteract T&D losses.

After the downstream stage, the next two highest contributing stages are the construction of core infrastructure, and the core operation of the plant. These are responsible for 17% and ~14% of the total GWP-total value per delivered 1kWh respectively.

For construction of core infrastructure, the largest drivers are the CO_2 fossil emissions from upstream manufacture of the required raw materials (41% of the GWP-total value for this stage). SZB construction raw material associated emissions cumulatively contribute approximately 7% of the total GWP-total value over all life cycle stages per delivered kWh, and 11% of the total GWP-total value per generated kWh. The number one contributor to these SZB construction material GWP impacts is steel (56%) with concrete being the second highest contributor (18%).

CO_2 fossil emissions associated with construction diesel combustion and electricity consumption required for constructing SZB are the second and third highest drivers, together contributing 18% and 11% of the GWP-total value of the core construction stage. This equates to 8% and 5% of the total GWP value per generated kWh and per delivered kWh, respectively.

In terms of core operation, 54% of the total core operation GWP value come from electricity and diesel consumption, with a further 29% associated with the materials needed for operation and an additional 13% associated with the disposal treatment of operational radioactive wastes.

Upstream milling and mining of yellowcake from which uranium is sourced is the next largest impact, contributing 12% and 19% of the total GWP-total value per delivered and generated kWh, respectively. 93% of the milling & mining contributions come from CO_2 fossil emissions, mostly linked to the energy consumption of these processes, in particular diesel combustion emissions.

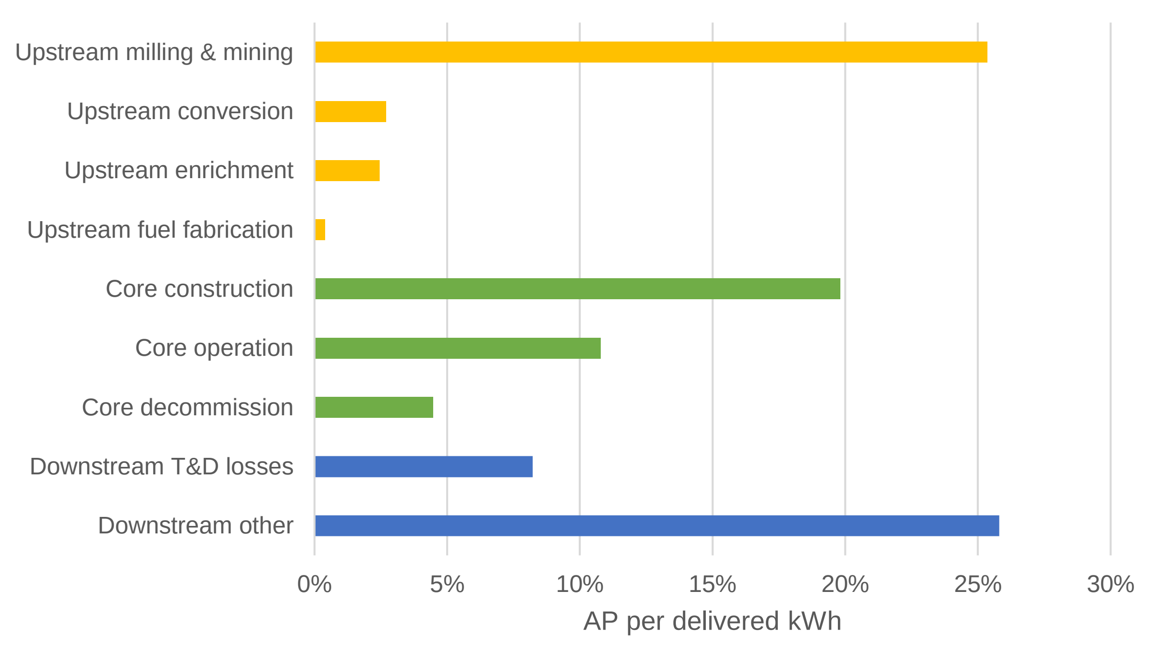
3.4.2 Acidification Potential (AP) by LC stage

This indicator takes into the account acidic gases that react with water in the atmosphere to form “acid rain”, which can cause ecosystem degradation. In terms of AP, sulphur dioxide gas emissions are responsible for just under half (48%) of the total value per delivered kWh and 40% of the total value per generated kWh, with a further 45% and 56% arising from emissions of nitrogen oxides, respectively. Hydrogen sulphide emissions to water are responsible for 3% and 1.5% of the total AP value per delivered and per generated kWh, respectively.

Figure 5 indicates that contributing just under 26% of the total AP value per delivered kWh, the ‘downstream other’ stage is the highest contributing substage. Much (73%) of the total value for ‘downstream other’ is from sulphur dioxide to air emissions for example those linked to grid infrastructure and related materials.

At a similar level of contribution, (25% of the total delivered kWh AP value) the upstream milling & mining stage is the second largest contributing stage with the top contributing emissions being nitrogen dioxide (68% of milling & mining AP), followed by sulphur dioxide (30% of milling & mining AP). These emissions are linked largely to the diesel combustion emissions that occur during mining.

Figure 5: Contribution by LC stage to total AP value per delivered kWh



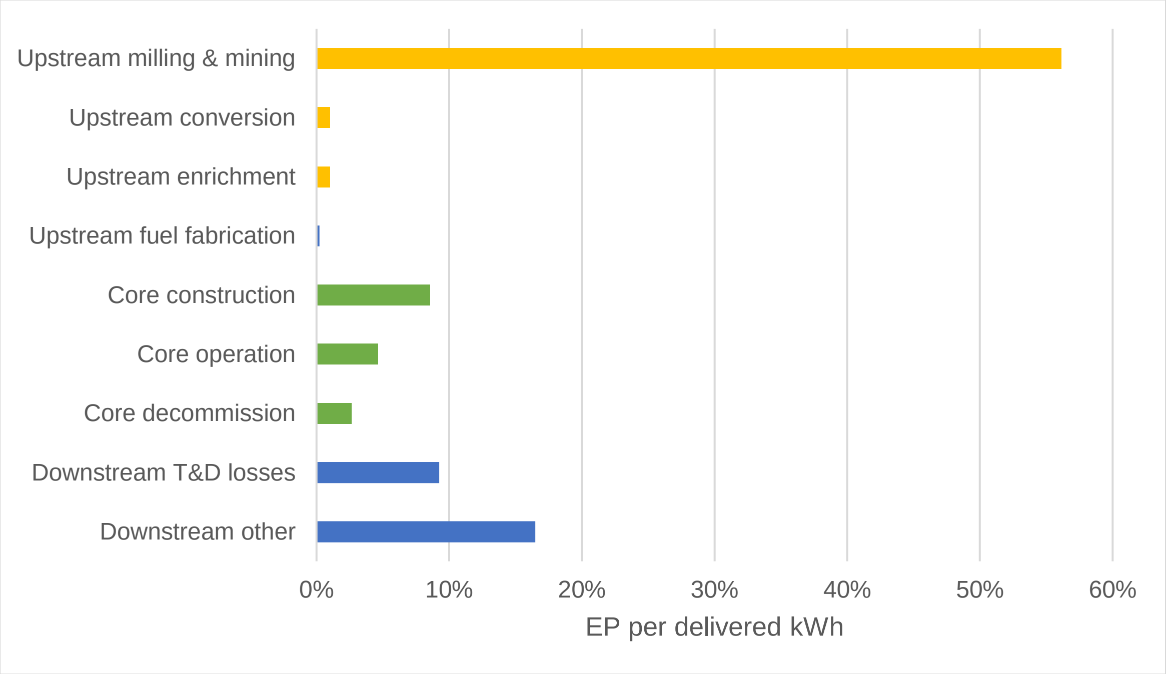
In terms of the core stages, construction of core infrastructure is responsible for 20% of the AP value per kWh delivered and 30% of the AP value per kWh generated. This is due to a combination of different emissions, including the upstream sulphur dioxide producing impacts of processing the construction materials required, particularly from copper wiring/cabling (or more specifically from production of explosives required for copper ore blasting). The copper wiring required for SZB infrastructure is responsible for 30% of the total AP value per kWh generated for the construction LC stage. Also, from nitrogen dioxides released during construction diesel combustion which make up most of the 17% of the total AP value (for the construction stage).

3.4.3 Eutrophication Potential (EP) by LC stage

Eutrophication is a reduction in water quality that can have detrimental effect on the local ecosystem. It is caused by an uncontrolled increase in nutrients such as phosphate and nitrogen, and of organic matter. In terms of EP relating to the generation and delivery of 1kWh from SZB, 49% of the substances that contribute to the total are nitrates and 34% are phosphates. In terms of the total EP value per generated kWh, these values are 58% and 26%. Nitrogen containing oxides contribute 14% to the total delivered kWh EP value and 12% to the total generated kWh EP value, with COD (chemical oxygen demand) and other nitrogen and phosphate containing chemical species responsible for the remainder.

Figure 6 demonstrates that 56% of the total EP value per delivered kWh comes from the upstream milling & mining stage. This equates to 76% of the total EP value per generated kWh. 16.5% of the total per delivered kWh comes from the ‘downstream other’.

Figure 6: Contribution by LC stage to total EP value per delivered kWh



For milling & mining, 84% of EP contributions are generated by nitrate emissions to groundwater which mainly arise within the modelled in-situ uranium leaching process as well as by nitrate emissions to air due to diesel combustion during this same process.

Phosphate emissions by the transmission network infrastructure drive the contribution from the ‘downstream other’ stage. These emissions mainly arise from the copper used, and are linked to the treatment of sulfidic tailings generated during extraction of the copper.

By comparison, the core stages cumulatively contribute almost 16% to the delivered per kWh EP value and 21% to the generated per kWh EP value. 54% of the total core stage EP value is from construction, largely related to upstream material manufacture of SZB construction materials (34.5% of the core stage EP value). The majority of the remainder for the core stage comes from operation (29% of all core stages) and is associated with electricity usage (24% of core operation), diesel usage (22% of core operation) and materials (21% of core operation). The decommissioning stage contributes 16.6% of the total EP value across all the core stages.

3.4.4 Photochemical Ozone Creation Potential (POCP) by LC stage

This indicator quantifies the ability of certain substances to take part in the creation of photochemical oxidants, primarily ground level ozone. These photochemical oxidants decrease air quality with negative effects on animals and the environment.

For the delivered kWh as modelled for SZB, 79% of these substances are nitrogen oxides, 12% are non-methane volatile organic compounds (NMVOCs) with the remainder being a mix of various sulphurous oxides, carbon monoxide, and hexane. In terms of the generated kWh, nitrogen oxides and NMVOCs contribute 81% and just under 12% of the total AP value.

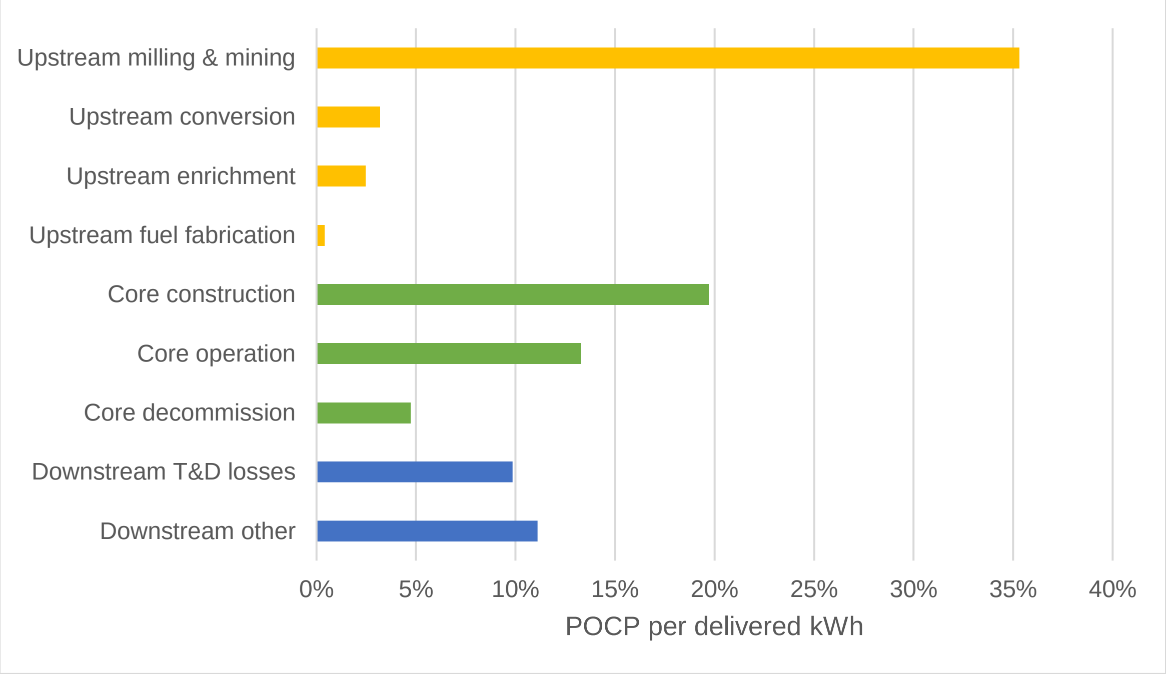
Figure 7 indicates that upstream milling & mining of uranium is responsible for the largest portion of the total POCP value per delivered kWh, contributing 35%. This equates to 45% of the total POCP value per generated kWh. The construction of core infrastructure is responsible for almost 20% (or 25% in terms of per generated kWh) with ‘downstream other’ contributing a further 11% to the total POCP value per delivered kWh.

