Life cycle carbon and environmental impact analysis of electricity from Hinkley Point C nuclear power plant development

NNB Generation Company HPC Limited

26th October 2021

Table of Contents

Glossary

Abbreviation	Definition
AC	Alternating Current
AD	Associated Development
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
AP	Acidification Potential
AWARE	Available WAter REmaining
BAT	Best Available Technique
BEIS	Department for Business, Energy & Industrial Strategy
BNG	Biodiversity Net Gain
BS	British Standard
CGI	Computer Generated Image
CGN	China General Nuclear Power Group
CH_4	Methane
CMD	Commission Member Document
CO	Carbon monoxide
COD	Chemical Oxygen Demand
COMAH	Control of Major Accident Hazards
COPC	Constituents of Potential Concern
CRP	Candidate representative person
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
DSSC	Disposal System Safety Case
EA	Environment Agency
EDF	Électricité de France
EDG	Emergency Diesel Generator
EMF	Electromagnetic Fields
EP	Eutrophication Potential
EPR	European Pressurised Water Reactor
ES	Environmental Statement
ESC	Environmental Safety Case
EU	European Union
FES	Future Energy Scenario
FRA	Flood Risk Assessment
GB	Great Britain
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
GLO	Global
GSP	Grid Supply Point
GWP	Global Warming Potential
HF	Hydrogen fluoride

Abbreviation	Definition
HLW	High Level (radioactive) Waste
HPC	Hinkley Point A
HPC	Hinkley Point C
HRA	Habitats Regulation Assessment
HVAC	Heating, ventilation and air-conditioning
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IES	International EPD System
ILW	Intermediate Level (radioactive) Waste
IPC	Infrastructure Planning Commission
IROPI	Imperative reasons of overriding public interest
IRR	Ionising Radiations Regulations
ISL	In situ leaching
ISO	International Organization for Standardization
LC	Life cycle
LCA	Life Cycle Assessment (LCA)
LCI	Life Cycle Inventory
LLW	Low Level (radioactive) Waste
LLWR	Low Level (radioactive) Waste Repository
LOAEL	Lowest Observed Adverse Effect Level (LOAEL)
LOOP	Loss of Offsite Power
MEH	Mechanical, Equipment and HVAC systems
N_2O	Nitrous oxide
NDA	Nuclear Decommissioning Authority
NMVOC	Non-Methane Volatile Organic Compounds
NOEL	No Observed Effect Level
NO_X	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
OESA	Operational Environmental Safety Assessment (OESA)
ONR	Office for Nuclear Regulation
P&R	Park and ride
PCR	Product Category Rules
PM2.5	Fine Particulate Matter
PO_4^3	Phosphate
POCP	Photochemical Oxidation Creation Potential
PWR	Pressurised Water Reactor
RNA	North America
RSR	Radioactive Substances Regulation
RWM	Radioactive Waste Management
SF	Spent fuel
SF_6	Sulphur hexafluoride
SFEF	Spent Fuel Encapsulation Facility

Abbreviation	Definition
SFIRF	Spent Fuel Inspection and Repackaging Facility
SO_2	Sulphur dioxide
SOAEL	Significant Observed Adverse Effect Level
SSSI	Site of Special Scientific Interest
SWESC	Site-Wide Environment Safety Case
SZC	Sizewell C
T&D	Transmission & Distribution
U_3O_8	Uranium oxide
UDG	Ultimate Diesel Generators
UF_4	Uranium tetrafluoride
UF_6	Uranium hexafluoride
UK	United Kingdom
UNCPC	United Nations Central Product Classification
UO_2	Uranium dioxide
USA	United States of America
VLLW	Very Low Level (radioactive) Waste
VOC	Volatile Organic Compound
WDA	Water Discharge Activity
WMP	Waste Management Plan
WSF	Water Scarcity Footprint

1 Preface

Producer: NNB Generation Company HPC Limited (HPC Co) is the holding company for the Hinkley Point C project, which is currently constructing a 3.2 GW nuclear power station in Somerset. The project is jointly owned by Électricité de France (EDF) (66%) and China General Nuclear Power Group (CGN) (33%). HPC Co is ISO14001 (EMS) and ISO9001 (QMS) certified. HPC Co's registered address is: 90 Whitfield Street, London, UK, W1T 4EZ. https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c

Product: Electricity from the future Hinkley Point C nuclear power plant development. 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 HPC Co.

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<table>
<tr><th colspan="4">Electricity, Steam and Hot Water Generation and Distribution PCR2007:08, version 4 serves as the core PCR</th></tr>
<tr><td colspan="4">Independent review of the declaration according to ISO 14040 (Environmental management – Life cycle assessment – Principles and framework) [1] and ISO 14044 (Environmental management – Life cycle assessment – Requirements and guidelines) [2])</td></tr>
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The purpose of this document is to communicate the potential life cycle environmental impacts associated with the construction, operation, and decommission of the future HPC nuclear power plant, in terms of electricity output generated and then delivered to a downstream user. This document also includes additional information as specified under the relevant Product Category Rules (PCR)[1]. Whilst not an Environmental Product Declaration (EPD) as it does not fully comply with the PCR, it is EPD-like in its character in that it is a communication document. The full Life Cycle Assessment (LCA) report and this document have undergone third party review by WSP USA Inc.

2 Introduction

HPC Co, is currently constructing a nuclear power station, HPC, in Somerset. Once operational, HPC Co estimates that the site would generate enough low carbon electricity to supply six million homes, helping 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 robustly quantify the key environmental impacts of HPC over its life, HPC Co wished to prepare an LCA for HPC, aligned as closely as possible to the relevant PCR, and to communicate these results publicly.

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

EPDs are formal, independently verified LCA that are conducted in accordance with PCR specific to the product system under study. In the case of nuclear power, the relevant PCR is ‘Electricity, Steam and Hot Water Generation and Distribution PCR2007:08, version 4’ (Electricity PCR). PCR requirements are based on ISO 14025 (Environmental Labels and Declarations – Type III environmental declarations – Principles and procedures) [3] and require conformance to ISO 14040 (Environmental management – Life cycle assessment – Principles and framework) [1] and ISO 14044 (Environmental management – Life cycle assessment – Requirements and guidelines) [2].

EPDs prepared under the Electricity PCR must be based on real-world facilities, for which primary operational data is available. The LCA has been carried out to align as much as possible with the PCR requirements, but is based on data from submitted proposals, rather than operational data. This study has been discussed and carried out in corporation with the International EPD System (IES)[2] but as HPC is not yet operational, the IES Technical Committee inferred that it would not be possible to prepare a traditional EPD at this point in time The Technical Committee did however recognise that the pilot character of the study reinforces the need for IES to investigate how to facilitate the needs for reporting environmental performance of design stage products.

HPC Co commissioned Ricardo to undertake an LCA in accordance with the Electricity PCR as much as possible, using the best available data from sources such as the Development Consent Order (DCO) submission and data recorded during construction so far. This work assesses HPC’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 HPC.
- The ‘downstream’ activities associated with distributing electricity to customers.

The assessment considers a selection of key environmental indicators, covering issues such as Global Warming Potential (GWP) and Acidification Potential (AP). It also reports on a number of resource use and waste output indicators. The assessment has been independently reviewed by WSP USA Inc. to ensure the work is carried out in accordance with ISO 14040 and ISO 14044. Deviations from the Electricity PCR are summarised in Appendix A1.

This document reports the work undertaken to assess HPC’s life cycle environmental impacts and the results of the study. The GWP value associated with generating 1kWh of net electricity at HPC has been calculated as 5.49g CO_2 eq., whilst that associated with a downstream user receiving 1kWh of electricity generated by HPC has been calculated as 10.91g CO_2 eq once the impacts of the transmission and distribution networks are taken into account.

Although the Electricity PCR has been followed where possible, generic data from ecoinvent database -a globally recognised life cycle inventory database- has been used in the absence of specific data for much of the offsite, upstream and downstream processes. Thus, it is important to note that it has not been fully possible to obtain and use specific data or to comply with all the non-LCA requirements nor all of the reporting categories in the PCR. The appendix A1 lists the key areas where it has not been to fully align with the PCR in this instance. Other appendices of HPC 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 the proposed Hinkley Point C nuclear power plant development” dated 26th October 2021.

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[2] IES is global programme responsible for the General Programme Instructions for EPD development, as well as the Electricity PCR.

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 3.2GWe (net) new nuclear power station HPC Co is building and plans to operate on the Somerset coast, 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 HPC's potential 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

HPC will comprise two EPRs with a combined estimated gross e net electricity output of 3.2GWe. EPRs are a type of Pressurised Water Reactor (PWR), 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.

Initial constructions started in 2016 with the bulk commencing in 2018, with a planned start of generation in 2026. It has been designed for an operational period of 60 years. Each unit is expected to run all day, every day, except during planned maintenance periods, assumed to occur every 18 months and unplanned outages.

The HPC project is currently in the construction stage and whilst some data is available for construction which has already occurred, so some construction data is not yet available and actual operational data does not yet exist. Table 1 below summarises the project's key characteristics.

Table 1: Overview of HPC details

Characteristic	Data
Reactor type	European Pressurised Water Reactor (EPR)
No. of reactors	2
Fuel	Enriched uranium oxide fuel (currently assumed enrichment level of 4.1%)
Start of construction	2016
Start of generation	2026 (estimated)
Start of decommissioning	2086 (estimated)
Designed service life	60‡ 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	Hinkley Point, Somerset, UK
Net generated	circa 3.2GWe
Gross generated	circa 3.5GWe
Transmission	Electricity will be transmitted at 400kV and subsequently distributed to the majority of customers through lower voltage distribution networks (from 132kV to 33kV)

‡ It should be noted that although the operating design life of HPC is 60 years, it may be possible to extend the life of the plant beyond that (some PWRs in America have now had nuclear regulatory approval for life extensions to 80 years). If life extension were to happen, it would be expected to reduce the lifetime environmental impact per functional unit below those numbers presented in this study.

3.1.2.2 Functional Unit

The function of HPC is to supply electrical energy to consumers. The functional unit is therefore of 1kWh net electricity generated and thereafter distributed to the customer. It is assumed for this LCA that the customer receives medium voltage electricity.

1kWh net refers to the gross electricity generated by the power station minus any of the generated electricity that is used internally within the HPC site. It is essentially the electricity available for export to the National Grid. Moreover, the electricity distributed will account for the generated electricity that is lost during transmission and distribution (T&D: all electricity that is transported over the T&D system has some losses).

Table 2 below compares HPC's lifetime gross generation and net generation (assuming a 60-year operational life), as well as the amount of HPC electricity delivered after T&D losses over the grid have been taken into account. The values for net gross and net generation are estimates provided by HPC Co based on calculated annual output of HPC. The net delivered value is the net generated value less the T&D losses applied in the model.