The majority (67%) of the milling & mining POCP impacts are associated with the in-situ leaching of uranium dataset, more specifically, from nitrogen oxides and NMVOCs emitted during production and combustion of the diesel needed for the leaching process.

Emissions from the combustion of diesel required for constructing, operation and decommissioning SZB is the largest single contributor (40%) to the core stage POCP allocation. Half of this value comes from operational stage diesel, 44% is from onsite construction diesel requirements, with the remainder from decommissioning. The second largest contributor to the core stage for the POCP indicator, 28%, are the embedded emissions of the SZB construction materials.

Infrastructure material related emissions in 'downstream other' are responsible for most of the downstream stage, with T&D losses contributing a slightly lower percentage.

Figure 7: Contribution by LC stage to total POCP value per delivered kWh



3.4.5 Particulate matter by LC stage

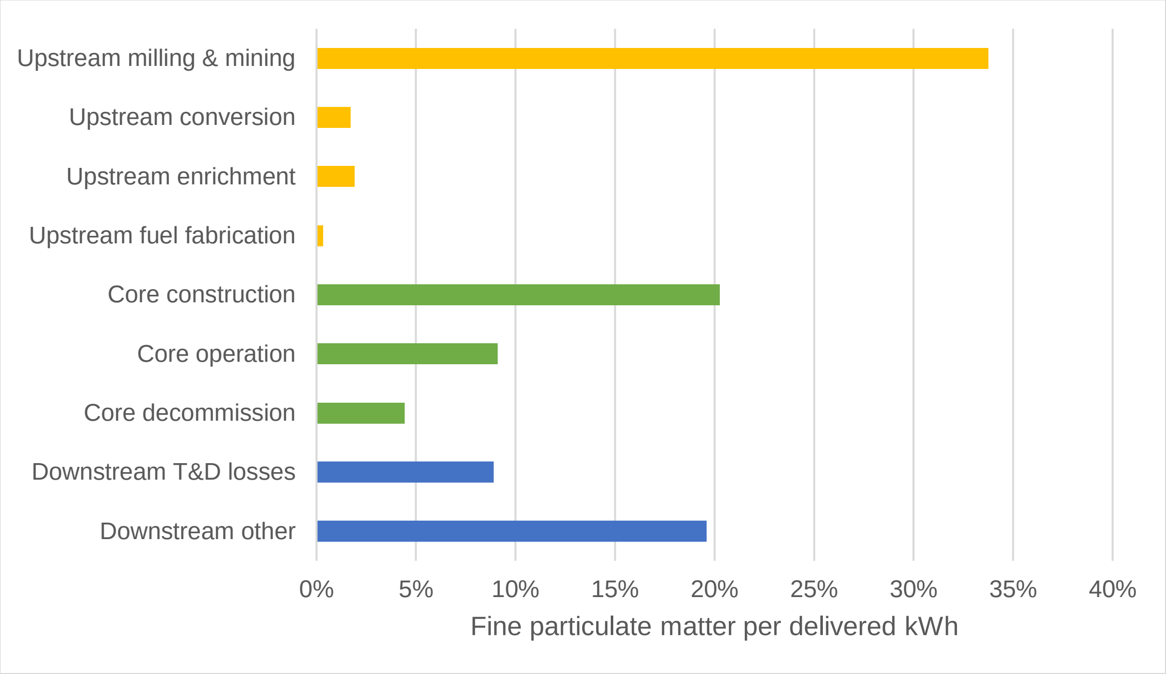
Particulate matter is a type of pollution formed from a mixture of solid particles and liquid droplets in the air. Fine particulates are a particular issue due to their 'inhalability' and the method (ReCiPe 2006 mid-point) used to calculate particulate matter, quantities such emissions in terms of particles of sizes smaller than 2.5 microns, PM2.5 equivalents.

Fine particulates smaller than 2.5 microns are responsible for 48% of the total particulate matter value, with a further 35% coming from sulphur dioxide particles and 16% from nitrogen oxides. The rest of the total is from other sulphur and nitrogen containing compounds. Note that sulphur oxide compounds can react with other compounds in the atmosphere to form small particulates which contribute to particulate matter.

Figure 8 indicates that the upstream uranium milling & mining stage, the 'downstream other' stage and the core construction stage, are collectively responsible for the majority of the total value. These stages contribute 34%, 19.5% and 20% of the total particulate matter value per delivered kWh, respectively. This translates to 47% and 28% in terms of generated kWh for the milling & mining stage, and for the core construction stage. (As the generated kWh value only covers impacts up until the electricity is ready to be transferred to the grid, no downstream impacts are applicable.)

The uranium milling & mining generates dusts and PM2.5 via opencast extraction, and diesel combustion required for all three modelled mining types generates nitrogen and sulphur oxides. In total diesel combustion at the milling and mining stage is responsible for ~40% of the total milling & mining PM2.5 value with the treatment of tailings responsible for ~43% of the total PM2.5 value. Electricity grid infrastructure and its construction generates a range of particulate material, in particular sulphur dioxide which contributes 66% of the 'downstream other' total particulate matter value. In terms of the core construction stage, particulates associated with upstream extraction and manufacturing of construction materials, and particulates from diesel consumption are the key drivers.

Figure 8: Contribution by LC stage to total particulate matter value per delivered kWh

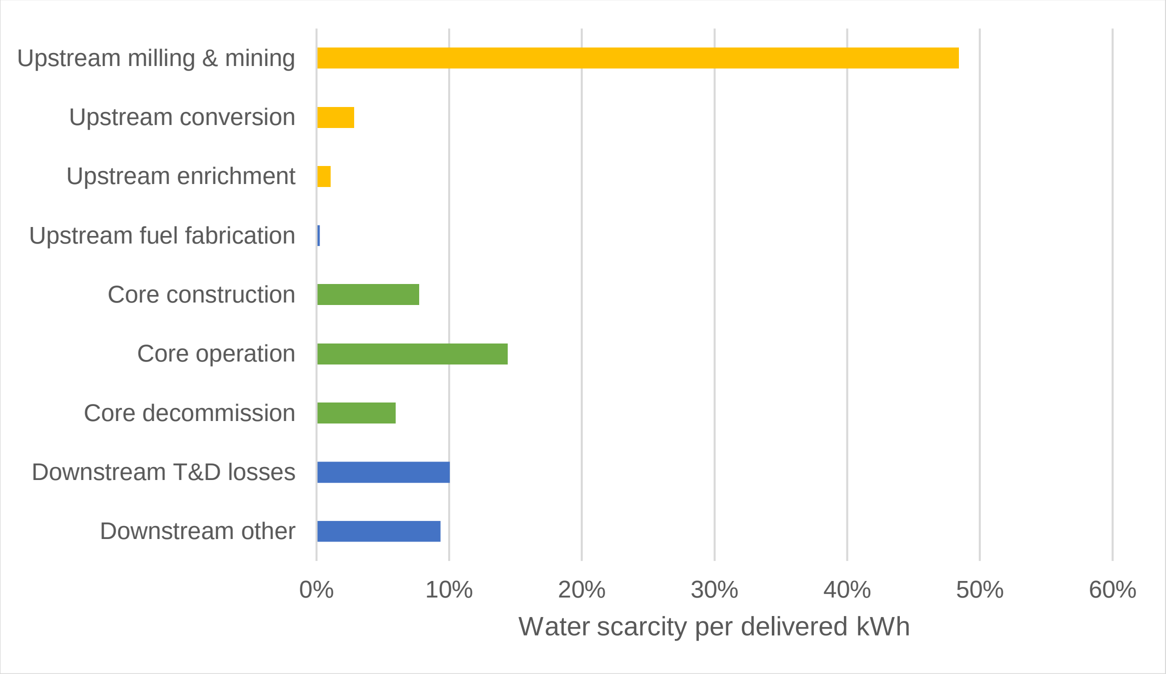


3.4.6 Water scarcity by LC stage

The AWARE method [8] reports in terms of potential water deprivation to the ecosystem and humans. It considers many variables including geography of region where water is extracted and agricultural water use. The higher the number, the higher the potential water deprivation or scarcity.

Figure 9 indicates that the stage with the highest potential for water scarcity is the upstream uranium milling & mining stage. This stage is responsible for 48% of the total AWARE value. Due to the complexity of the method, and numerous flows of water within the model, it is difficult to establish the exact reasons for the values generated. However, the higher potential of the milling & mining may be associated with the fact that the mines are in locations where there is already higher stress on water resources. The volume of freshwater usage embedded in each stage also has influence.

Figure 9: Contribution by LC stage to total water scarcity value per delivered kWh



3.4.7 Sensitivity analysis

As seen in the previous section, after the upstream stage (which is not under the direct management of EDF which therefore makes it harder to obtain more data on for future LCA iterations), the core construction stage is the highest contributor per generated kWh for the majority of the environmental indicators assessed and the highest contributor in terms of the core sub-stages for all categories except for water scarcity.

Construction stage data for SZB was based on an extrapolation of SZC data, on a per tonne of concrete basis. Construction data for SZC was apportioned to the tonnage of SZC concrete and then this was applied to the total tonnage of SZB concrete to prorate values to the other materials. This SZB concrete tonnage was based on a concrete volume which EDF supplied as SZB specific data. In the lack of other information, a concrete density of 2,370kg/m^3 to reflect normal concrete was applied to convert the SZB specific volume into mass. However, if the volume of SZB concrete provided was for high density nuclear concrete, then this would generate a different mass of SZB concrete, and hence all the construction values which hinge off this value by extrapolation would be different. As decommissioning non-radioactive wastes are also based on construction material inputs, this will also change, as will related transport impacts.

A sensitivity analysis was carried out to see how sensitive the overall results would be to increases in construction data values using a density reflective of high-density nuclear concrete as opposed to normal concrete. The density used to convert the SZB specific concrete volume to tonnage is 3,800kg/m^3. This value was supplied in the separate LCA project for HPC and was informed by site contractors.

The use of the higher density concrete value within the calculation of the SZB concrete and other construction material processes, results in an increase in the results for all the core environmental impact categories for the core construction, core decommissioning, and downstream T&D losses stages. Therefore, the generated and delivered values increase accordingly.

They increase respectively from 10.14g to 11.92g CO_2 eq. per generated kWh, and from 16.13g to 18.13g CO_2 eq. per delivered kWh. These are increases of are 18% and 12% respectively. In terms of increases within the stages, the largest increase of 45% occurs in the core construction stage. Increases are also observed in the decommissioning stage (as concrete is required to package wastes) and the downstream T&D loss stage. This latter increase is because T&D covers compensatory generation needed to balance out losses of electricity lost during T&D. Therefore, is it essentially a fraction of the upstream and core impact, hence is affected in the concrete sensitivity. Overall, the increases per generated and per delivered kWh are relatively large changes showing that the model and results, are strongly sensitive to the change of concrete density applied. Therefore, it important to not take the results as absolute values but to consider the potential range they cover. In reality, the density of the concrete probably ranges across the different components of the site, so the actual results could be considered to sit somewhere between those generated for the baseline and this sensitivity scenario.

3.4.8 Global Warming Potential (GWP) focus

The potential carbon impacts are of most interest to EDF, so this section explores the GWP results further. It looks specifically at GWP-total values.

3.4.8.1 Global Warming Potential (GWP) absolute values

The lifetime impact of generating SZB's electricity is calculated to be 3,693,213t CO_2 eq. This can be seen in Table 11 below. Of this, the core stages, which are the LC stages that EDF has most control over, are responsible for 2,425,855t CO_2 eq.

Table 11: Total lifetime GWP values of SZB

Environmental impact	GWP (t CO_2 eq.)
Upstream	1,267,358
Core construction	1,004,214
Core operation	846,799
Core decommission	574,842
Total generated	**3,693,213**
Downstream T&D losses	459,903
Downstream other	1,721,461
Total delivered	**5,874,577**

Theoretically, if a downstream user was to receive 100% of the lifetime quantity of electricity generated by SZB, the impacts of counteracting downstream T&D losses and of the grid infrastructure, would add an additional 2,181,364t CO_2 eq. This downstream stage is largely beyond EDF's control. Adding this downstream impact onto the total generated impact results in a value of 5,874,577t CO_2 eq.