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

Gross generation	Net generation	Net delivered
1,694,098,080 MWh	1,569,751,800 MWh	1,395,922,392 MWh

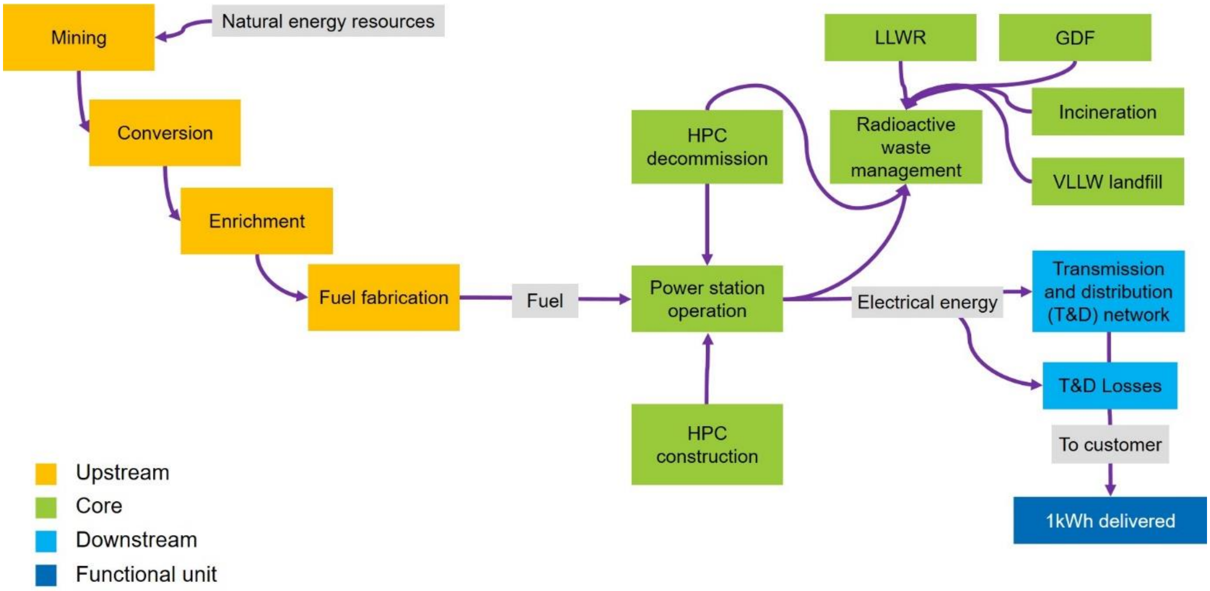
In order to report to the functional unit of 1kWh net electricity generated and distributed to the customer, results have been calculated to represent the impacts that arise from generating the electricity and whilst distributing this electricity to the customer. It has been assumed that the user receives all of the 1kWh of electricity. Impacts from grid infrastructure and operation, as well as additional generation impacts arising due to T&D losses, have been assigned to the downstream stage. Therefore, the impacts of generating 1kWh of net electricity at SZC are covered by the upstream and core stages, whilst those incurred whilst distributing and delivering 1kWh to the customer, are covered only in the downstream stage. Results are thus shown for both 1kWh net generated electricity and 1kWh delivered electricity, where those of the delivered kWh cover upstream, core and downstream stages.

3.1.2.3 System boundary

In line with the electricity PCR, the scope of this LCA is cradle-to-grave, excluding the impacts from use of the electricity downstream (i.e., after delivery). As such, the LCA model and the results are divided into three different life cycle stages. This is shown in Figure 1 below. It is important to note that, while all impacts associated with generating the electricity lost in T&D are included in this study, they are accounted for in the downstream life cycle stage "T&D Losses", not the core life cycle stage:

- **Upstream**: activities occurring 'before' the HPC facility, capturing processes associated with the mining, conversion, enrichment and fabrication of nuclear fuel which the plant will use.
- **Core**: capturing the construction and decommission of the HPC project 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 at the low level waste repository (LLWR), the future geological disposal facility (GDF), via incineration and via very low level waste (VLLW) landfill. The handling and disposal of all high level radioactive waste (HLW), intermediate level radioactive waste (ILW) and low level radioactive waste (LLW) generated during operation and decommissions is covered where applicable.
- **Downstream**: activities 'after' the HPC facility, 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 T&D 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

ISO14044 requires LCA studies to consider the impact of temporal differences within the data modelled. In terms of temporal representativeness, forecasting of UK grid electricity mix has been applied to the HPC site for the operational module which is anticipated to begin in 2026. Forecasting has also been applied for decommissioning which is expected in the 2080s. The operational electricity for the potential future Geographical Disposal Facility (GDF) has been modelled using 2040 forecasted UK grid electricity mix as this is when it will potentially be accepting waste. For construction, due to being in the next couple of years, no forecasting of UK grid electricity mix was applied. The assessment period covered the time from the start of HPC construction up until the end of decommissioning.

In terms of geography, a number of geographies were considered. Downstream and core activities will occur in the UK, whilst fuel conversion, enrichment and fuel fabrication are assumed to take place in France. Mining operations have been assumed, for the purposes of this study, to take place across the world 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 HPC on a physical basis (i.e., by the mass or volume), 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 HPC Co for all of the core life cycle stages and were based on an extensive evidence base including mainly HPC specific data, some data from SZC and data from other UK nuclear power plants. This data will be considered as specific data in the context of this LCA. The latter has been collected from the LCA database ecoinvent, v3.7 cut-off database as implemented in SimaPro[3] v9.1.

Specific data was also obtained from HPC's potential future suppliers of fuel fabrication via the SZC Co LCA project. Although HPC is likely to use a different enriched uranium supplier to SZC, it was anticipated that the centrifuge process is similar to that of SZC's uranium enricher. Therefore, specific data available from SZC's uranium enricher was used. Whilst this data may change in the future prior to operation, it can be considered to be the most reliable data available to HPC Co at this point in time. A specific dataset was also created for the UK future Geological Disposal Facility (GDF) based on data provided by SZC Co. This data was derived from a public study from Radioactive Waste Management (RWM) and further informed by discussions between HPC Co and RWM. The data supplied for this study was based on the most conservative of the three scenarios scoped in the RWM report [4].

Generic datasets have been used to represent the life cycle stages substages for conversion, milling and mining, downstream infrastructure and offsite waste treatment.

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 other life cycle stages or sub-stages, it has been considered necessary to make assumptions regarding the electricity type that HPC (or activities associated with HPC) will consume during its lifetime as mentioned in section 3.1.2.4. 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 excluded processes as required by the Electricity PCR (business travel, commuter travel, R&D activities and impacts from 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 have been excluded. Therefore, the life cycle inventory (LCI) data for core operation can be considered to meet the cut-off criteria of the Electricity PCR. In terms of core infrastructure, HPC Co has attempted to include as much as possible. Where there are uncertainties with respect to construction materials, conservative uplifts to the amounts of materials have been applied and are considered to comfortably cover the materials required.

3.1.2.8 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

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[3] SimaPro is a world leading and internally recognised LCA software used across business, industry and academia

changes to technology or demand although some attempt at representing the influence of future UK electricity grid mix has been made.

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 transmission and distribution networks), no specific data was available. Therefore, ecoinvent datasets have been used as proxies.

It is also important to note that whilst HPC Co have based values on the most recent available core data, until HPC has been fully constructed and is under operation, this should be considered to be a design LCA.

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 HPC, 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 60-year operation of HPC.

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

Table 3: Processes included in the key life cycle inventories

Stage	Included processes
Upstream*	Fuel and electricity consumption, emissions, production of materials required, infrastructure, wastes, transport of uranium from previous upstream stage.
Core operation	Materials required for operation, transport of materials and fuel to site, fuel and electricity requirements (including reserve power), water requirements, emissions, packaging of radioactive wastes on site, 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	Materials required for construction of the HPC facility including reactors and other infrastructure such as roads and temporary structures, cables and machinery, reinvestment of construction materials, transport of materials to site, transport of wastes from site, fuel and electricity consumption, water consumption, treatment/disposal of wastes generated.
Core infrastructure: decommission	Fuel, electricity and water needed for decommissioning, raw materials required for packaging of radioactive wastes, transport of packaging materials to site, transport of wastes (both radioactive and non-radioactive), treatment/disposal of wastes.
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 to be used at HPC. For the purposes of this study, it is assumed that HPC will purchase uranium fuel assemblies from Framatome (the fuel assembler), who will be provided with enriched uranium sources from an Orano enrichment facility in France. As the future potential suppliers of uranium mining and conversion services to HPC are not known, 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%	Rio Tinto	Rossing, near Swakopmund, Namibia
Mining (total)	**100%**	**See above**	**See above**
Conversion	**100%**	**Orano**	**Pierrelatte & Malvési, France**
Enrichment	**100%**	**Orano**	**Pierrelatte, France**
Fuel fabrication	**100%**	**Framatome**	**Romans-sur-Isère, France**

† Note that whilst HPC plans to use the services of Framatome and Orano for fuel fabrication and enrichment at the listed sites, for conversion and mining, the listed companies and specific locations are purely assumptions for this project.

All upstream data has been linked to the reference mass (3,900 tonnes) of enriched uranium needed for 60 years of operation, during which the plant is expected to generate 1,57TWh of electricity (net).

Table 5 shows the reference flow mass from each upstream stage in relation to the required operational enriched uranium.

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

Upstream fuel	Mass (t)
Underground sourced milled uranium*	67
ISL sourced uranium	19,157
Open pit sourced milled uranium*	5,366
Converted uranium	31,200
Enriched uranium	3,900

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

3.2.2 Core

3.2.2.1 Core operation

As per 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

In relation to off-site facilities for the treatment/deposition of wastes generated during operation of HPC, 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) 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

In relation to off-site facilities for the treatment/deposition of wastes generated during operation of HPC, 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.

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). Transmission networks connect with distribution networks at grid supply points (GSP) [8]. In Great Britain, transmission networks operate at 275kV and 400kV. Distribution networks operate at 132kV and below.

Transmission losses occur when a portion of the energy of an electrical current travelling along a network is dissipated as heat as a result of the electrical resistance in the network. In addition to transmission losses, distribution losses also occur, where energy is lost between a GSP and a household or factory. Transmission losses are lower (as a percentage) than distribution losses. The National Grid suggests that transmission network losses are around 1.7% compared to a further 5-8% that is lost over distribution networks [9]. These losses affect all forms of power generation that are connected to the electricity network.

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 which is factored in within the dataset.

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 HPC Co. Therefore, a generic ecoinvent dataset for medium voltage electricity was used, into which the HPC 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 [8]
Distribution loss	8%*	National Grid document 2019 [8]
Step up loss	3%	ecoinvent dataset

*The highest value in the range was used for conservatism

It is important to note that additional upstream and core impacts due to T&D losses are assigned to the downstream stage, alongside impacts of the infrastructure and operation of the grid. In order to do this, the impacts of generating 1kWh at HPC must 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 HPC due to losses on the network.

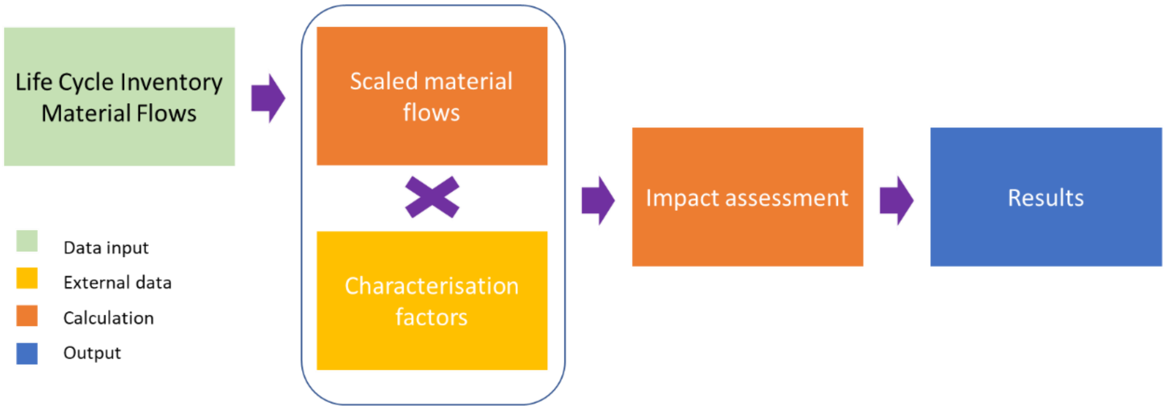
As summarised in Table 6, this study has applied the 3% step-up loss contained within the ecoinvent database to model step-up losses affecting the distribution of electricity supplied by HPC. However, following this study's analysis, further information was provided based on calculations by HPC Co indicating that this loss may be as low as 0.21%.