A breakdown of GWP value for delivered electricity by each LC stage is shown in Figure 10 below alongside the equivalent breakdown for generated electricity. It should be reiterated that reference to GWP refers to GWP-total values (i.e., the cumulative values of GWP-biogenic, GWP-fossil or GWP-luluc).

Figure 10: GWP breakdown of 1kWh SZB generated and 1kWh delivered electricity per LC stage

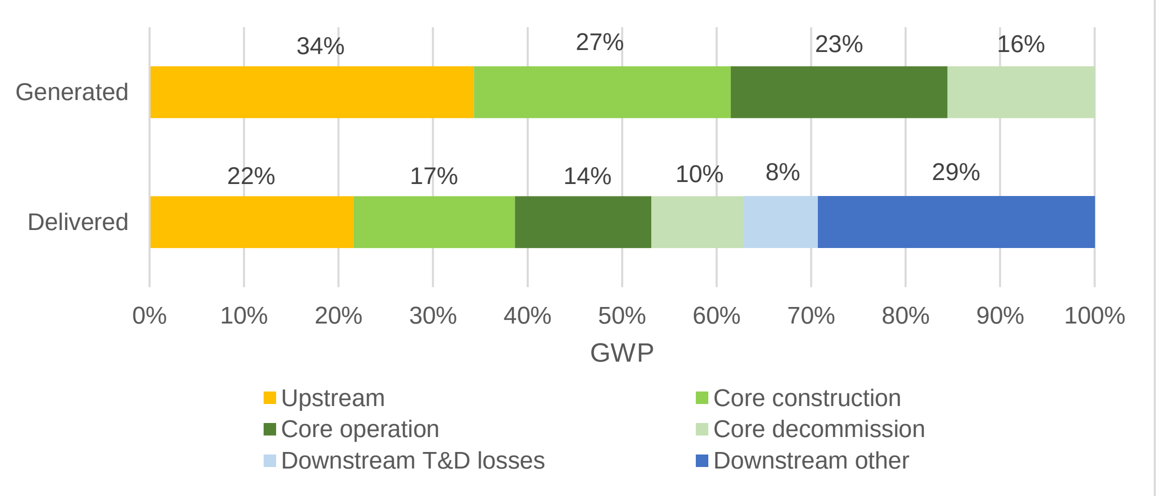


Figure 10 shows when considering the impacts of purely generating 1kWh of electricity at SZB, the upstream stage is just over a third of the GWP impacts. This impact represents the nuclear fuel supply chain and is further broken down into its four key stages in next section. The remaining two thirds can be attributed to the core stage, with 27% coming from core construction (construction of

SZB but also infrastructure of offsite facilities such as waste treatment facilities). 23% arises due to operation of SZB and 16% is associated with SZB decommissioning activities.

When considering the additional impacts of distributing this generated electricity to a medium voltage user, additional GWP impacts arise, which shifts the percentage distribution. 37% of the total GWP value associated with a delivered kWh of electricity generated from SZB, comes from downstream impacts. This is made up of largely ‘downstream other’ contributions. This encompasses the infrastructure and operational requirements of the grid itself and includes the impacts of materials needed such as metals for pylons and emission leakages of SF_6 insulation (a powerful greenhouse gas), as included in the ecoinvent dataset. These types of impacts are related to the grid itself and would therefore be relevant to any type of electricity transported over the grid.

The other downstream LC stage, ‘Downstream T&D losses’, is responsible for just under 8% of the total GWP value for a delivered kWh of electricity. This encompasses the additional impacts associated with generating and distributing electricity required to mitigate the losses in the T&D network. These types of losses affect all forms of power generation that are connected to the electricity network.

Upstream impacts are responsible for 22% of the total GWP value of delivering 1kWh of electricity.

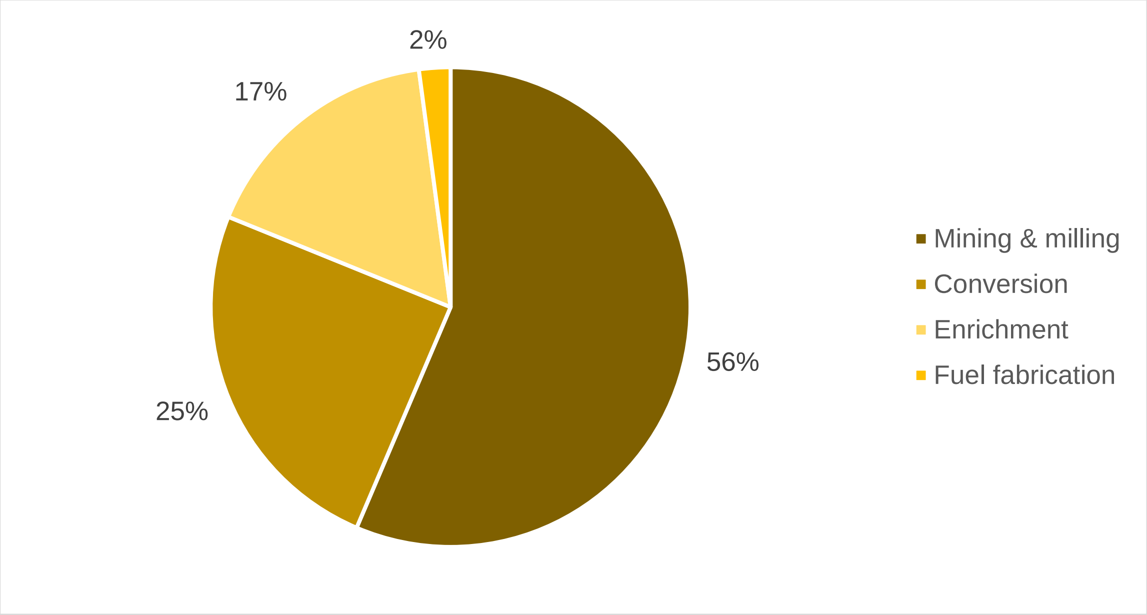
The construction of core infrastructure is responsible for 17% of the total delivered kWh GWP value. Core operation and core decommissioning are responsible for 14% and 10% of the total, respectively. In total, core impacts account for the roughly the remaining 41% of the total GWP value.

The following subsections show where the key GWP contributions come from for upstream and core LC stages. Note that the percentages in the labels do not necessarily sum to 100% due to rounding.

3.4.8.2 Upstream

This section provides a breakdown of the four upstream LC stages’ GWP contribution. Together, these stages contribute a GWP value of 3.48g CO_2 eq. per kWh generated, over the 40-year operational life of SZB. It should be noted that this value is the same per kWh delivered since the extra impacts arising from the generation of electricity required to overcome losses are assigned to the downstream LC stage. Figure 11 shows the split of the GWP-total value over the four upstream stages.

Figure 11: GWP breakdown of LCA stage – upstream



3.4.8.2.1.1 Milling and mining

Figure 11 shows that the majority (56%) of the upstream GWP impacts are associated with the milling and mining of uranium from nature. Milling and mining was modelled using ecoinvent datasets. 58%

of the total GWP contribution for milling and mining comes from the ISL mining dataset (Uranium, in yellowcake {GLO} | uranium production, in yellowcake, in-situ leaching | Cut-off, U), within which combusted diesel is the key contributing process (95% of this 58%). ISL mining is responsible for the highest percentage of mined uranium (per the split defined earlier in Table 4) and it is therefore understandable that it accounts for the highest GWP. However, it should be noted that ISL is an energy intensive process due to the pumping requirements of the mining technology.

The datasets representing the milling and mining of uranium from an open cast mine are responsible for 17% of the total milling and mining GWP value. The highest contributor within the open cast mined uranium ore process is milling energy. Conversely mining and milling provide roughly equal contributions within the underground mine source (which cumulatively contributes approximately a quarter of the total milling and mining GWP value). It should be noted that these are facets of the generic ecoinvent dataset so are not site specific.

3.4.8.2.1.2 Conversion

The conversion process, whereby uranium ore is refined and converted to UF_6, is responsible for a quarter of the upstream GWP impacts. Its contributions arise mostly from gas usage in the ecoinvent dataset used (63%). Energy for the wet conversion process (as modelled in this study) is needed for processes such as evaporation, calcining and drying. The disposal of the LLW generated is the next highest contributor to the conversion GWP value 15%. Contributing just under 8% of the total conversion stage GWP-total value, the upstream production of the nitric acid used in the ecoinvent conversion dataset, is the third highest contributor.

3.4.8.2.1.3 Enrichment

The enrichment of uranium, as modelled in this study, generates 17% of the upstream GWP impacts. SimaPro network flows indicate that this is largely from the UK electricity grid mix dataset, used for operating the centrifuge process (67%), and due to the embedded enrichment facility infrastructure dataset (24.5%).

3.4.8.2.1.4 Fuel fabrication

The final stage of the nuclear fuel supply chain, prior to its transportation to SZB, is fuel fabrication, where enriched uranium is packaged into fuel assemblies. In this study, fuel fabrication generates only 2% of the total upstream impacts, with key contributions from the electricity (20%) and gas (18%) requirements plus fuel assembly material (~39%).

3.4.8.3 Core construction

This section explores the percentage breakdown of the GWP value assigned to core construction, part of the core infrastructure stage, is described. Together, these processes or sub-stages generate a GWP value of 2.76g CO_2 eq. per kWh generated over the 40-year operational life of SZB. This value is the same per kWh delivered since the extra impacts arising from the generation of electricity required to overcome losses are assigned to the downstream LC stage.

Figure 12: GWP breakdown of LCA stage - construction of core infrastructure

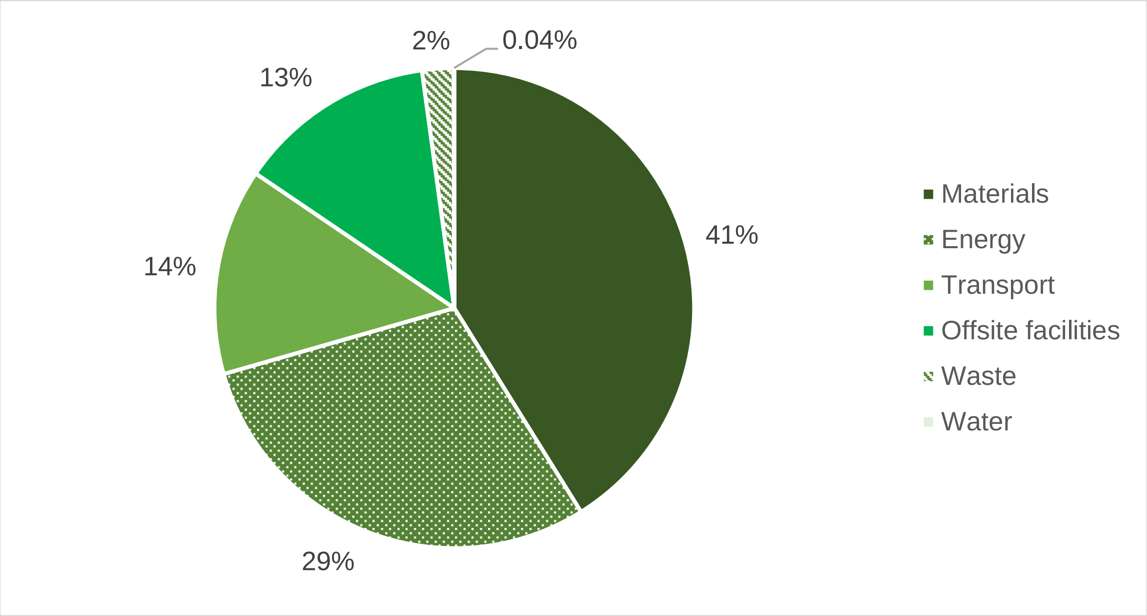


Figure 12 shows that 70% of the GWP value associated with construction of core infrastructure is from energy and material usage, with 41% from the embodied carbon of the SZB construction materials. The highest contributing construction material is steel, contributing ~56% of SZB construction material input GWP value, with concrete coming second at ~18%.

29% of the total GWP value for construction of core infrastructure is associated with the energy needed for constructing SZB. This energy relates to both UK grid electricity (based on current mix) and diesel. The contribution between electricity and diesel is split 62%/38%, respectively.

The transportation of construction materials and earth works to the SZB site and transport of construction wastes offsite, including waste soils, are together responsible for 14% of the core infrastructure construction's GWP. Transport impacts include, amongst others, emissions from fuel combustion and vehicle operation, as well as embodied carbon in the vehicle itself and the road infrastructure.