The detailed analysis contained in this report is based on losses of 3% but a sensitivity analysis was carried out indicating the key environmental impact emissions per delivered kWh may be slightly lower (on average 1.2% lower) if a 0.21% step-up loss is used.

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 environmental indicators. First, each inventory is scaled to deliver the correct amount per functional unit (1kWh of net generated HPC electricity) as well as for 1kWh of delivered electricity. The inventories are built in a cascading hierarchy by which each 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).

3.4 Life cycle results

3.4.1 Environmental impacts

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

Results have been analysed further in section 3.5.8 with further focus on carbon.

3.4.2 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 secondary data was available for non-HPC controlled stages, for which details of reuse and recycled material was 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-HPC 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, 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. As they have not been further analysed, they have been reported as per the minimum LC stages required by the Electricity PCR, so core infrastructure covers both core construction and decommission.

3.4.3 Waste and material outputs

The waste and material outputs for the LCA per functional unit are shown in Table 9. A number of waste output types and quantities have been declared. Due to the lack of primary data for non-HPC controlled stages, some have only been declared for the HPC core stages where total inventory input data has been divided by HPC's lifetime generation electricity. For other outputs, existing methods have been used to report results for all stages. Where is has not been possible to report a value, the result is reported as 'ND' (not declared), in the table. Where not all stages have been declared for a particular waste output, the core operation and infrastructure stages should be considered to only include HPC on-site facilities (i.e., offsite core impacts, such as operation of waste facilities have not been included due to lack of primary data).

Results for waste and material outputs have not been further analysed as they are a facet of reporting the inventory as opposed to an actual calculation of impacts. As they have not been further analysed, they have been reported as per the minimum LC stages required by the Electricity PCR, so core infrastructure covers both core construction and decommission.

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 distributed
GWP total (g CO_2 eq.)	2.76	1.68	0.80	0.25	**5.49**	0.68	4.73	**10.91**
GWP total (kg CO_2 eq.)	2.76E-03	1.68E-03	8.02E-04	2.49E-04	**5.49E-03**	6.84E-04	4.73E-03	**1.09E-02**
GWP fossil (kg CO_2 eq.)	2.76E-03	1.62E-03	7.70E-04	2.46E-04	**5.39E-03**	6.72E-04	4.72E-03	**1.08E-02**
GWP biogenic (kg CO_2 eq.)	4.24E-06	5.90E-05	2.68E-05	6.90E-07	**9.08E-05**	1.13E-05	2.94E-06	**1.05E-04**
GWP lulac (kg CO_2 eq.)	1.06E-06	1.85E-06	4.71E-06	2.35E-06	**9.97E-06**	1.24E-06	2.58E-06	**1.38E-05**
AP (kg SO_2 eq.)	2.72E-05	1.30E-05	8.44E-06	1.18E-06	**4.98E-05**	6.21E-06	2.68E-05	**8.29E-05**
EP (kg PO_4^{3-} eq.)	3.90E-05	4.52E-06	3.13E-06	3.97E-07	**4.71E-05**	5.86E-06	1.27E-05	**6.56E-05**
POCP (kg NMVOC eq.)	3.02E-05	1.08E-05	6.42E-06	1.15E-06	**4.85E-05**	6.04E-06	9.47E-06	**6.40E-05**
Particulate matter emissions (kg PM2.5 eq.)	1.41E-05	4.84E-06	2.75E-06	4.77E-07	**2.22E-05**	2.76E-06	8.54E-06	**3.35E-05**
WSF (m^3 world eq. deprived)	2.21E-03	2.43E-04	1.74E-04	5.48E-05	**2.68E-03**	3.33E-04	4.47E-04	**3.46E-03**

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

Resource use	Unit/kWh	Upstream	Core operation	Core infrastructure	Total generated	Downstream T&D losses	Downstream other	Total distributed
Non-renewable material resources								
Aluminium	g	3.95E-03	7.54E-04	3.16E-03	7.86E-03	9.79E-04	3.31E-02	4.20E-02
Clay, bentonite	g	8.18E-04	4.11E-04	1.72E-01	1.74E-01	2.16E-02	2.06E-03	1.97E-01
Basalt	g	1.72E-04	4.85E-05	1.77E-04	3.97E-04	4.94E-05	3.66E-04	8.13E-04
Chromium	g	4.62E-03	3.79E-03	1.20E-02	2.05E-02	2.55E-03	1.59E-03	2.46E-02
Copper	g	1.86E-03	7.63E-03	9.07E-03	1.86E-02	2.31E-03	3.99E-02	6.08E-02
Dolomite	g	9.57E-04	4.40E-04	2.58E-03	3.97E-03	4.95E-04	2.32E-03	6.79E-03
Feldspar	g	5.88E-10	1.34E-10	5.71E-09	6.44E-09	8.02E-10	8.20E-10	8.06E-09
Fluorspar	g	2.58E-02	3.66E-04	5.69E-04	2.67E-02	3.33E-03	1.33E-03	3.14E-02
Gravel	g	4.98E-01	1.65E-01	3.89E+00	4.56E+00	5.67E-01	2.44E+00	7.56E+00
Sand	g	7.40E-02	1.50E-02	2.99E-02	1.19E-01	1.48E-02	5.85E-01	7.19E-01
Rock	g	1.33E-02	2.20E-03	7.03E-02	8.58E-02	1.07E-02	4.26E-02	1.39E-01
Gypsum	g	3.27E-03	4.30E-04	7.71E-03	1.14E-02	1.42E-03	1.23E-02	2.51E-02
Iron	g	6.30E-02	3.76E-02	2.16E-01	3.17E-01	3.94E-02	1.79E-01	5.35E-01
Lead	g	4.01E-04	4.78E-05	1.25E-04	5.73E-04	7.14E-05	8.04E-04	1.45E-03
Calcite	g	1.32E-01	2.96E-02	4.30E-01	5.91E-01	7.36E-02	3.85E-01	1.05E+00
Magnesium	g	3.33E-04	2.64E-05	8.73E-05	4.47E-04	5.56E-05	1.18E-03	1.68E-03
Manganese	g	4.87E-04	2.47E-04	5.19E-04	1.25E-03	1.56E-04	1.13E-04	1.52E-03
Nickel	g	2.16E-03	2.22E-03	7.25E-03	1.16E-02	1.45E-03	1.34E-03	1.44E-02
Olivine	g	7.85E-09	9.02E-09	1.29E-08	2.97E-08	3.70E-09	1.33E-08	4.67E-08
Sodium chloride	g	3.69E-02	2.85E-03	9.66E-03	4.94E-02	6.15E-03	8.05E-03	6.36E-02
Soil	g	0.00E+00	0.00E+00	1.24E+00	1.24E+00	1.54E-01	0.00E+00	1.39E+00
Sulphur	g	2.20E-05	7.53E-06	1.50E-05	4.45E-05	5.55E-06	3.94E-05	8.95E-05
Tin	g	1.66E-06	7.95E-07	1.69E-06	4.15E-06	5.17E-07	1.31E-06	5.98E-06
Titanium	g	2.89E-04	7.85E-05	2.56E-04	6.24E-04	7.76E-05	3.14E-04	1.02E-03
Zinc	g	1.80E-03	1.95E-04	5.41E-04	2.54E-03	3.16E-04	3.33E-03	6.18E-03
Zirconium	g	4.23E-05	1.20E-05	4.17E-05	9.60E-05	1.20E-05	5.01E-05	1.58E-04

Resource use	Unit/kWh	Upstream	Core operation	Core infrastructure	Total generated	Downstream T&D losses	Downstream other	Total distributed
Renewable material resources								
Wood	g	3.44E-11	2.42E-10	9.66E-11	3.73E-10	4.65E-11	4.58E-11	4.65E-10
Non-renewable energy resources								
Crude oil	g	4.60E-01	8.90E-02	3.48E-01	8.97E-01	1.12E-01	1.06E-01	1.11E+00
Hard coal	g	2.03E-01	6.80E-02	2.93E-01	5.65E-01	7.03E-02	3.60E-01	9.95E-01
Lignite	g	5.64E-02	1.13E-02	4.08E-02	1.08E-01	1.35E-02	4.85E-02	1.70E-01
Natural gas	g	2.73E-01	1.19E-01	1.36E-01	5.29E-01	6.58E-02	4.63E-02	6.41E-01
Uranium in ore	g	2.45E-02	1.39E-05	2.29E-05	2.45E-02	3.05E-03	1.13E-06	2.76E-02
Uranium in ore, primary energy	MJ	1.37E-02	7.79E-06	1.28E-05	1.37E-02	1.71E-03	6.30E-07	1.54E-02
Peat	g	4.48E-04	1.44E-04	7.08E-04	1.30E-03	1.62E-04	1.24E-04	1.59E-03
Renewable energy resources								
Energy, in biomass	MJ	6.87E-04	4.72E-03	1.91E-03	7.32E-03	9.11E-04	9.50E-04	9.18E-03
Energy, potential (in hydropower reservoir), converted	MJ	2.89E-03	8.83E-04	1.30E-03	5.07E-03	6.31E-04	1.26E-03	6.96E-03
Energy, solar, converted	MJ	6.38E-07	5.00E-04	4.38E-04	9.38E-04	1.17E-04	4.50E-07	1.06E-03
Energy, kinetic (in wind), converted	MJ	3.55E-04	3.64E-03	5.34E-03	9.34E-03	1.16E-03	5.17E-05	1.06E-02
Water resources								
Ground water	m3	6.82E-04	3.95E-04	2.25E-03	3.33E-03	1.18E-03	4.93E-03	9.45E-03
River water	m3	1.86E-02	3.42E-02	1.11E-02	6.39E-02	1.36E-01	9.38E-03	2.10E-01
Sea/salt water	m3	1.76E-04	9.81E-05	3.86E-04	6.60E-04	5.53E-04	1.27E-03	2.48E-03
Water, specified natural origin	m3	1.44E-05	1.32E-05	5.31E-04	5.59E-04	9.68E-05	8.84E-05	7.44E-04
Water, unspecified natural origin	m3	2.28E+01	1.10E+01	1.41E+01	4.78E+01	6.10E+00	1.04E+01	6.43E+01
Use of secondary material								
Aluminium	g	0	0	3.60E-03	ND	ND	0	ND
Steel	g	1.10E-03	3.81E-03	2.84E-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 losses	Downstream other	Total distributed
All hazardous wastes disposed	g	1.01E-04	1.57E-04	2.79E-04	5.37E-04	6.69E-05	9.88E-05	7.03E-04
Total radioactive wastes generated	g	ND	7.04E-03	2.25E-02	ND	ND	ND	ND
HLW generated	g	ND	3.66E-03	0.00E+00	ND	ND	ND	ND
ILW and LLW generated	g	ND	3.37E-03	2.25E-02	ND	ND	ND	ND
Depleted uranium, spent UF_6	g	ND	2.48E-03	ND	ND	ND	ND	ND
Total volume of repository needed for radioactive wastes as disposed	m^3	1.75E-08	9.45E-09	1.43E-08	4.12E-08	5.13E-09	1.62E-11	4.64E-08
Volume of repository needed for radioactive wastes as disposed, HLW/ILW	m^3	9.79E-12	6.38E-09	3.47E-09	9.86E-09	1.23E-09	5.00E-13	1.11E-08
Volume of repository needed for radioactive wastes as disposed, LLW	m^3	1.75E-08	3.07E-09	1.08E-08	3.14E-08	3.90E-09	1.57E-11	3.53E-08
Waste to recycling	g	ND	4.07E-03	3.41E-01	ND	ND	ND	ND
Materials for reuse	g	ND	0.00E+00	1.00E+00	ND	ND	ND	ND
Inert waste disposed of	g	1.80E-01	7.24E-02	4.73E+00	4.98E+00	6.21E-01	6.79E+00	1.24E+01
Other non-hazardous waste disposed of	g	2.22E-01	1.52E-01	3.99E-01	7.73E-04	9.62E-05	1.91E-04	1.06E-03