The infrastructure of offsite facilities used for treating/disposing of operational radioactive wastes (as embedded with the ecoinvent datasets for radioactive waste disposal) is responsible for 13%.

The treatment and disposal of waste generated during the construction period is responsible for 2% of the total infrastructure construction GWP value.

The impact of water usage during construction, can be considered to be relatively insignificant in terms of GWP, at 0.04%.

3.4.8.4 Core operation

This section examines the percentage breakdown of the GWP value assigned to core operation of the SZB over its estimated 40-year life. Together, these processes or sub-stages generate a GWP value of 2.33g CO_2 eq. per kWh generated. This includes commissioning of the SZB reactor and related buildings. As with the previous upstream and core processes, this value is the same per kWh delivered, since the extra impacts arising from the generation of electricity required to overcome losses are assigned to the downstream LC stage.

Figure 13: GWP breakdown of LCA stage – core operation

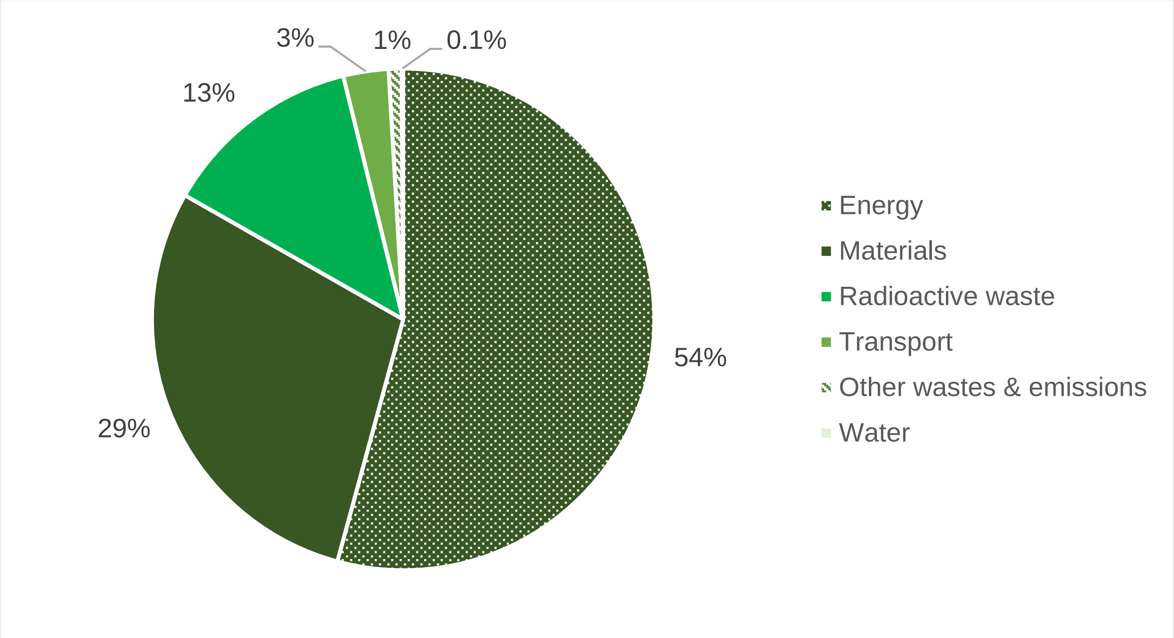


Figure 13 shows that in terms of core operation, 54% of the GWP value comes from energy requirements. This consists of electricity imports and diesel usage. These two energy sources respectively contribute at a 72%/28% split.

29% of the core operation GWP value can be allocated to the materials needed for commissioning and operation of SZB. This includes materials such as stainless steel that are required to package radioactive wastes generated during operation.

A further 13% of core operation’s GWP value comes from the offsite treatment and disposal of radioactive wastes. A large portion of this is due to the incineration dataset used to represent LLW incineration, mostly from emissions to air.

Transport of materials to site and of wastes from site to their respective offsite disposal or treatment locations contribute 3%.

During operation, SZB will generate non-radioactive wastes, and direct emissions to air and water. These cumulatively account for approximately 1% of the core operation GWP value in the model.

Water usage contributes a relatively small amount of the operational GWP value (0.3%).

3.4.8.5 Core decommissioning

This section describes the percentage breakdown of the GWP value assigned to general decommissioning of the SZB development. Together, these processes or sub-stages generate a GWP value of 1.58g CO_2 eq. per kWh generated delivered over the 40-year operational life of SZB. Again, this value can be considered to be the same per kWh delivered since losses are assigned to the downstream life cycle stage.

Figure 14: GWP breakdown of LCA stage – decommission of core infrastructure

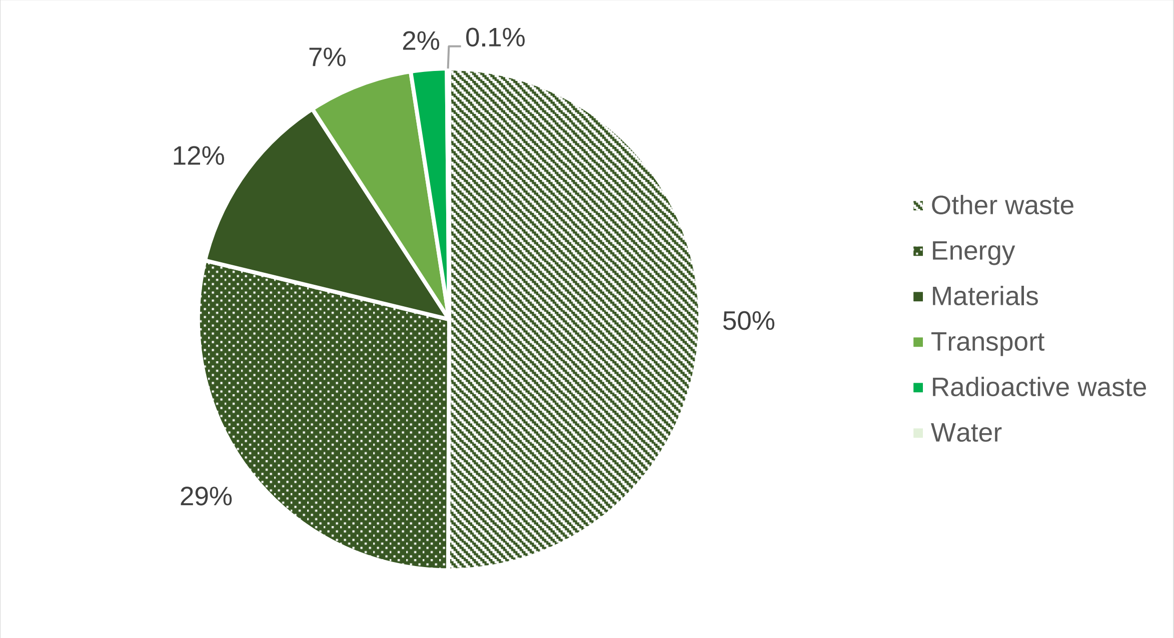


Figure 14 shows half of decommissioning's GWP comes the disposal of non-radioactive wastes. The majority (over 95%) of this impact is associated with emissions from the incineration of the hazardous component of this waste. The quantity of non-radioactive wastes disposed is likely to be an overestimate as some quantity of the material of infrastructures to be removed, will also be covered by radioactive waste modelled, so this can be considered to be conservative. It should also be noted that there is uncertainty surrounding this value as it is derived from the construction material input quantities which have been based on an extrapolation from SZC data.

The next largest contributor is the energy usage. The GWP from energy usage is contributed by the electricity (modelled with the forecast 2035 UK grid mix dataset) and to a lesser extent, diesel. The split of GWP impacts between electricity and diesel is 90%/10%, respectively.

Embodied carbon of the materials needed for decommissioning, essentially packaging of the radioactive wastes, contributes 12% of the decommissioning GWP value.

Transport of packaging materials to site and of wastes offsite contributes 7% of the decommissioning GWP value. A large quantity of materials will be needed to be transported for suitable offsite disposal and recycling. The absolute GWP contribution of this transportation is likely an overestimate of the actual carbon impacts, as diesel vehicles are less likely used in the 2035, instead replaced with 'greener' lower carbon fuelled vehicles.

The disposal of radioactive waste contributes 2% of the decommissioning GWP value, whilst 0.1% is from water usage, such as that used in cooling pools at the SZB site.

3.4.9 Data quality and commentary

With all models, uncertainty exists. A key aspect of uncertainty within this study is that as SZB specific (historical) construction data was not available, approximations of the likely quantities and types of materials, utilities, wastes, and associated transport, were used to represent the construction of SZB. These values were extrapolated from SZC specific data which SZC Co had estimated based on very detailed plans for the future SZC plant (as EPR which is a type of PWR), for a separate LCA model. This extrapolation was done on a per tonne of concrete basis as it is assumed that concrete is the bulk of the construction material used and a key component of a nuclear power plant. It is considered that this extrapolated data is the most suitable and quality data to use in the absence of extensive SZB historic construction data. Additionally, SZC Co has confidence that the data it has provided was reflective of the most up-to-date plans and data.

For the SZC data on which SZB construction data was based, other than the 0.03% mass of SZC construction material inputs and whose impacts are assumed to be more than covered by the uplifts applied to the other SZC construction materials, no known flows into or out of the system have been excluded. Results show that construction materials are responsible for 41% of the core construction value, which in turn is 17% of the total GWP value for 1kWh of delivered electricity, meaning construction materials contribute 7% of the total GWP value. Therefore, the requirement has been met for data to be included for elementary flows to and from the product system contributing to a minimum of 99% of the declared environmental impacts.

A further certain degree of uncertainty is introduced in the form of assumptions that have needed to be applied to derive primary data in the format required for the LCA, for example (but not limited to) assumptions of the specific material composition of components, the density of materials and assumed locations of disposal sites. However, EDF has applied rationale and adopted a conservative approach when applying these assumptions.

EDF was not able to disclose details of SZB’s upstream supply chain. Therefore, specific data was not available. In this absence, specific data supplied by SZC’s potential fuel fabricator and uranium enricher was used. Whilst this data may not reflect the exact suppliers which EDF uses, it can be considered to be the most reliable data available for modelling at this point in time. This has additionally been supplemented with data from fuel fabrication and enrichment ecoinvent datasets to ensure that no ‘key’ input or output flows are unaccounted for. A dataset was created for the UK future GDF based on data provided by SZC Co which was derived from the most conservative of the three scenarios currently scoped. In terms of the uranium sources at mining and milling stages, splits representing realistic potential mining types for virgin sources was assumed and can be considered to be conservative.

Generic datasets have been used to represent the life cycle stages substages for conversion, milling and mining, downstream infrastructure and offsite waste treatment. For these purposes and in the absence of available specific data, the selected ecoinvent datasets were chosen based on their technological and geographical relevance, so are considered suitable and representative for purpose in this instance. Generic data (ecoinvent datasets) was also used to represent all upstream infrastructure. It is understood that the ecoinvent datasets represent technological averages for the given geographies and reflect recent time frames.

All ecoinvent data processes contain a level of uncertainty. Uncertainty analysis of the selected ecoinvent datasets in the model was carried out within SimaPro. Looking at the uncertainty within the ecoinvent datasets themselves, it indicates with 95% confidence that results range from 14.8g to 18.0g CO_2 eq. / kWh delivered and from 9.11g to 11.5g CO_2 eq. / kWh generated.

Where specific data from EDF has been provided, it can be assumed that the quality of data is high. Where this was not available, the use of ecoinvent dataset ensures some level of quality.

Proxy datasets were used at various points within the model where an exact or same material type was not available within the ecoinvent database and the closest considered alternative ecoinvent dataset was used instead. A total of seven proxy datasets have been used to represent top level data in this study. This is relevant to fuel fabrication, which is responsible for less than 1% of the total GWP value for a delivered kWh of SZB electricity. Therefore, it can be assumed that impacts associated with proxy data do not exceed 10% of the overall GWP impact from the product system. While the extrapolation of construction data discussed in this report does not represent proxy data flows, it is a key source of uncertainty that does account for more than 10% of the overall impact.

The assessment of the data quality parameters as per the full LCA report conclude that the overall data quality of the study is sufficient to allow conclusions to be made in accordance with the goal and scope although results should be interpreted with some caution as the construction data is an extrapolation of data from another site. As with any LCA modelling, it is important to note that estimated impact results are only relative statements which do not indicate the end points of the impact categories, exceeding threshold values, safety margins or risks.

4 Additional Environmental Information

This section provides additional environmental information that is not part of the LCA but is considered an important environmental aspect of the production of electricity at SZB.