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

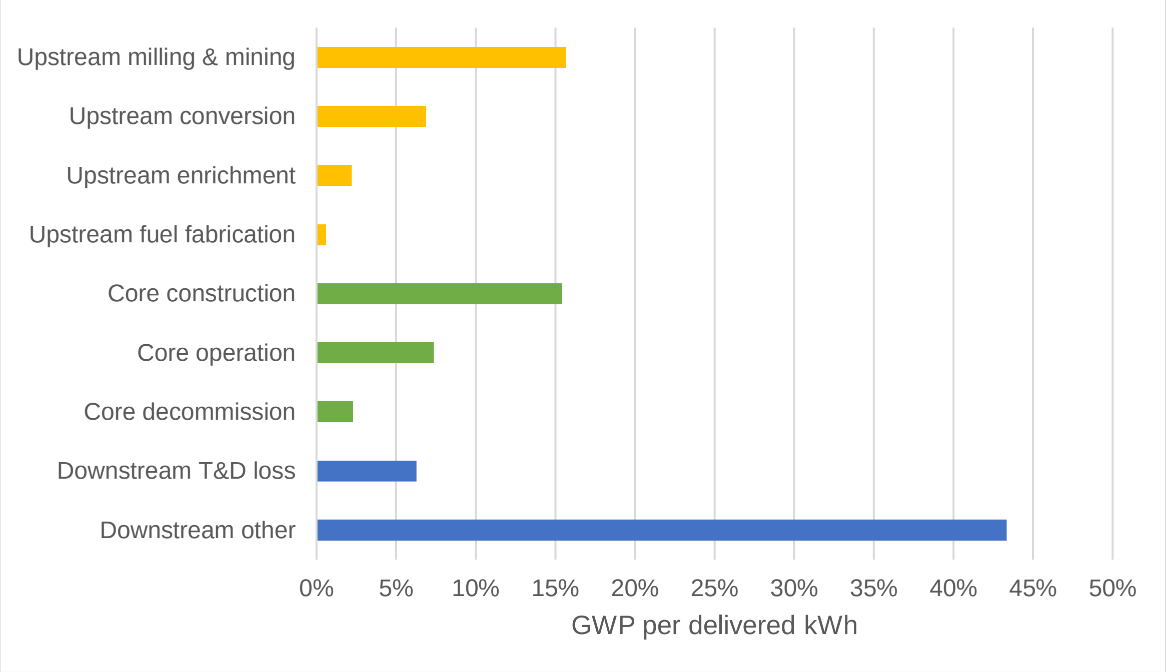
3.5 Life cycle results interpretation

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.

3.5.1 Global Warming Potential (GWP) by LC stage

Figure 4 shows how each LC stages contributes to the total GWP value associated with generating and delivering 1kWh of HPC electricity.

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



The total downstream stage is responsible for just under 50% of the total GWP value, with the majority of its contribution (87% of the downstream stage) associated with ‘downstream other’. This element of the downstream stage encompasses both the infrastructure and operational requirements of the grid itself. It includes impacts of materials needed for aspects such as metals needed for pylons and emission leakages of SF_6 insulation (a powerful greenhouse gas), as included in the ecoinvent dataset. It is these SF_6 emissions, alongside nitrous oxide (N_2O) emissions, that drive the GWP value in this ‘downstream other’ LC stage contributing approximately 34% and 36% of the ‘downstream other’ GWP value, respectively. According to the ecoinvent dataset, N_2O emissions may arise due to ionisation of air due to proximity to electromagnetic fields and high voltage lines.

After the downstream stage, the next two highest contributing stages are milling & mining, and construction of core infrastructure, responsible respectively for 16% and 15% of the total GWP value per delivered 1kWh (and 31% each to the total GWP value per generated kWh). 93% of the milling & mining contributions come from CO_2 fossil emissions, linked mainly to the energy consumption of these processes, in particular diesel combustion emissions. For construction of core infrastructure, the largest driver (47%) of the GWP value is CO_2 fossil emissions from upstream manufacture of the raw materials needed. CO_2 fossil emissions associated with construction diesel combustion and electricity consumption are the second and third drivers contributing ~15% each to the construction of core infrastructure stage.

3.5.2 Acidification Potential (AP) by LC stage

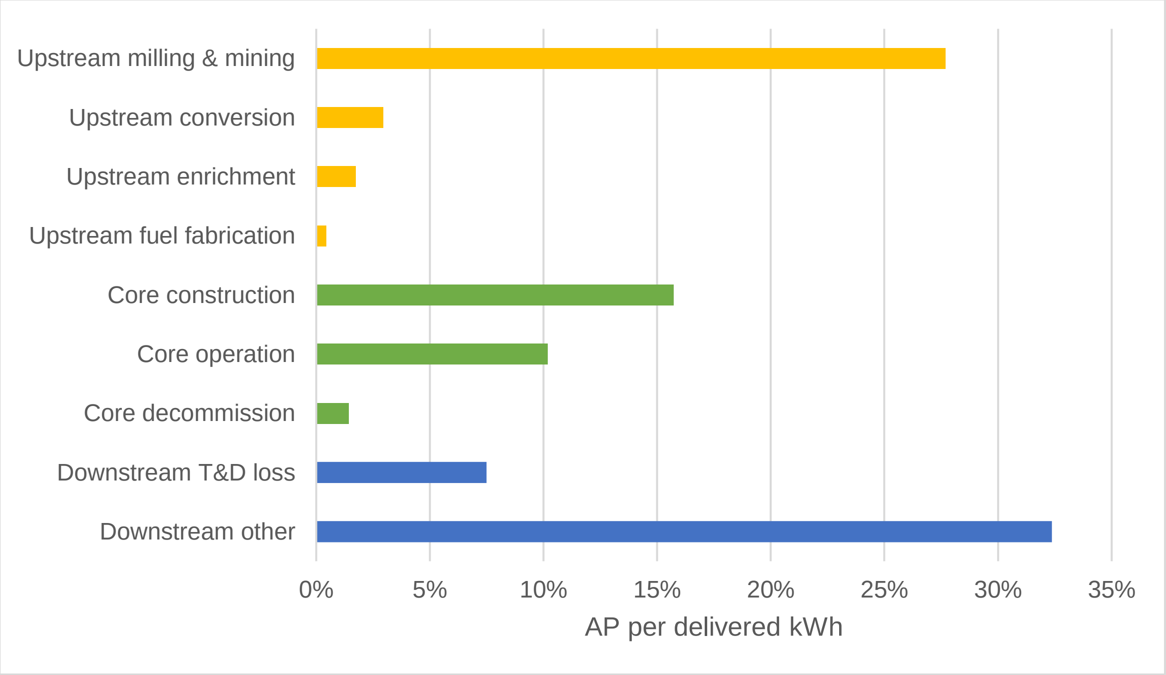
This indicator takes into the account acidic gases that react with water in the atmosphere to form “acid rain”, which can cause ecosystem degradation.

In terms of AP, sulphur dioxide gas emissions are responsible for half of the total value per delivered kWh and 39% of the total value per generated kWh, with a further 43% arising from emissions of nitrogen oxides. Hydrogen sulphide is responsible for 4%. These numbers per generated kWh are respectively 40%, 52% and 2%.

Figure 5indicates that the 'downstream other' stage is again most significant, being responsible for 32% of the total AP value per delivered kWh. 73% of the total AP value for 'downstream other' is from sulphur dioxide emissions for example those linked to grid infrastructure and related materials.

The upstream milling & mining stage is the second largest contributing stage, contributing 28% of the total AP value per delivered kWh and 46% of that per generated kWh. Top contributing emissions to this stage are nitrogen dioxide (68% of milling & mining AP), followed by sulphur dioxide (30% of milling & mining AP). These emissions are linked to the diesel combustion emissions that occur during mining and milling.

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



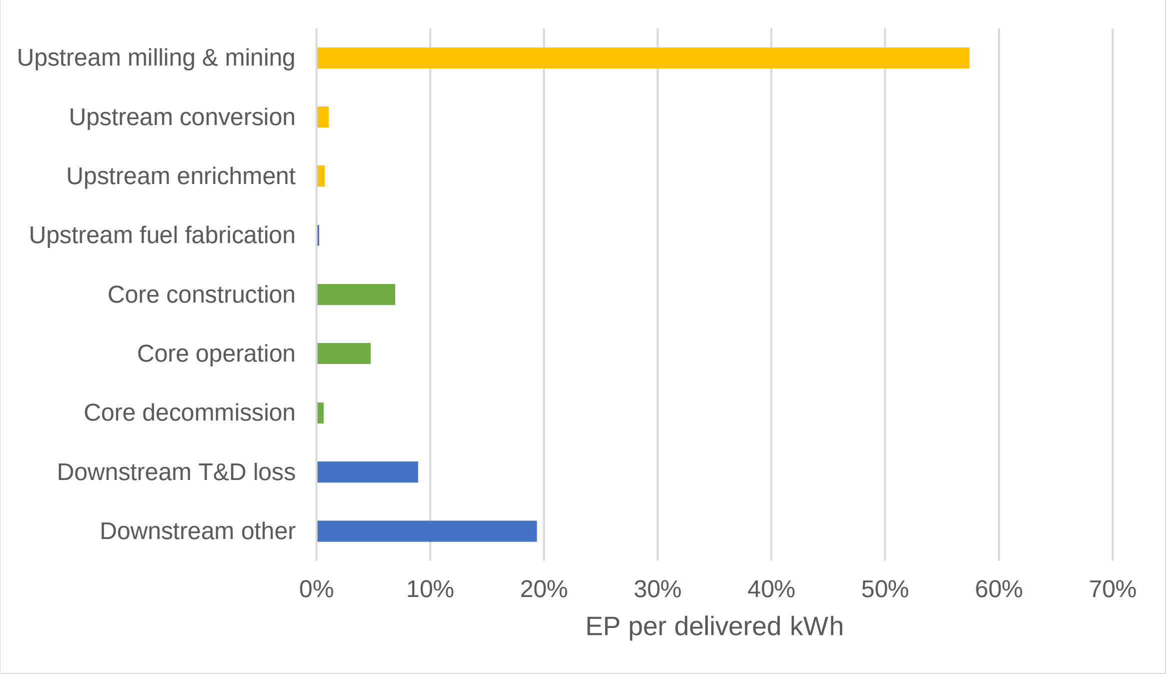
In terms of the core stages, construction of core infrastructure is responsible for 16% of the AP value. This is due to a combination of the upstream sulphur dioxide producing impacts of processing the construction materials required, particularly from copper wiring/cabling. Also, from nitrogen dioxides released during construction diesel combustion.

3.5.3 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 of nutrients such as phosphate and nitrogen, and of organic matter. In terms of EP relating to the generation and delivering of 1kWh from HPC, 50% of the substances that contribute to the total are nitrates and 35% are phosphates. In terms of total EP value per generated kWh only (not including downstream impacts), these values are 61% and 24%. Nitrogen containing oxides contribute 13% to the total delivered kWh EP value and 11% of 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 57% of the total EP value per delivered kWh comes from the upstream milling & mining stage, with 19% from the 'downstream other'. In terms of the total EP value per generated kWh, upstream miling & mining is responsible for 80% of this number.

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 nitrogen oxide 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 12% and 17% of the total EP value per delivered and per generated kWh, respectively. Roughly half of that value is from construction, largely related to upstream material manufacture, with copper responsible for 43% of the total AP value for this stage. The majority of the remainder for the core stage comes from operation (39% of all core stages) and is associated with materials (62% of core operation) and diesel usage (15% of core operation).

3.5.4 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.

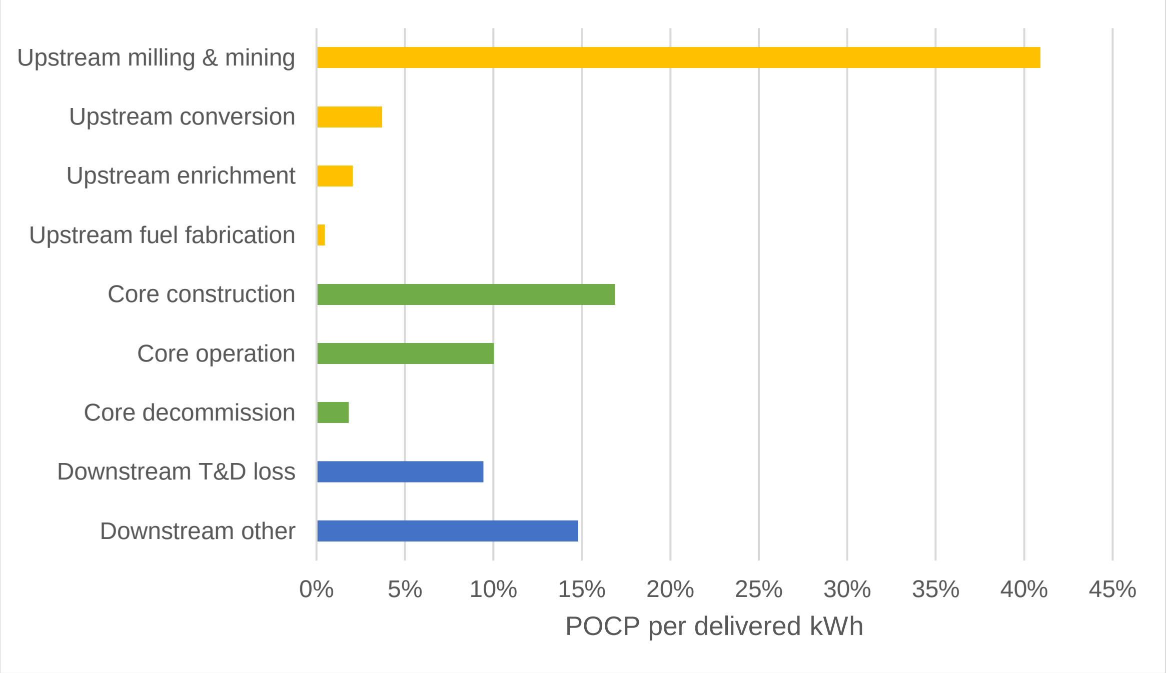
For the delivered kWh as modelled for HPC, 79% of these substances are nitrogen oxides, 12% are non-methane volatile organic compounds (NMVOCs) with the remainder being a mix of various sulphurous oxides and volatile organic compounds.

Figure 7 indicates that upstream milling & mining of uranium is responsible for the largest portion of the total POCP value per delivered kWh, contributing just over 40%. This equates to ~54% of the total POCP value per generated kWh. The construction of core infrastructure is responsible for 17% (or 22% in terms of per generated kWh) with 'downstream other' contributing a further 15% to the total POCP value per delivered kWh.

67% of the milling & mining POCP impacts are associated with the in-situ leaching of uranium dataset and arise largely from nitrogen oxides and NMVOCs emitted by diesel combustion. Diesel combustion emissions are responsible for ~84% of all milling and mining POCP impacts.

Emissions from the combustion of diesel required for HPC construction are the main contributors (~44%) to the core stage POCP allocation, whilst infrastructure material related emissions are responsible for most of the downstream stage.

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



3.5.5 Particulate matter by LC stage

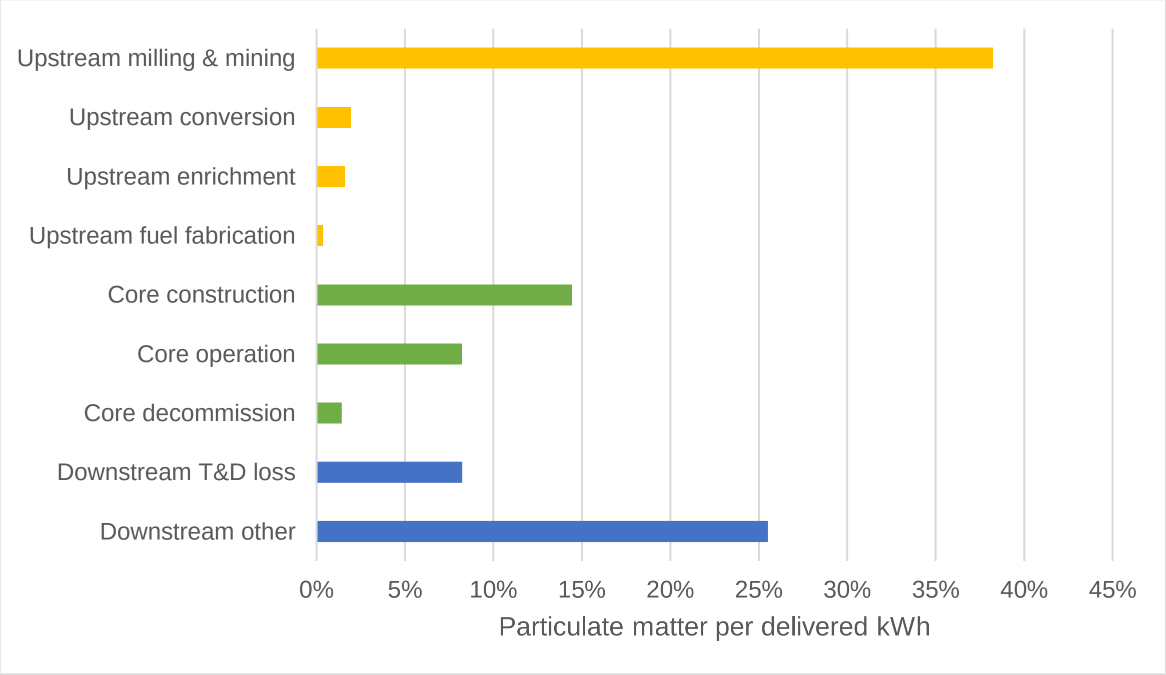
Particulate matter is a type of pollution formed from a mixture of solid particles and liquid droplets in the air. Fine particulates are a particular issue due to their ‘inhalability’ and the method (ReCiPe 2006 mid-point) used to calculate particulate matter quantities such emissions in terms of particles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

Fine particulates smaller than 2.5 microns are responsible for 46% of the total particulate matter value, with a further 35% coming from sulphur dioxide particles and 17% from nitrogen oxides. The rest of the total is from other sulphur and nitrogen containing compounds.

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 38%, 26% and 14% of the total particulate matter value per delivered kWh, respectively. This translates to 58% and 21% 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 materials, in particular sulphur dioxide which contributes 66% of the ‘downstream other’ total particulate matter value. In terms of the core construction stage, particulates from diesel consumption and those associated with upstream extraction and manufacturing of construction materials are the key drivers.

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

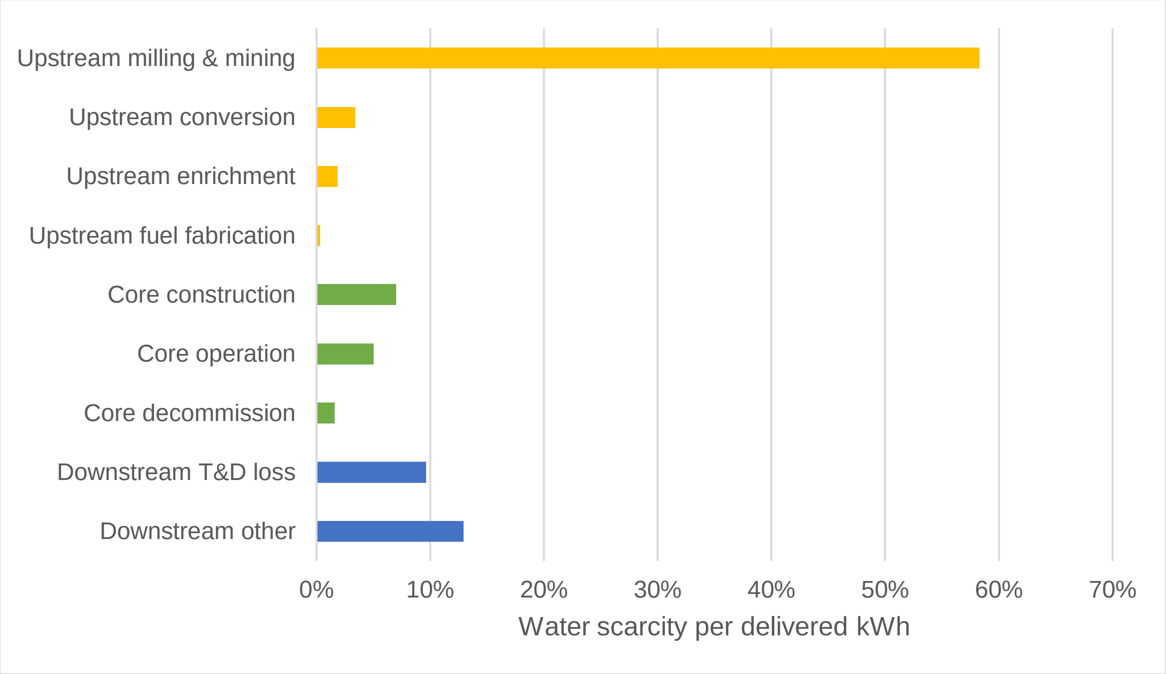


3.5.6 Water scarcity by LC stage

The AWARE method reports in terms of potential water deprivation to the ecosystem and humans. It takes into account 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 58% 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 value for water scarcity per delivered kWh



3.5.7 Sensitivity analysis

3.5.7.1 Concrete type sensitivity

As seen in the previous section, it can be seen that after the upstream stage (which is not under the control SZC Co and 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. Within this core construction LCA stage, it was observed that in general, the highest contributing substage was that of the materials required to construct the HPC development, particularly those associated with the steel and concrete used.