4.1 Radiation protection

The handling of radioactive substances in various forms is part of the daily operations of facilities in the nuclear fuel cycle. The emission of ionizing radiation from these substances results in doses to the people working in the facility (dose to personnel) as well as (a lesser extent) to people outside the facility (dose to third party).

4.1.1 Protection of the operating personnel

In all SZB facilities, regulations to protect working people are stipulated. A low level of radiation exposure, however, cannot be ruled out. In order to quantify the radiation exposure, average individual doses are shown for all facilities representing the full nuclear fuel cycle.

For comparison, in the UK, annual statutory dose limits for exposure to ionising radiation arising from sources other than medical and natural background are set at levels which ensure that the risk of harm to any person receiving such doses is low. The current annual statutory dose limit for classified workers is 20 millisieverts (mSv) [10]. However, UK legislation requires doses to workers to be as low as reasonably practicable and EDF Energy operates a policy of minimising risks according to this principle. It also operates to a more restrictive Company Dose Restriction Level of 10mSv.

Table 12: Average annual dose to personnel at the facilities in the nuclear fuel cycle for the SZB reference period

Fuel cycle stage	Facility, Location	Average annual dose to personnel (mSv per year)	
		2018	2019
Mining and milling	Orano/Cameco, Cigar Lake and McClean Mill, Canada [31]	0.47	0.57
	Orano, Muyunkum and Torkuduk mines, Kazakhstan [32]	2.5*	2.5*
	CNNC Rossing Uranium, Rossing mine, Namibia [33]	1.2	1.4
Conversion	Orano, Malvési, France [34]	0.038	0.039
	Orano, Pierrelatte, France [35]	0.05	0.03
Enrichment	Urenco facility, Capenhurst, UK [36]	0.39‡	0.26‡
Fuel Fabrication	Framatome facility, Romans-sur-Isère, France [37]	0.90†	0.96†
Generation	Sizewell B, Suffolk, UK	0.132 (2016 - 2020 5 year average)	

* Average for June 2018 to July 2019, average for all Orano mining employees, not mine specific; ‡ Average of four different Urenco enrichment sites; † Average occupational dose for Framatome employees

4.1.2 Protection of third parties

The controlled release of radioactive substances to air and water within clearly regulated and safe limits is normal during operation of facilities in the nuclear fuel cycle. This can result in a small dose being received by members of the public from the consumption of local foods and exposure to intertidal sediments. Discharges from SZB are monitored and are subject to strict control as required by the Environment Agency (EA) for England and Wales which issues permits specifying the maximum limits within which discharges should be kept. These annual discharge limits for SZB are shown in Table 13 below, along with the actual discharge values since 2018. It can be seen that for each of the listed discharge species, the annual discharges are within the annual limit.

Table 13: Discharge authorisation limits to three significant figures

Discharge species	**Annual discharge limit** [17] [18] [19]	**Annual discharges**			**Unit**
		2018 [17]	**2019** [18]	**2020** [19]	
Gaseous releases					
Tritium	3,000	367	396	660	GBq
Carbon-14	500	215	258	390	GBq
Iodine-131	0.500	0.0116	0.0180	0.018	GBq
Noble gases	30,000	2,620	2,680	2,620	GBq
Particulate beta	0.100	0.00350	0.003	0.003	GBq
Liquid releases					
Tritium	80,000	11,200	28,000	22,700	GBq
Caesium-137	20.0	0.312	0.273	0.200	GBq
Other radionuclides	130	4.30	12.0	3.30	GBq

To determine the effect of these discharges on the general public the EA carry out monitoring around the station. Historically, most of the activity entering the local environment was due to Sizewell A (SZA) (now decommissioning with much reduced discharges), weapons testing and Chernobyl fallout and only a small fraction will be due to SZB. Local accumulation of radioactivity is still dominated by the historical discharges from SZA. Doses to the most exposed members of the public in the vicinity of Sizewell are summarised from the Centre for Environment, Fisheries and Aquaculture Science (Cefas) 2019 monitoring report [14] in

Table 14. These should be compared with public dose limits of 1mSv from artificial sources and typical natural exposures of 2.3mSv.

Table 14: Dose to members of the public

Pathway	Exposure (mSv) to Prenatal children of local inhabitants (0.5-1km)	Exposure (mSv) to seafood consumers	Exposure (mSv) to infant inhabitants and consumers of locally grown food
Fish and shellfish consumption	<0.005	<0.005	-
Other local food	<0.005	-	<0.005
External radiation from intertidal areas or the shoreline	<0.005	<0.005	-
Gaseous plume related pathways	<0.005	-	<0.005
Direct radiation from site	<0.005	-	-
Total	<0.025	<0.010	<0.010

4.2 Radiological safety and human health risks

Fuel production and power plant operation have the potential for very low frequency but high consequence events. Accidents associated with the final waste repository would have relatively low consequences (compared with reactor faults).

4.2.1 SZB

4.2.1.1 Regulation

The activities at SZB are governed by various Acts of Parliament. Of particular importance is the Nuclear Installations Act 1965 (as amended) [15], which requires a license to be granted to construct, operate and decommission a nuclear site. The site license places conditions on the licensee to ensure the safe management of the site. The site nuclear operations are regulated by the Office for Nuclear Regulation (ONR). In addition, environmental activities are regulated by the EA, chiefly under the Environmental Permitting Regulations 2010 [16].

4.2.1.2 Nuclear safety

Design and operation of nuclear power plants incorporates protection against technical faults as well as hazards such as fire, flooding and earthquakes. These systems are intended to prevent the release of activity to the environment.

- Prevention – Safety was a key design criterion for SZB. The credible fault scenarios have been identified and analysed, and plant operating, maintenance and testing procedures are in place to avoid the occurrence of these faults.
- Protection – The plant is designed with protection against all credible faults. This protection provides all essential safety functions necessary to prevent a release of activity to the environment. The essential safety functions are for trip, shutdown, post trip cooling and monitoring of the reactor. The protection systems are designed with redundancy, diversity and separation, in order to minimise the risk of failure of these functions.
- Mitigation – In the unlikely event that main protections systems fail to avoid a release of activity, there are arrangements to minimise the risk of exposure to the operator, public and environment. These include the instructions for the plant operator to carry out recovery actions and accident management, and also the provision of an emergency plan [17].

SZB has the following specific barriers against the release of radioactive emissions:

- The solid fuel itself provides containment. It is in the form of very stable and hard ceramic pellets that contain the fission products produced in the nuclear reaction
- The fuel pellets are contained within a stainless-steel cladding that is designed to be leak tight and resistant to damage by heat, corrosion and radiation
- The main containment building is made from pre-stressed concrete and lined with steel. The use of a cylinder with a hemispherical dome provides a very strong configuration
- SZB also has a second containment building made of reinforced concrete which encloses the first one [18]

4.2.1.3 Nuclear safety risks at SZB

The risks due to operation at SZB are managed in such a way as to meet with the requirements of the UK Office for Nuclear Regulation guidelines on Tolerability of Risk from Nuclear Power Stations [18]. These guidelines we derived by considering societal attitudes to risk from a variety of sources, such as large industrial plant including operation. They define three levels of risk, according to the likelihood of an event causing the death of one or more members of the public. The first is a frequency cut-off above which it is not permissible to operate (the upper tolerable level). Below this is a region termed the Tolerable if ALARP region, where the ALARP (As Low as Reasonably Practicable) principle requires the licensee to do everything practicable to minimise risks. Lastly is the acceptable level of risk, for which the risk is sufficiently low that no further actions to reduce it are necessary (the broadly acceptable level).

In order to satisfy these requirements EDF has adopted frequency limits for events of various consequences, ranging from minor releases to a significant release of activity, such as may result from core melt. In order to show that these frequency targets are met, all credible reactor faults are identified and analysed. These faults include failure of the shutdown systems as well as faults with the primary and secondary coolants. A probabilistic risk assessment is used to calculate the actual risk in each category. In addition to this, deterministic rules are applied to ensure that for each fault the number of independent lines of protection is commensurate with the fault frequency.

4.2.2 Final repository

4.2.2.1 Nuclear safety

The analysis presented in this section is based upon research undertaken by the Nuclear Decommissioning Authority (NDA) and relates to its Phased Geological Repository concept for ILW/LLW and its Reference HLW/spent fuel (SF) concept [19]. The reference case is generic, in the sense that it could represent a range of potentially suitable sites. It is not based on a specific real site, but nevertheless, it is intended that the reference case is reasonably realistic, in that the values of parameters of the system are physically reasonable. It is intended that the levels of uncertainty in the parameters should be realistic, in that they should be of the level that might be expected after a suitable site investigation programme.

The development of the final disposal concepts has been undertaken in accordance with NDA's Generic Operational Safety Assessment procedures [20]. Its scope includes examination of the on-site transport of the waste packages, transfer of the waste packages below ground, emplacement of the waste packages in the vaults and other general associated activities, such as maintenance or cleaning of equipment, or the operation of the ventilation system. To identify the faults or hazards that could be associated with these different activities NDA uses the HAZOP (Hazard and Operability) process.

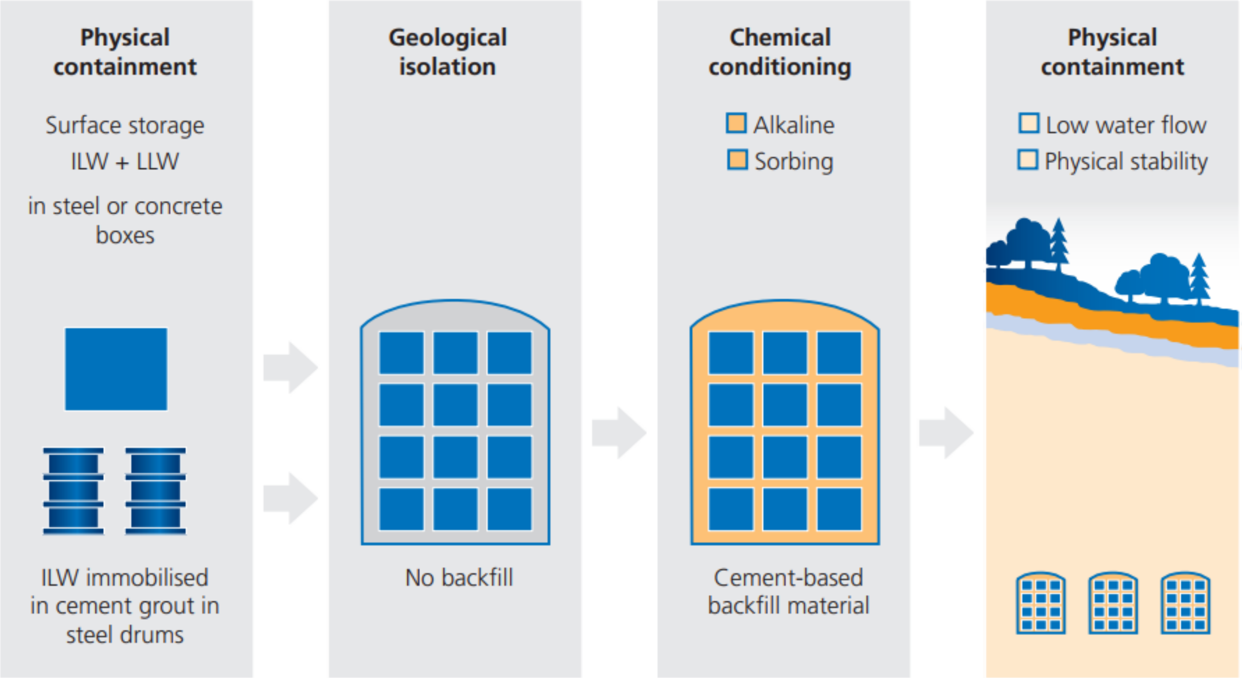
This study assumes waste will be disposed of in the future UK GDF.

Effective barriers against radioactive emissions are a priority consideration in the design of the final disposal facilities. Successive phases of packaging, emplacement, backfilling and repository sealing, and closure build up a multi-barrier disposal concept (Figure 15). These include:

- Physical containment by immobilisation and packaging of wastes in steel or concrete containers

- Geological isolation by emplacement of the waste packages in vaults excavated deep underground within a suitable geological environment
- Chemical conditioning by backfilling the vaults with a cement-based material (the NDA Reference Vault Backfill – NRVB) at a time determined by future generations
- Geological containment achieved by the suitable geological environment, after final sealing and closure of the repository at a time determined by future generations

Figure 15: The multi-barrier disposal concept [19]



Where faults and hazards cannot be eliminated, they are subject to the following detailed assessments:

- A design basis accident analysis, to judge whether there are sufficient safety measures within the design and what safety status these features should be assigned. The higher the safety status, the more critical the system is to ensuring safety.
- A Probabilistic Safety Assessment (PSA) to determine the potential annual risk from operations at the facility to both workers and members of the public [21].