This sensitivity analysis has focused on the concrete type modelled, in particular, how sensitive the overall results would be to a different dataset being used, one based on a high density nuclear concrete whose properties are essential for radiation shielding. The main difference between ‘standard’ concrete and high density nuclear concrete is the type of aggregate used, with high density concrete requiring heavy weight aggregates such as magnetite or iron shot. The upstream material extraction and processing activities may be different to those of more traditional normal weight aggregates resulting in different embodied environmental impacts. Therefore, this sensitivity analysis has looked in more detail at how sensitive the key results of the model are to a high density nuclear concrete made with heavy weight aggregate. This concrete mix was provided by HPC Co and has already been used for some of the infrastructure built so far. It contains MagnaDense from LKAB as opposed to gravel and sands. A dataset was created based on this mix using other ecoinvent datasets and EPD data [10] for the MagnaDense material. This mix was swapped from the modelled ecoinvent dataset for the key main site infrastructures.

The use of the heavy weight mix concrete dataset, results in small changes to the key environmental impacts results for the core construction stage, and thus for those for the total generated kWh, the downstream T&D, and for the total delivered kWh. However, in terms of percentage of the existing HPC model, all changes from this sensitivity are within ±0.5% across all the key impact categories except for the particulate matter category. For this category, the result per delivered kWh is 1.6% higher and 2.2% higher per generated kWh. It should be noted that this is the environmental impact category for which a proxy value had to be used for the MagnaDense dataset as opposed to data from the MagnaDense EPD.

In terms of GWP-total, the total generated per kWh value decreases from 5.49g CO_2 eq to 5.48g CO_2 eq. and the delivered per kWh value decreases from 10.91g CO_2 eq to 10.89g CO_2 eq. Generally, the sensitivity analysis indicates that whilst substituting the dataset for normal concrete with that of heavy weight concrete in the key core main HPC infrastructures, the model is not highly sensitive to this change.

3.5.7.2 Step-up loss sensitivity

As mentioned in section 3.2.3, following analysis of the existing HPC model, SZC Co supplied an estimate of the likely step-up losses of as low as 0.21% and which would be applicable to HPC. Step-up losses occur when net electricity is transferred to the grid via the primary transformer at the SZC. This 0.21% value was based on engineering estimates by SZC Co. The sensitivity of the model to this reduction has therefore been tested by swapping the current 3% to the estimated 0.21%. This change affects only the downstream stage and thus the total delivered kWh value.

The key environmental impact results per LC stage showed that decreasing the step-up loss from 3% to 0.21%, decreases the total GWP per delivered kWh from 10.91g CO_2 eq to 10.66g CO_2 eq. For the other core environmental indicators, an average decrease of 2.5% is observed due to an approximate 25% reduction in the downstream T&D loss impacts. Changes to ‘downstream other’ are much lower with an average reduction of 1.2% across the assessed impact categories.

3.5.8 Global Warming Potential (GWP) focus

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

3.5.8.1 Global Warming Potential (GWP) absolute values

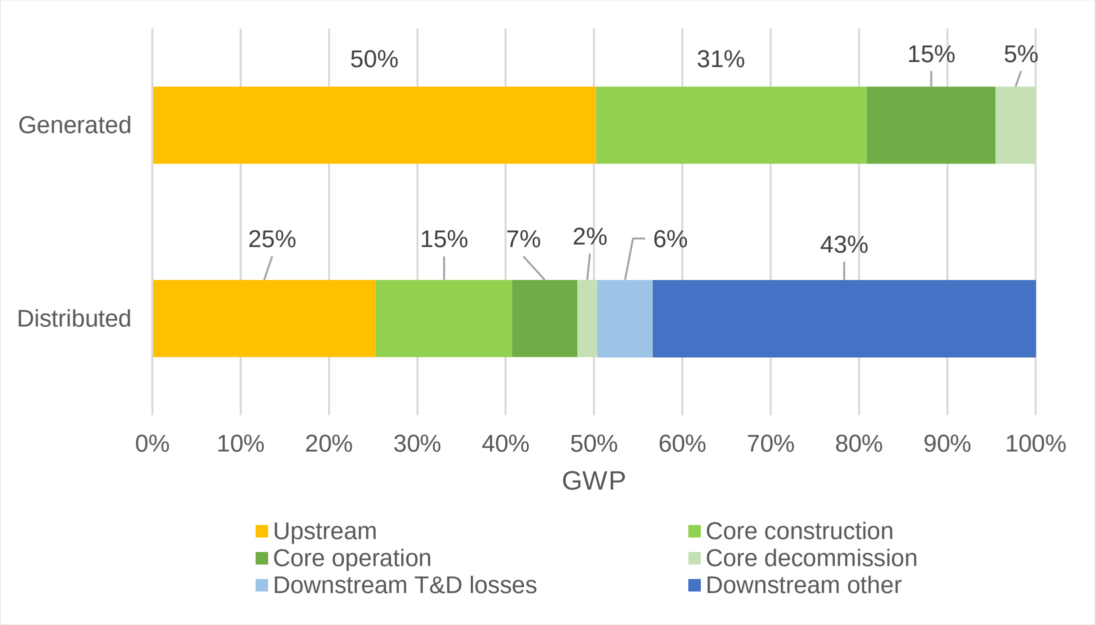
The estimated absolute GWP values over the total cycle of HPC are shown below in Table 10 for reference. These relate to the net generation and net delivered reference values given in Table 2 whilst the total delivered value relates to a higher net generated value that would be required to ensure that 1kWh reaches the downstream customer taking into account T&D losses, which sit in the downstream stage. The table indicates that the core stage, which is the LC stage that HPC has most control over, is responsible for 4,290,432t CO_2 eq. over its total life cycle.

Table 10: Total life cycle GWP values of HPC

Environmental impact	GWP (t CO_2 eq.)
Upstream	4,334,407
Core construction	2,641,571
Core operation	1,258,181
Core decommission	390,679
Total generated	**8,624,838**
Downstream T&D losses	1,074,021
Downstream other	7,421,693
Total delivered	**17,120,553**

A breakdown of GWP value for per kWh delivered electricity by each LC stage is shown in Figure 10below 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-lulac).

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



As seen in Figure 10, when considering the impacts of generating 1kWh of electricity at HPC, the upstream stage is responsible for half of the GWP impacts. This impact represents the nuclear fuel supply chain and is further broken down into its four key stages in the following subsections. The remaining 50% can be attributed to the core stage, with 31% coming from core construction (construction of HPC and infrastructure of offsite facilities such as waste treatment facilities). 15% arises due to operation of HPC and just 5% is associated with HPC 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. Almost half of the total GWP value associated with a delivered kWh of electricity from HPC, 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 6% of the total GWP value for a delivered kWh of electricity. This encompasses the additional impacts from generating electricity which are 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 a quarter of the total GWP value of delivering 1kWh of electricity.

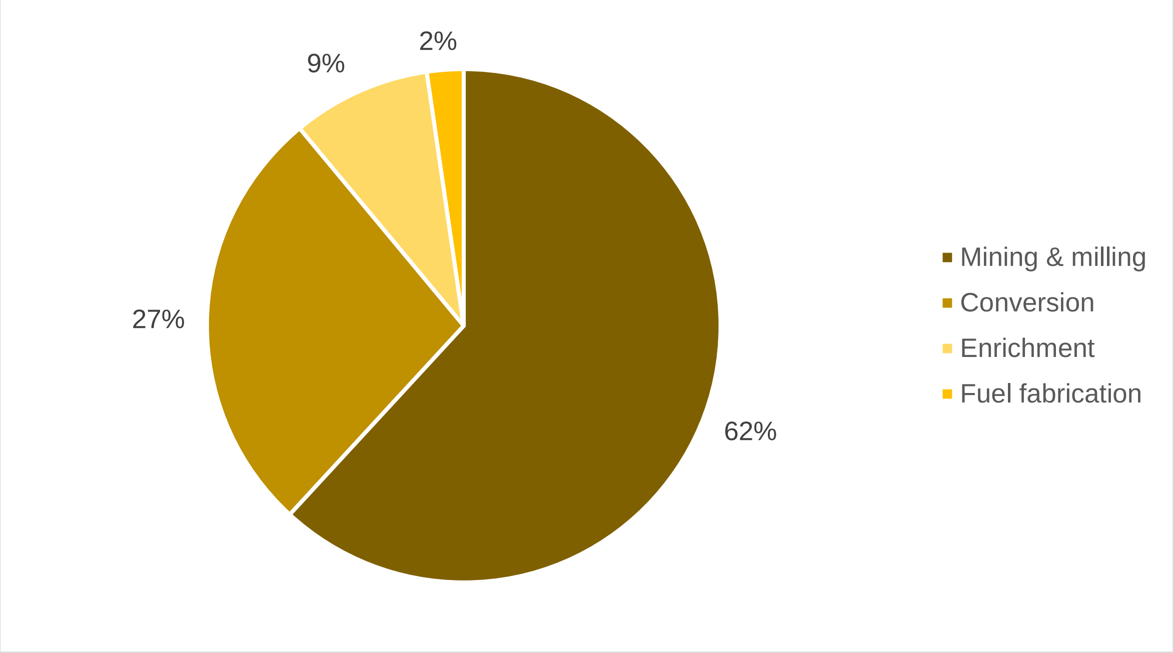
The next largest contributing stage is the construction of core infrastructure, which is responsible for 15% of the total delivered kWh GWP value. Core operation and Core decommissioning are responsible for 7% and 2% of the total, respectively. In total, core impacts account for the last 25% of the total 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.

3.5.8.2 Upstream

This section provides a breakdown of the four upstream LC stages’ GWP contribution. Together, these stages contribute a GWP value of 2.76g CO_2 eq. per kWh generated, over the 60-year operational life of HPC. 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



3.5.8.2.1 Milling and mining

Figure 11 shows that the majority (62%) of the upstream GWP impacts are associated with the milling and mining of uranium from nature. As no specific data was available, milling and mining was modelled using ecoinvent datasets. The largest GWP contribution (58%) 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%). 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 from 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, and no energy forecasting has been applied.

3.5.8.2.2 Conversion

The conversion process, whereby uranium ore is refined and converted to UF_6, is responsible for 27% 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.

3.5.8.2.3 Enrichment

The enrichment of uranium, as based on the process modelled, generates 9% of the upstream GWP impacts. SimaPro network flows indicate that this is largely due to the embedded enrichment facility infrastructure dataset (52%) and from the French electricity grid mix dataset, used for operating the centrifuge process (33%).

3.5.8.2.4 Fuel fabrication

The final stage of the nuclear fuel supply chain, prior to its transportation to HPC, 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%).