Events and accidents would include instances such as flooding, fire, adverse weather, rock falls, seismic events etc. The NDA has undertaken work on seismic events and glaciation, primarily when investigations were still underway at Sellafield (these ceased in 1997). Assessments of how a repository may evolve in response to both seismicity and major disruptive events (e.g., glaciation) would be key considerations in a repository siting process. However, the effects of these and other natural disruptive events are highly site specific and are therefore not explicitly considered.

The overall outcome is an Operational Safety Assessment showing that the current limits stated in the Ionising Radiations Regulations can be met and that no significant challenges to the viability of the concept have been identified. Furthermore, most of the activities planned for Phased Geological Repository Concept are comparable to those carried out on licensed nuclear sites in the UK, and other nuclear sites throughout the world.

4.2.2.2 Nuclear safety risks at the final waste repository

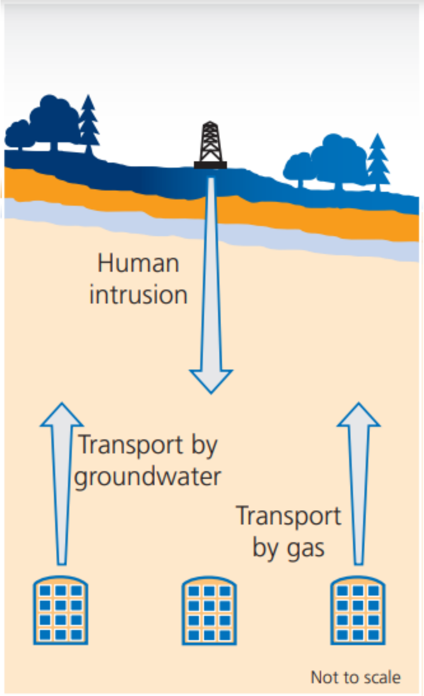
ILW/LLW repository

Three major pathways have been identified for the return of radionuclides to the environment:

- Groundwater (including natural discharge and abstraction from a domestic well)
- Gas

- Human intrusion

Figure 16: Schematic illustration of main assessment pathways (not to scale) [19]

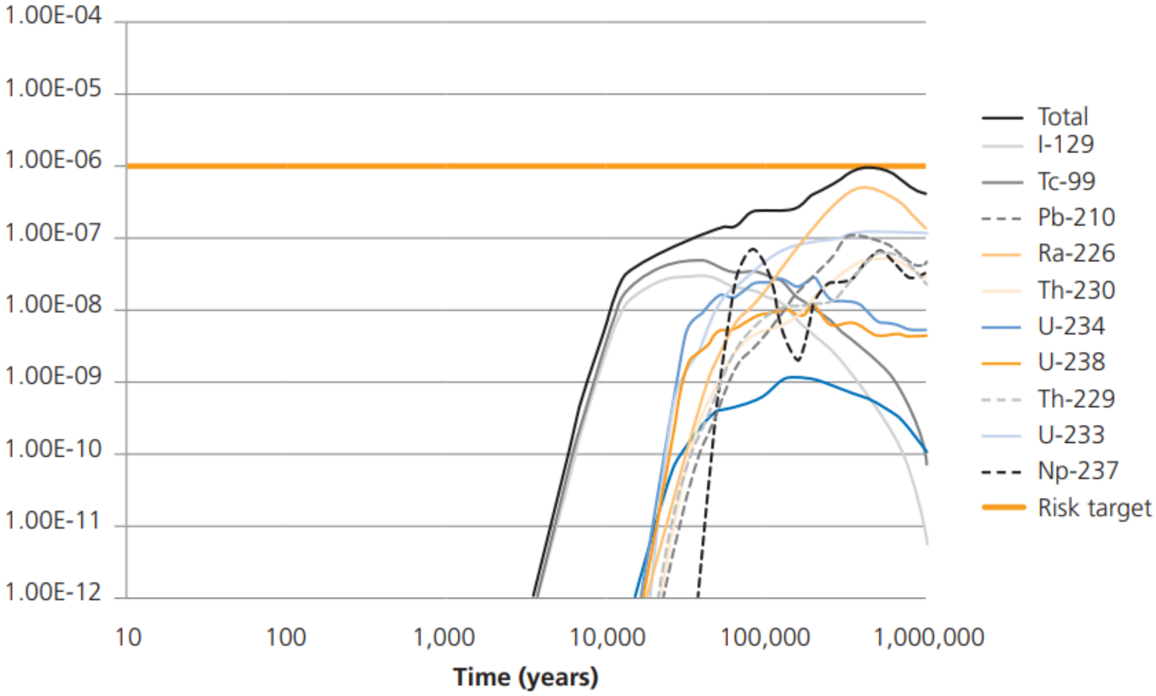


Groundwater pathway

The reference case radiological risk versus time plot for the groundwater pathway, is shown in Figure 17. It also identifies the key radionuclides for this pathway. In accordance with the definition of the reference case, the total radiological risk remains below the broadly acceptable level of 10^{-6} per year at all times.

The results presented in Figure 17 are for the whole inventory of UK waste arisings. The specific contribution from the Sizewell B power station waste will also be below the regulatory risk target.

Figure 17: Reference case radiological risk against time [19]



Gas pathway

The radioactive gases of main concern in the assessment of the gas pathway are Carbon 14 bearing methane, radon and tritium. However, given the relatively short half-lives of radon (radon 222, the longest-lived radon isotope, has a half-life of less than 4 days) and tritium (12 years), any significant delay in the transit of these radionuclides from a repository to the land surface would negate their radiological significance. The breakthrough of gas at the surface is estimated to occur at around 6,000 years after repository closure – the risk from repository-derived tritium and radon is therefore assessed to be insignificant.

Human intrusion pathway

Two human intrusion pathway scenarios are identified. In the first scenario (the ‘geotechnical worker scenario’), core from exploratory drilling is subjected to laboratory analysis by a geotechnical worker. The second scenario (the ‘site occupier scenario’) concerns the distribution of spoil from the exploratory drilling operations onto the land surface in the vicinity of the borehole site. Some radionuclides would then remain in the soil in the vicinity of the site for considerable periods of time, affecting individuals who occupy the site after the end of drilling activities and make use of the land for growing food. The risks to individuals in these scenarios are not quantified but would depend upon the details of the event.

4.2.2.3 HLW/SF Repository Concept

As part of a collaborative project with the Swedish Nuclear Fuel and Waste Management Company (SKB), the NDA has performed a preliminary post-closure safety assessment for the Reference HLW/spent fuel Concept [22]. Calculations have been carried out for the groundwater, gas and human intrusion pathways. The potential for a criticality has also been assessed. A probabilistic calculation of risk has been carried out using this model assuming one canister of each of PWR fuel, AGR fuel and HLW has a defect that ultimately results in failure. It should be noted that SZB itself does not generate HLW.

A model has been developed for assessing the risk from the groundwater pathway which draws on a conceptual model and data developed by SKB for the KBS-3 concept and uses the same geosphere and biosphere model as the NDA’s Generic Performance Assessment (GPA03) [22]. The annual individual risk was found to be substantially below the acceptable risk target.

The conclusions of the assessment of the gas pathway are that radioactive gas generation from a failed canister of PWR fuel, AGR fuel or HLW is not significant, and does not pose an unacceptable radiological risk.

For the assessment of inadvertent human intrusion into a deep geological repository for the Reference HLW/ spent fuel concept, annual individual radiological risks for the geotechnical worker scenario are calculated to be below the regulatory risk target. In the case of the site occupier scenario, the radiological risk from radon associated with the HLW/spent fuel is lower than the radiological risk from naturally occurring radon by a factor of 40.

The potential for a criticality in the Reference HLW/spent fuel concept has been assessed and shows there is no risk of criticality.

4.2.2.4 Nuclear safety risks from the transport of radioactive materials

Radioactive waste can be transported by road, sea, or air, and must meet stringent international transport regulations. More hazardous waste will be transported inside robust containers designed to withstand the severe tests prescribed by the regulations i.e., a free fall from 9 meters onto a rigid surface, an 800^{o}C fire for 30 minutes and a water immersion test equivalent to a water depth of 200m.

PSAs of the proposed transport operation show the radiological accident risks to be very low and orders of magnitude less than the levels accepted by the Health and Safety Executive as “broadly acceptable” [23].

4.3 Environmental risks

Environmental risks at SZB are managed in accordance with EDF Energy’s Environmental policy. Briefly, the policy involves complying with relevant legislation and regulations, minimising environmental impact and waste, promoting energy efficiency, developing a sense of environmental responsibility among staff and openly reporting environmental performance. SZB’s environmental management system (EMS) is certified to the ISO 14001:2004 standard.

A key part of Sizewell B’s environmental management is the systematic environmental risk reduction process continually employed on site. The process involves 1) identifying the most significant areas of environmental risk for further assessment; 2) carrying out an environmental impact assessment to identify recommended barriers to minimise or prevent the threats; 3) implementing the recommendations in order of significance. The process is reviewed annually. Whilst the process does not quantify risks in absolute terms it does subjectively take account of the frequency and consequences as part of the scoring system and then ranks them in order of their significance.

Table 15: Environmental risks

Priority	Description
1	Heating & Ventilation (HV) Refrigerant Management
2	Fuel Oil Supply to Combustion Plant
3	Active Drainage
4	HV Switchgear
5	Contaminated Ventilation
6	Radioactive Solid Low Level Waste Management
7	Transformer Oil Containment
8	Active Emissions
9	Management Control
10	Cooling Water Abstraction

4.4 Land use

The total area of the Sizewell B site is approximately 675ha (including leased land and sea), of which around 42ha is permanently exploited for operational activities.

4.4.1 Land use classification for the Sizewell site

A classification has been made of the ecological habitats around the SZB Power Station, within EDF Energy’s current land ownership boundary. Using information and data collected by EDF since its acquisition of the land, Figure 18 and Figure 19 overleaf provide a comparison of the ecological habitats prior to construction of the power station, with the habitats following both construction and the implementation of EDF Energy’s Integrated Land Management Plan (ILMP) for the estate [24].

The maps, however, do not demonstrate the condition of the habitats. It has not been possible to fully quantify any possible changes in habitat condition or species populations that may have been indirectly due to the power station construction and operation. No complete comparable baseline data exists for pre-construction. Also, the data is complex and subject to many influencing factors. However, regular monitoring from the year 2000 provides an indication of the success of the wider land management. A qualitative description of the habitat loss and habitat creation/enhancement is provided in the following section, together with a descriptive summary of the detailed monitoring results.

In 2010 Galloper Wind Farm leased land from EDF near Sizewell Wents for construction of their sub-station.

The varied landscapes of the Suffolk Coast and Heaths Area of Outstanding Natural Beauty (AONB) provide a rich and diverse range of habitats including wetland, coast, lowland heath and woodland. The variety and proximity of these different habitats contribute to the area's high environmental value. Created over many centuries by the interaction of natural processes and human activity, the Suffolk Coast can be divided into three principal geological areas: the lowland heath separated by large tracts of arable land and coniferous forestry plantations on the higher ground of the Sandlings, the flat low lying marshes and reedbeds of the river valleys, and the coast which is deeply indented by the river estuaries and bounded by eroding cliffs and long shingle beaches. Each of these three geological areas and the diversity of ecological habitats associated with them can be found at Sizewell.

Figure 18: Sizewell estate – ecological habitat pre-construction

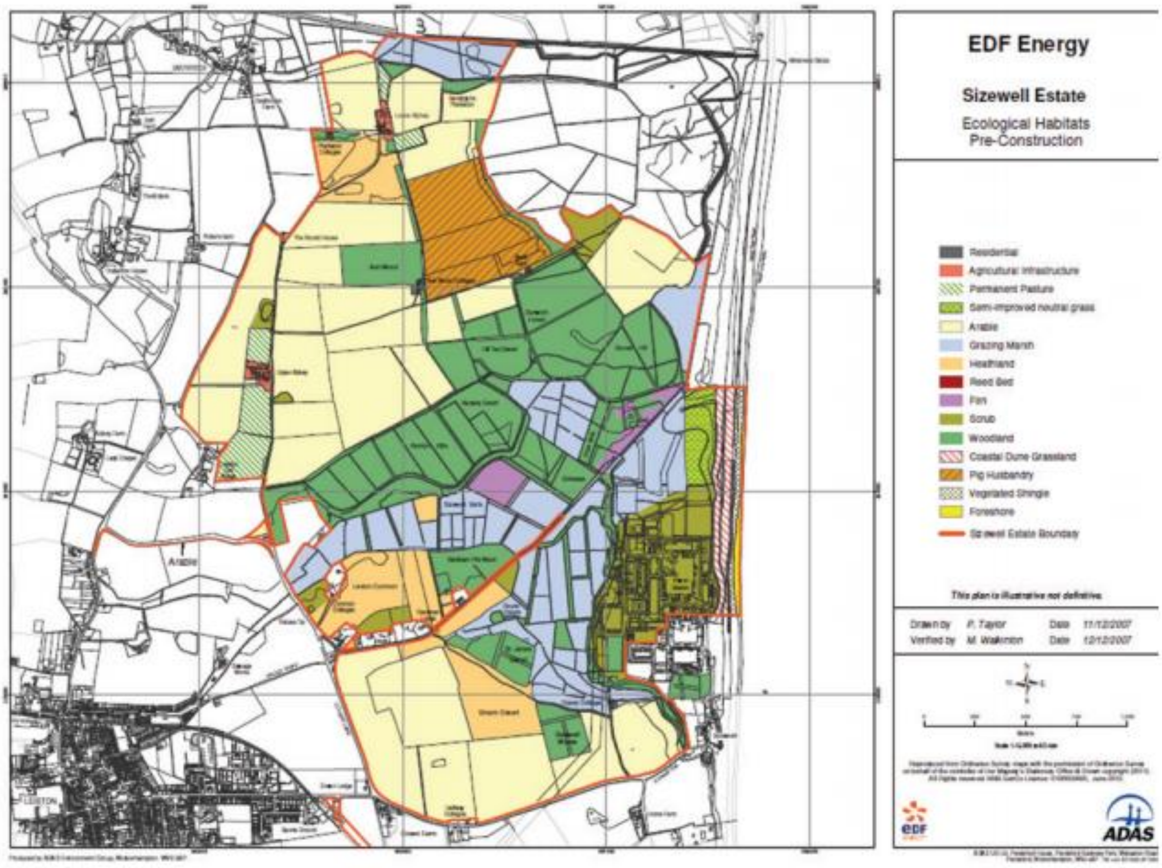
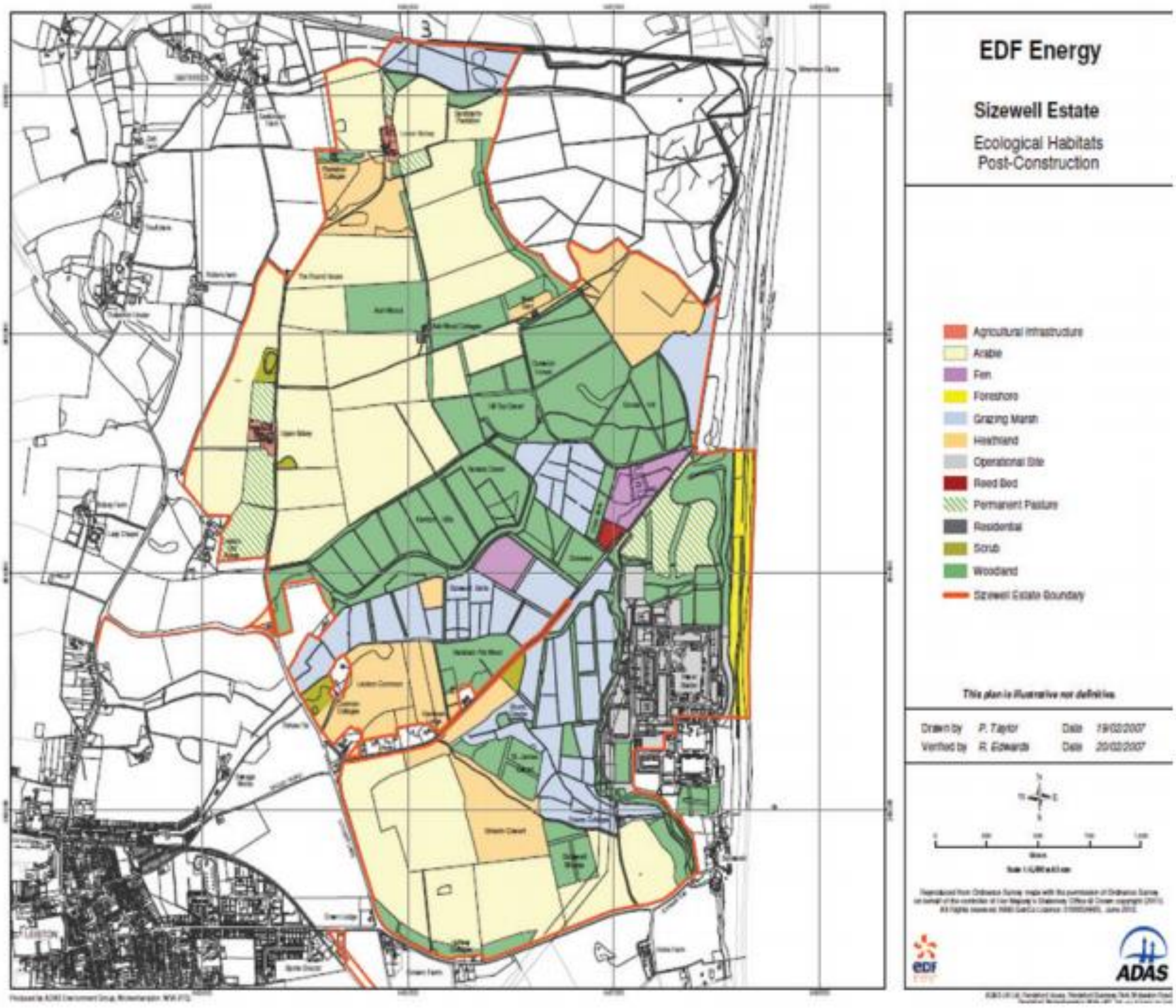


Figure 19: Sizewell estate – ecological habitat post-construction



4.4.2 Statutory designations

4.4.2.1 International

The Minsmere Walberswick Heath and Marshes Special Protection Area (SPA) and Special Area of Conservation (SAC) lies just to the north of Sizewell and comprises grazing marsh, extensive reedbeds, the estuary of the River Blyth and areas of lowland heath and woodland. It supports nationally important numbers of breeding and wintering birds. The site also qualifies as a Wetland of International Importance under the Ramsar Convention.

4.4.2.2 National

The Minsmere Walberswick Heaths and Marshes Sites of Special Scientific Interest (SSSI) contain a complex series of habitats, notably reedbeds and lowland heath which combine to create an area of exceptional interest especially for birds.

The 104.33ha Sizewell Marshes SSSI immediately to the west of the station are important for their large area of lowland, unimproved wet meadows which support outstanding assemblages of invertebrates and breeding birds. Several nationally scarce plants are also present.

The Leiston Aldeburgh SSSI, 3km to the south of Sizewell, contains a rich mosaic of habitats including acid grassland, heath, scrub, woodland, fen, open water and vegetated shingle. The variety of habitats supports a diverse and abundant community of breeding and overwintering birds, a high number of dragonfly species and many scarce plants.

4.4.2.3 Local

There are five County Wildlife Sites close to Sizewell: Leiston Common is an area of lowland heathland within EDF's landholding to the west of the Sizewell Belts, and the beach and foreshore immediately to the east of the station comprises vegetated shingle and coastal dune grassland habitats. The Sizewell Rigs, the cooling water structure offshore from SZA, supports a kittiwake colony of some 200 nests. The Sizewell Levels and Associated Areas includes the marshland, reedbeds and fen to the west of the power station almost all of which is also part of the Sizewell Marshes SSSI. Outside of the SSSI, the County Wildlife Site extends to the north encompassing the wet woodland at Leiston Carr, Fiscal Policy woodland, the Kenton and Goose Hills plantation and a small area of meadow adjacent to Leiston Common.

The Southern Minsmere Levels is directly adjacent to the Minsmere SPA, SAC and SSSI and is of interest for its breeding and wintering wildfowl and waders.

4.4.3 Biodiversity

The ecological habitats which existed at the SZB site existed when the land was acquired for development are shown in Table 16. Note that the totals do not sum to the same value due unavailability of certain data pre-construction. This SZB landholding has been assembled in parallel with the development of the power station which commenced construction in the mid-1980s. The present operational site was acquired by the Central Electricity Generation Board (CEGB) in 1960 in connection with the construction of SZA. Kenton and Goose Hills to the north west of the site was planted by the Forestry Commission in 1958 and subsequently purchased in 1988 by CEGB. In 1992 the company purchased the Sizewell Belts marshes and some agricultural land to the west of the station. Gooderhams Fen, some 6ha, north east of the station was acquired in 1993. Finally, Abbey Farms was purchased in 1995 to provide land for future expansion of generation capacity.

The habitats when EDF acquired the land were, in the main, degraded through intensive use of the more productive land for agriculture and forestry and a lack of management of the woodlands, marsh dykes and other marginal areas. The land developed for the SZB station was previously used as construction and contractors' areas during the building of SZA and prior to development for SZB was a mix of concrete hardstanding, grassland and scrub. To the north was an area of low-lying grazing marshes of similar habitat quality to the marshes to the west which were designated SSSI in 1986. The eastern edge of the site comprised vegetated shingle and coastal dune grassland.

Table 16: Land use classification of the SZB estate in 2021 versus pre-construction

Ecological habitats	Pre construction (ha)	Current area (ha)	% change
Arable, pig husbandry* and permanent pasture	268.5	128.7	-52%
Grazing marsh	105.6	73.4	-30%
Heathland	50.1	69.3	38%
Reedbed	0	10.2	-
Fen	7.3	3.8	-48%
Scrub	47	4.4	-91%
Woodland	156	198.3	27%
Foreshore including coastal dune grassland and vegetated shingle	15.4	10.8	-30%
Semi improved neutral grassland	6.98	No data	-
Operational site, artificial surfaces	No data	32	-
Agricultural infrastructure	No data	3.1	-
Residential	No data	0.5	-
Foreshore including coastal dune grassland and vegetated shingle	No data	12.3	-

Ecological habitats	Pre construction (ha)	Current area (ha)	% change
Grassland, tussocked grassland	No data	101.6	-
Leased land	No data	25.4	-
Open water	No data	0.9	-
Total	**656.82**	**674.7**	3%

* No data was available for ‘pig husbandry’ land for current period

4.4.3.1 Current biodiversity

The present station development occupies an area of former hardstanding, grassland and scrub, most of which has probably naturally regenerated following use of the land in connection with the building of SZA. To the north, grazing marshes were raised during construction to allow use for contractors’ laydown, spoil storage, etc. Subsequent restoration of the area has been to pasture and woodland/scrub of significantly lower ecological diversity than the original coastal grazing marsh habitat.

The shingle beach in front of the power station was extensively disturbed during construction. The area has been restored and replanted with plant communities taken from the site prior to construction, propagated and then replanted. No regular, comparable botanical monitoring has subsequently been undertaken so it is difficult to assess the success of the project and many factors may have influenced the plant communities which are now present.

4.4.3.2 EDF and biodiversity

EDF Energy Nuclear Generation’s Biodiversity Action Plan (BAP) identifies the priority habitats and species at each of the sites; sets and monitors targets and identifies ways in which staff and local communities can be involved through education, participation and partnership [25].

Maintaining this biodiversity requires continuing active management and EDF Energy Nuclear Generation has developed ILMPs for each of its power station sites including SZB. The SZB ILMP sets out objectives, policies and prescriptions for managing the land aimed at protecting and enhancing biodiversity, conserving the local landscape character and historical heritage, and encouraging public recreation, education and community participation whilst at the same time meeting the needs of the business.

In 1992 EDF (formally British Energy) entered into a partnership with the Suffolk Wildlife Trust to manage the Sizewell estate. Since then, through the implementation of the ILMP in partnership with the Trust, substantive changes and improvements have been made to the variety of ecological habitats on the wider estate.

115ha of SSSI grazing marsh and fen have been restored under an Environmentally Sensitive Areas (ESA) agreement through grazing, control of invasive scrub and water level management. A 1.14ha reedbed has been created. 76ha of heathland and acid grassland is being restored across the Estate including 15ha which is being reverted from arable.

In keeping with much of the Suffolk coast, a significant proportion of the Sandlings part of the estate is intensively cropped arable land. Field margins provide habitat for invertebrates and small mammals and act as wildlife corridors. The hedgerows on the estate were largely established as single species, usually hawthorn, during the period of enclosure. All of the estate’s hedges have been managed under a Hedgerow Management Plan. Whilst some 3,000m of hedgerow have been restored by coppicing and restocking with native species.