3.5.8.3 Core construction

This section explores the percentage breakdown of the GWP value assigned to core construction, part of the core infrastructure stage. Together, these processes or sub-stages generate a GWP value of 1.68gCO_2 eq. per kWh generated over the 60-year operational life of HPC. 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

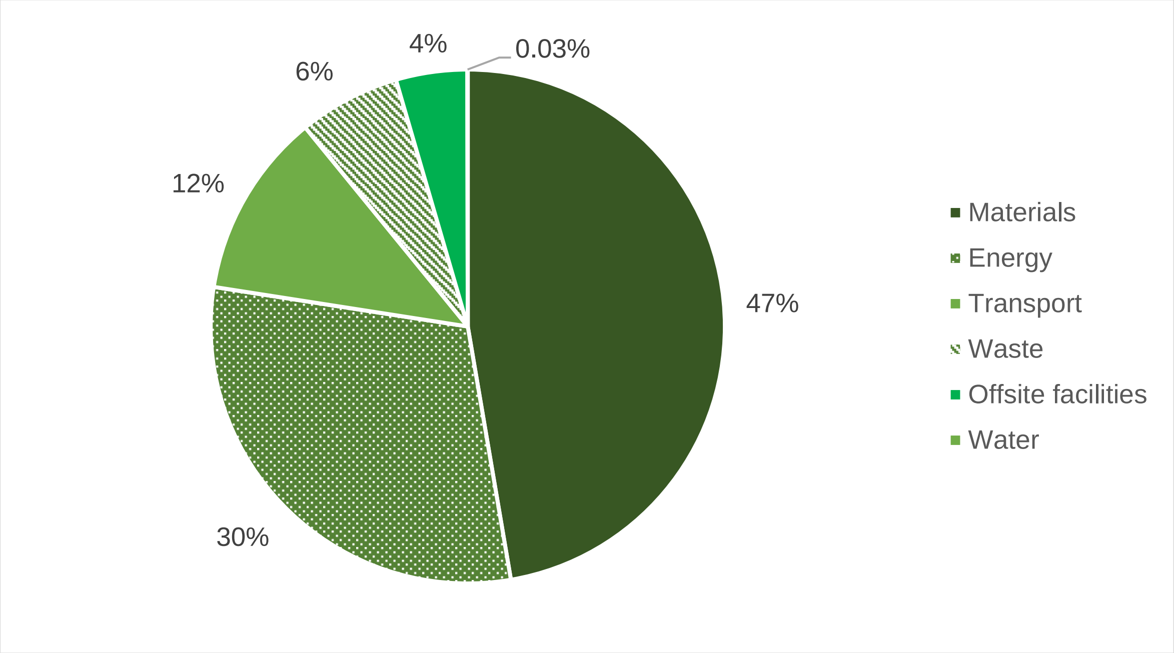


Figure 12 shows that 77% of the GWP value associated with construction of core infrastructure is from energy and material usage, with 47% from the embodied carbon of the construction materials required such as reinforcing steel (15%) and concrete (just under 10%), and 30% associated with the energy needed for constructing the HPC development. This energy relates to both UK grid electricity (based on current mix) and diesel. This split is approximately 50%/50% between the electricity and the diesel.

The transportation of construction materials and earth works to the HPC site and transport of construction wastes offsite, including waste soils, are together responsible for 12% 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 treatment and disposal of waste generated during the construction period is responsible for 6% of the total infrastructure construction GWP value. The infrastructure and operation of offsite facilities used for treating/disposing of operational radioactive wastes (as embedded with the ecoinvent datasets for radioactive waste disposal) is responsible for 4%.

The impact of water usage during construction can be considered to be relatively insignificant, at 0.03%.

3.5.8.4 Core operation

This section examines the percentage breakdown of the GWP value assigned to core operation of the HPC EPRs over their estimated 60-year life. Together, these processes or sub-stages generate a GWP value of 0.80g CO_2 eq. per kWh generated. This includes commissioning of the HPC reactors 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

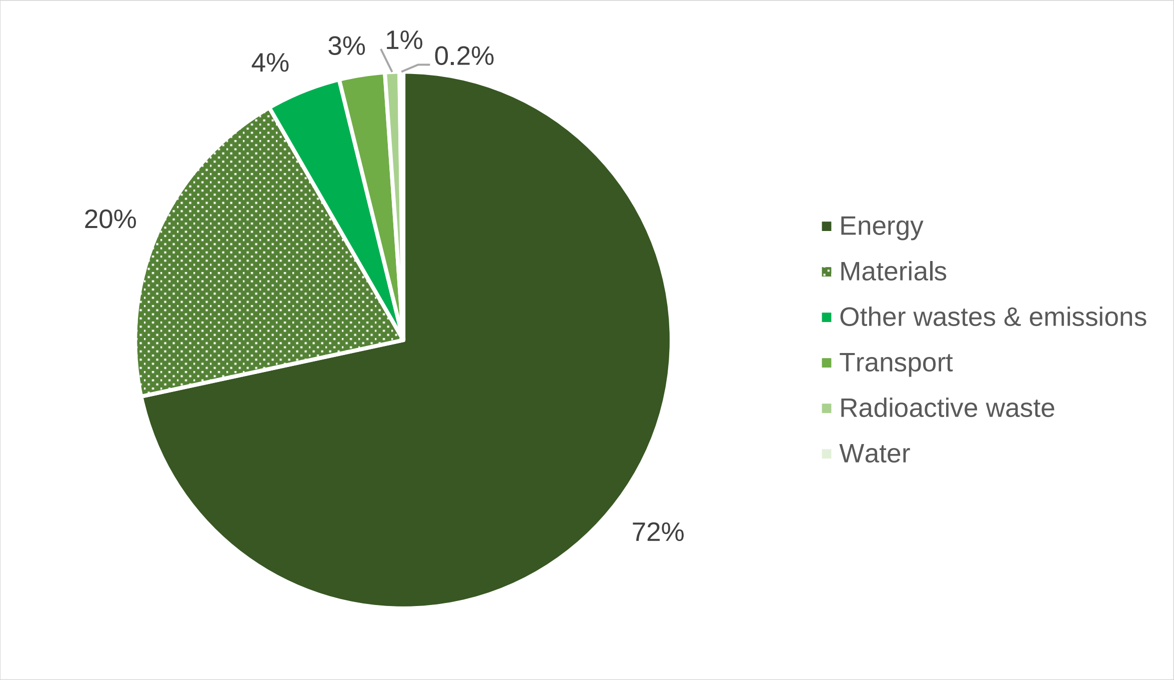


Figure 13 shows that in terms of core operation, 72% of the GWP value comes from energy requirements. This consists of electricity imports, modelled as per the forecasted 2026 UK electricity grid mix and diesel usage. The split of energy GWP value from electricity and diesel is 63%/27%, respectively.

20% of the core operation GWP value can be allocated to the materials needed for commissioning and operation of the HPC plant. This includes materials such as stainless steel that are required to package radioactive wastes generated during operation.

During operation, HPC Co expect to generate non-radioactive wastes, direct emissions to air and water. These cumulatively account for 4% of the core operation GWP value.

Transport of materials to site and of wastes from site to their respective offsite disposal or treatment locations contribute 3%. A further 1% 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.

Decarbonised water (the proxy dataset used to represent deionised water) contributes a relatively small amount of GWP (0.2%).

3.5.8.5 Core decommissioning

This section describes the percentage breakdown of the GWP value assigned to core decommissioning of the HPC development. Together, these processes or sub-stages generate a GWP value of 0.25g CO_2 eq. per kWh generated over the 60-year operational life of HPC. 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

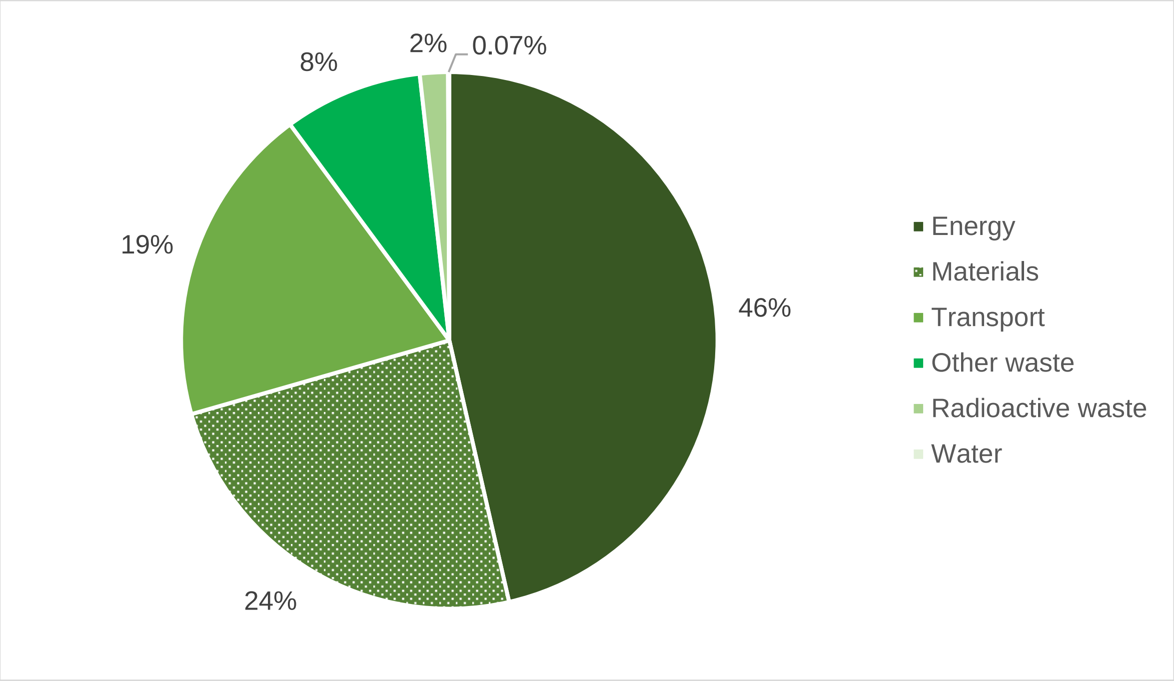


Figure 14 shows just less than half of decommissioning's GWP comes from the energy used. The GWP from energy usage is mainly contributed by the forecast 2050 UK electricity grid mix, and to a lesser extent, diesel, at a 84%/16% split, respectively.

24% of the decommissioning GWP value is from the embodied carbon of the materials needed for packaging radioactive waste.

Transport of packaging materials to site and of wastes offsite contributes 19% 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 unlikely to be used in the 2080s, instead replaced with 'greener' lower carbon fuels.

The disposal of non-radioactive wastes is responsible for 8% of the GWP value whilst the disposal of radioactive waste (rad waste) contributes only 2% to the decommissioning model. This lower associated GWP value is derived mostly from the operational energy and materials from within the GDF dataset. It should be noted that this is relatively low though as a 2040 electricity grid mix has been used to model the operation of the GDF.

Less than 0.1% of decommissioning GWP is from decarbonised water usage, such as that used in cooling pools at the HPC site.

3.5.9 Data quality and commentary

Other than the 0.03% mass of construction material inputs which have been excluded, and whose impacts are assumed to be more than covered by the uplifts applied to the other construction materials, no known flows into or out of the system have been excluded. Results show that construction materials are responsible for 47% of the core construction value, which in turn is 15% of the total GWP value for 1kWh of delivered electricity, meaning construction materials contribute approximately 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.

With all models, uncertainty exists. HPC Co has confidence that the data it has provided is reflective of the most up-to-date plans and data for the HPC development at the point of writing and has adopted a conservative approach to reflect any uncertainty or estimates required. Data from HPC Co is dated from within the past five years with the exception of the nuclear decommissioning data, where 2014 documents have been used, since these represent the most recent information and plans available at the time of writing (this reflects the current status of documentation for Hinkley Point C's Funded Decommissioning Programme).