Woodland on the Sandlings part of the estate is mainly coniferous plantation, the largest of these being Kenton and Goose Hills which occupies around 95ha of the central part of the estate. Small areas of lowland mixed deciduous woodland plantations are scattered throughout the estate. Prior to its acquisition, the woodlands had seen little recent management and were suffering windblow. A total of 170,000 trees and shrubs have been planted since 1990 with 30ha of new woodland planted and other woods thinned and restocked. Rides have been cleared and widened with woody shrubs planted along ride edges.

Regular monitoring of habitats and species is undertaken at SZB. Because of the complexity of factors influencing wildlife populations, many external to EDF's landholding, it is difficult to precisely analyse the effects of the power station operation and the company's land management on the local wildlife. For example, the overall number of breeding bird territories on the Estate has increased since 1999 which probably points to a general improvement in the habitat across the Estate. However, eight breeding species have been lost and only two new species added. Overall, these trends mirror national trends which suggest the declines are subject to external factors beyond the influence of local management. The monitoring data does demonstrate that the wildlife populations have largely been sustained, and in some cases enhanced, by the proactive approach to land management.

In 2009 SZB was awarded the Wildlife Trust's Biodiversity Benchmark for its land management.

4.5 Electromagnetic fields

The term "electromagnetic field" (EMF) refers to the lower frequency range of the electromagnetic spectrum (up to 300GHz). Fields of different frequencies interact with the body in different ways. EMFs are omnipresent in our environment – whether from natural or man-made sources, intended as in the case of radio signals or unintended as a by-product of power transmission or electrical appliances.

Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. The strength of the electric field is measured in volts per metre (V/m). Any electrical wire that is charged will produce an associated electric field. This field exists even when there is no current flowing. Electric fields are strongest close to a charge or charged conductor, and their strength rapidly diminishes with distance from it. Conductors such as metal shield them very effectively. Other materials, such as building materials and trees, provide some shielding capability. Therefore, the electric fields from power lines outside the house are reduced by walls, buildings, and trees. When power lines are buried in the ground, the electric fields at the surface are hardly detectable.

Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field. The strength of the magnetic field is measured in amperes per metre (A/m). But more common is to specify to a related quantity, the flux density (in microtesla, µT). Magnetic fields are not blocked by common materials such as the walls of buildings.

The main source of electromagnetic fields in SZB is the conversion of kinetic energy into electricity in the generator.

In June 2013, the European Commission published Directive 2013/35/EU on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) [26]. This became law in the UK on 1st July 2016. Control is also exercised through the general duties in the Health and Safety at Work etc Act 1974 [27], the Management of Health and Safety at Work Regulations 1999 [28] and by reference to International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [29]. In 2010 the ICNIRP issued new guidelines for the frequency range 1Hz to 100kHz. These guidelines are currently used both by industry and HSE Inspectors when assessing risk from exposure to electromagnetic fields. For occupational exposure the limits set out in the ICNIRP guidelines are 1800µT for magnetic fields and 46kV/m for electric.

4.6 Noise

The most recent complete noise measurement survey was an internally survey carried out at SZB in 2019. Measurements were taken of the existing noise levels in a number of areas around the site including the turbine halls, operation, fuel and waste buildings, and auxiliary areas.

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A1 Deviations from the Electricity PCR

Table 17: Summary of deviations from the Electricity PCR requirements

PCR section	Requirement	Comment
4.3.1.1: Upstream Processes & 4.3.1.2: Core Processes	The PCR indicates that the “storage of auxiliary materials and chemicals at energy conversion site” should be included in the upstream results, but that “storage processes of any inputs or outputs of the energy conversion performed by the company” should be included in the core results.	SZB includes storage facilities. The impacts associated with storage were modelled within the core stage, not the upstream stage.
4.3.1.1: Upstream Processes	The PCR indicates that infrastructure associated with upstream processes should be included with exclusion motivated by the cut-off rules.	SZB is not able to share information or get data from enrichment, fuel fabrication, conversion and mining & milling sites’ infrastructure burdens. Assumptions were made based on global uranium sourcing and a generic ecoinvent data set was used. Infrastructure is included to the extent that it is included in the selected ecoinvent datasets.
4.3.2.3: Geographical boundaries	The PCR states that "data for core operation shall be site-specific."	For off-site core operation, data for the potential UK GDF was based on design plans (so not historical data) and for other offsite waste facilities, specific data was not available so ecoinvent data was used.
4.7.2: Core processes & 4.10.2.3: Nuclear technologies	The PCR states that “Specific data shall be used for amounts of inputs and outputs in activities of handling/treatment/storage of fuel related waste”.	Ricardo interprets this to refer to operational data for offsite radioactive waste treatment facilities. Radioactive waste from SZB will go to UK LLWR, incineration, licensed landfill and metal recycling. No specific data was available for these sites. Therefore, best fit generic ecoinvent datasets have been used. For metal recycling, impacts were cut-off at the point they reach the recycling facility.
4.7.2: Core processes & 4.10.2.3: Nuclear technologies	Similar to the above, infrastructure data is also to be reported for these offsite facilities.	Again, specific data was not available. Infrastructure has been covered to the extent that it is in the generic ecoinvent datasets used to represent these treatment facilities/disposal sites. These do not appear to include dismantling of the disposal sites.
5.4.4: Environmental Performance	The PCR requires that the LCA results be reported in terms of the three core modules (upstream, core, downstream) and total.	To provide additional insight, Ricardo has reported to a more granular level, in terms of upstream, core construction, core operation, core decommission, total generated, downstream T&D losses, downstream other and total delivered. These results can be combined by the reader to obtain results per the three core stages as required.

PCR section	Requirement	Comment
5.4.4.2: Use of Resources	The PCR requires that results are expressed as: Primary energy resources – Renewable (MJ, net calorific value) – used as energy carrier and used as material Primary energy resources – Non-renewable (MJ, net calorific value) – used as energy carrier and used as material	Ricardo has reported primary energy resources in a similar way to the Vattenfall EPD (https://portal.environdec.com/api/api/v1/EPDLibrary/Files/edd6ae95-c679-42c1-98c7-b5818d841c5b/Data) in terms of raw input flow inventories as opposed to applying an assumption (for example) that crude oil input flows are used to plastic (material) or petrol (energy).
5.4.4.2: Use of Resources	The PCR requires that results are expressed in terms of secondary material used.	This is possible for the SZB site but not for upstream, downstream, or offsite (non-EDF) facilities/sites as this information on inventory data was not available. Therefore, these have been reported as 'ND' (not declared).
5.4.4.3: Waste Production and Output Flows	The PCR requires that results are reported as “Low-level, no treatment (such as mining/milling wastes), in case of nuclear power, for upstream and downstream stages”.	Low level radioactive waste (LLW) without further treatment was not estimated or declared as it was not clear what ‘treatment’ referred to. Even LLW which go to final repositories will incur impacts, so it was not considered relevant to try to account for this indicator.
5.4.4.3: Waste Production and Output Flows	The PCR also requires that results are reported as components for reuse, materials for energy recovery and material for recycling, for upstream, core and downstream stages.	This data was not available for stages which are not under the control of EDF as ecoinvent data was used (where waste is followed to the grave so generated amounts not readily available). Results have been reported at top level for components of the core stage controlled by EDF (i.e., not the offsite waste repositories for which generic ecoinvent datasets were used).
5.4.5.2: Additional environmental information not based on LCA	The PCR requires that specific environmental information that is not related to the LCA shall be reported.	It was not possible to fully cover all of the non-LCA requirements of the PCR. The below rows indicate those particular aspects of the non-LCA information that the PCR specifies shall be reported but where it has not been possible to completely meet the requirement.
5.4.5.2: Additional environmental information not based on LCA - Radiology	The PCR requires that the following issues shall be addressed: "in the case of nuclear power, during normal operation in the reference year/period in the main life cycle stages, fuel production, operation of energy conversion plant, and management of fuel residues expressed as dose in mSv."	Ricardo instead obtained (from online review) annual mSv values to personnel for the upstream stages for the specific companies assumed for this LCA for the reference period. These are for specific facilities/companies, which may or may not be part of SZB’s supply chain. For the management of fuel residues, a value has not been provided.
5.4.5.2: Additional environmental information not based on LCA - Risk related issues	The PCR requires that the following issues shall be addressed: "Risk related issues - radiology and human toxicological risks"	This has been addressed qualitatively in sections such as "Regulation" and “Nuclear safety”.

PCR section	Requirement	Comment
5.4.5.2: Additional environmental information not based on LCA - Risk related issues	The PCR requires that the following issues shall be addressed: "Risk related issues - environmental risks" • "Mishaps with environmental impact, that happen less frequent than once in three years should be identified and the impacts quantified • Potential undesired events with high or very high impact but low or minute probability (e.g., nuclear reactor meltdown…etc.) shall be identified and described qualitatively."	EDF has not quantified environmental risks in absolute terms but it does subjectively take account of the frequency and consequences as part of the scoring system and then ranks them in order of their significance. Safety aspects to prevent high impact events have been addressed in the communication document.
5.4.5.2: Additional environmental information not based on LCA - Land use and land use change	The PCR specifies that the following issues shall be addressed "land use and land use change expressed in square meters of specified land category according to Corine Land Cover Classes before and after exploitation where before is the area in the situation before the start of the activities within the lifecycle and after is the area in the time period corresponding to the validity of the EPD. Focus is on the core module meaning that all core module land use shall be classified but also land exploited by fuel suppliers (mining, forestry or agriculture) shall be quantified and classified. Other significant land use in up- and down-stream processes should be included (https://land.copernicus.eu/user-corner/technical-library/copy_of_Nomenclature.pdf)".	Regarding land use, primary data is not readily available beyond the SZB site and EDF has chosen to report land use changes only for SZB. EDF does not collect data in terms of the Corine Land Cover Classes but quantities where available have been given in other land category classes. Due to change of ownership, data for the pre-construction period is limited. The PCR also specifies that the number of years be given that the areas are occupied, expressed as the area occupied per year of operation. This has not been given although some description of timeline of SZB has been given within the document
5.4.5.2: Additional environmental information not based on LCA - Impacts of biodiversity	The PCR requires that the following issues shall be addressed "Direct regional impacts concerning nature conservation issues like biodiversity and visual impact connected to land use."	Information for upstream, downstream, and offsite core facilities was not readily available so only information on onsite biodiversity has been provided.
5.4.5.2: Additional environmental information not based on LCA – Visual impacts	The PCR requires that the following issues shall be addressed: “Visual impacts”	This has not been explicitly addressed although an image of the plant is shown on the cover page.

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Review of the LCA Report (Dated May 24th, 2022) “Life Cycle Assessment of Sizewell B nuclear power plant development,” and EPD-style document (Dated May 24th, 2022) “Life cycle assessment of electricity from Sizewell B nuclear power plant development” Prepared by Ricardo Energy & Environment, Ricardo-AEA Ltd.

Review Statement Prepared by the Critical Reviewer:

Julie Sinistore, PhD

May 24th, 2022

The Critical Reviewer has completed the review of the report and Environmental Product Declaration (EPD)-style document named above. The review has found that:

- the approaches used to carry out the LCA aspects of this analysis are consistent with the ISO 14040 (2006a) and ISO 14044 (2006b) principles;
- the methods used to carry out the LCA appear to be scientifically and technically valid;
- the interpretations of the results are defensible; and
- the report is transparent concerning the study steps.

The review was conducted according to the aforementioned standards as the EPD-style document is intended to be communicated externally. The review was conducted in three stages. The reviewer first reviewed the first draft of the report and submitted written comments to the study authors. The report authors responded to these comments and submitted a revised draft of the LCA report and EPD-style document based on that report. A second round of comments were submitted to the report authors from the reviewer. The study was then finalized by the report authors, and the reviewer performed a third, and final, review. The reviewer’s comments and responses to those comments have been documented in an Excel file called “WSP Critical Review EDF SZB LCA report - round 2 - May 2022 post rev 2 - WSP.”

This review should in no way be construed as an endorsement of the products or the results of this study.

Note that the EPD-style document is not an EPD nor is it intended to be construed or communicated as one. These documents were not reviewed per the relevant EPD standard ISO 14025. The EPD-style document was prepared to be consistent with the relevant Product Category Rule (PCR) for electricity from nuclear power, however, it was determined that some information required by the PCR would not be available for use in this study, therefore, an EPD could not be completed and verified. A complete list of the exact deviations from the PCR is provided in appendix A1 in the EPD-style document and appendix A13 in the LCA report. The reviewer has concluded that the documents include all of the mandatory elements required by the ISO standards 14040 and 14044 standards. Additional elements not included in an LCA arise from the requirements of the PCR such that, if the missing information required by the PCR becomes available, the EPD will be able to be developed and verified at a later time.

This review statement applies only to the documents named above, dated May 24th, 2022, and not to any other versions, derivative reports, excerpts, press releases, or similar publications.

Julie Sinistore

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