Additionally, HPC Co has a high degree of confidence in the sources on which values are based. A 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 certain components, the density of materials and assumed locations of future disposal sites. However, HPC Co has applied rationale and adopted a conservative approach when applying these assumptions.

Specific data was also obtained from the potential future fuel fabricator and whilst it wasn't available from the most likely supplier of enriched uranium, specific data from that of the modelled SZC enricher was available for use. Whilst this data may change in the future prior to operation and whilst the enricher is different for SZC and HPC, it can be considered to be the most representative data available 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.

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 focusing on the GWP indicator. Looking at the uncertainty within the ecoinvent datasets themselves, it indicates with 95% confidence that results range from 9.44g CO_2 eq. to 11.5g CO_2 eq. / kWh delivered and from 4.55g CO_2 eq. to 6.36g CO_2 eq. / kWh generated.

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. This is relevant to fuel fabrication, where chromium was used in the place of zirconium, which is also the proxy selected in the generic ecoinvent dataset. However, fuel fabrication is responsible for 1% of the total GWP value for a delivered kWh of HPC electricity. It is also relevant for operational material inputs, where these proxy datasets, such as those used to represent the Hydrex chemicals, accounted for around 2% of the total operational material GWP value. Therefore, for the GWP impacts associated with known proxy data do not exceed 10% of the overall GWP impact from the product system.

Concrete is one of the key drivers of impacts in the core construction LC stage. A sensitivity analysis on the concrete dataset used has been carried out and indicates that modelling with a more specific potential high density nuclear concrete mix, will not have a significant impact on the key results per LC stage. This implies that the core interpretation of the GWP results is not likely to change and that the conclusions would remain relevant regardless of this change.

Overall, it is considered that the characteristics of data within the model are sufficient to meet the goal of the study. 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

4.1 Risk Management: Nuclear & Environmental Safety

Sections 4.2 to 1.5 below relate to environmental safety and radioactive waste management. Conventional hazards are addressed in a subsequent section [1.6].

Over the course of several decades, nuclear energy has been proven to be one of the safest forms of power generation. Safety and environmental protection are the overriding priority for power plant operators, and this is reflected in a combination of physical, organisational and cultural considerations including:

- Nuclear power stations are designed with safety and environmental protection as the paramount feature;
- The nuclear industry is overseen by stringent independent regulation and legislation which is underpinned by an extensive scientific base;
- The industry is characterised by a culture that prioritises safety and environmental protection, continuous improvement; and
- There is a very high degree of industrial collaboration to facilitate knowledge sharing and operating experience with the aim of disseminating best practice and improving achieved safety standards.

The following sections describe the factors above and the potential radiological impacts of HPC to humans and the environment.

4.2 Regulation and Legislation

4.2.1 Regulatory Authorities

The main authorities responsible for nuclear regulation in the UK are the Office for Nuclear Regulation (ONR) and the Environment Agency (EA).

The ONR is responsible for the regulation of nuclear safety and security across the UK. The ONR achieves this by working with other international regulators to identify safety and security issues of common concern and identify best practices that are applied internationally. The ONR ensures that these issues are satisfied in the UK by issuing – and monitoring compliance with – nuclear site licences [11].

The ONR enforces the licensing process under the Nuclear Installations Act 1965 (as amended), which gives them authority to grant a licence to an operator to build, operate and decommission a nuclear facility such as a power station. The ‘Site Licence’ [12] is specific to the site and design of the power station. This includes a list of 36 standard conditions that must be met (for example having a Safety Case, trained operators, maintenance of plant, operating rules, number of installations permitted, storage of radioactive substances, etc). As a licence holder, the operating company must by law comply with the requirements. The nuclear site licence granted by the ONR is a legal document and is issued and must be complied with for the full lifecycle of the power station from design and construction through to decommissioning.

The EA is responsible for the regulation of environmental protection across England. They work with a wide range of businesses and organisations to manage the use of their resources; to increase their resilience to flooding and coastal erosion; and to protect and improve water, land and biodiversity. With regards to nuclear generation, the key activities which require permitting by the EA under the Environmental Permitting (England and Wales) Regulations 2018 (as amended) [13] are:

- Radioactive Substances Activities – under the Radioactive Substances Regulations (RSR) (Schedule 23)
  - An operator will need an RSR permit in order to receive/dispose of radioactive waste, and / or to keep/use mobile radioactive apparatus.

  - The RSR permit is held by the operator and includes a list of 52 permit conditions relating to Management, Operations, Disposal & Monitoring of Radioactive Discharges, and Notification.
  - Some elements under schedule 23 are not applied to a nuclear licensed site by virtue of the site licence already regulating these aspects (e.g., the accumulation of radioactive waste). A Memorandum of Understanding is in place between the EA and ONR to enable close working and consistent regulation.
- Water Discharge Activity (WDA) (Schedule 21)
  - Required to allow the discharge of non-radioactive cooling water and trade effluents from HPC back into the sea (cooling water comes from and returns to the sea);
- Combustion Activity (CA) (Schedule 1 (Part 2, Chapter 1, Section 1.1))
  - Required to allow the operation of the diesel generators in the unlikely event the power station experiences a loss of normal onsite or offsite power supply. The permit also covers the routine testing running of the diesel generators.

The operating HPC site will also have a Marine Management Organisation (MMO) licence for works associated with the forebay, as per the current nuclear fleet. The MMO is an executive non-departmental public body of the Department for Environment, Food and Rural Affairs who license and regulate marine activities in the seas around England and Wales.

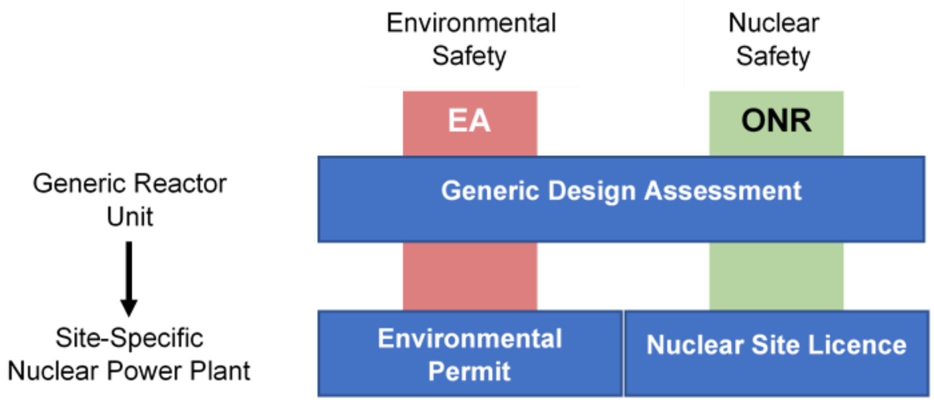
The operator must maintain compliance with all conditions stated within each permit whilst they are performing associated activities; throughout the design, construction, operation and decommissioning of the plant. If the operator does not comply with the permit conditions they are in breach of the law. HPC also complies with a number of other consents which they operate under for the construction phase of the project, including EA permits, Local Authority permits and MMO licences.

4.2.2 Regulatory Framework

The UK new nuclear regulatory framework is split into the three following key components as seen in Figure 15:

- Generic Design Assessment (GDA)
- Nuclear Site Licencing
- Environmental Permitting

Figure 15: Visual overview of the UK new nuclear regulatory framework



4.2.2.1 Generic Design Assessment (GDA)

The GDA is an assessment of potential reactor unit designs planned for operation in the UK. It is a joint process undertaken by the ONR and the EA in which they can engage with a prospective nuclear reactor vendor. This ensures that nuclear safety and environmental protection are incorporated into a reactor design from an early stage. The process focusses purely on the reactor design of a single unit at a generic ‘site’ and does not consider any site-specific issues. The GDA assesses whether the reactor design can theoretically meet the UK nuclear regulatory requirements and is a precursor to the site-specific assessments which assess whether the design meets regulatory requirements when constructed at a specific location.

The regulators undertake a technical assessment of the submissions provided by the reactor designer vendor and provide advice about any issues they identify, thus allowing issues to be resolved at an early stage. It is an extensive and rigorous process, taking four to five years and requiring significant resource and effort to ensure the ONR and EA’s high standards are met. The process is systematic and contains four steps, with the assessment becoming increasingly detailed as the process develops. The GDA is also open and transparent – the regulators publish reports at the end of each step. This means that anyone can view the detailed design information and have the opportunity to comment on it via the GDA comments process [14].

4.2.2.2 Nuclear Site Licencing

The safety of nuclear installations in the UK is regulated through the nuclear site licence and the conditions attached to it. A nuclear site licence has to be obtained and retained in order to construct, operate, and decommission a nuclear power plant.

When assessing licence applications, the key themes for consideration relate to:

- Demonstrating suitable capability, resources and arrangements within the applicant corporate body for each stage of the project;
- Proposed activities at the site and relevant safety case, ensuring risks are eliminated, or reduced As Low As Reasonably Practicable (ALARP) – see below;
- The nature and location of the site.

Once the licence is granted, it will be contingent on a variety of conditions, which includes having suitable and sufficient operational and management arrangements in place to ensure nuclear safety. Each licence will have 36 standard conditions attached to it. These conditions cover the full lifecycle of the plant: design, construction, operation, and decommissioning [15].

Throughout the life of the plant, the ONR will rigorously check compliance with the licence conditions by making site visits, continued assessments of safety performance and compliance with the safety case (see below) and management arrangements. If the power station is found to be non-compliant with any of the conditions stated within its licence or operating the plant in a way that is outside of the safety case there is a wide range of enforcement mechanisms available to ONR – from the provision of advice, through to prosecution – in accordance with the ONR’s Enforcement Policy Statement and the Regulators Compliance Code [16].

Safety Case

Under the Nuclear Site Licence, the applicant must submit and maintain a safety case throughout the life cycle of the power station. The term “safety case” encompasses the totality of the documentation developed by a licensee to demonstrate high standards of nuclear safety and how the plant with be safely operated [17].

The safety case describes the hazards considered in the design of the plant and how the plant is designed to ensure its safe operation in terms of materials, controls, construction methods, engineering standards etc. In this way it describes the things that can go wrong at the plant and provides evidence for how the plant is designed to prevent these occurring. It also clearly shows the boundary of the hazards the plant is designed for - the ‘Design Basis’ of the plant. The nuclear safety case provides the information required to allow the safe operation of the power station and UK’s strict safety standards to be maintained [18].

In order to meet the high safety standards of the nuclear industry, the safety case must consider any fault/hazard that is deemed ‘credible’ by the operator or regulator. A design fault is deemed ‘credible’ even if it has a very low probability of occurring by itself (for new nuclear stations, probabilities with a likelihood greater than approximately 1 in 100,000 years [19] are considered [20]) and are also considered in combination with other credible faults. Examples of ‘credible’ faults include (but are not limited to): Equipment failures; operator error; and internal/external hazards such as fire, earthquakes, and airplane crashes.

Probabilistic assessments are also provided for the worst-case scenarios when multiple faults may occur at one time. This is due to their potential for serious consequences such as a core melt accident. The probability of an event causing core damage to the UK EPR^{TM} resulting in a large radiological release (the United Kingdom defines a large release as involving 104TBq of iodine-131 (I-131) or 200TBq of cesium-137 or 200TBq of other isotopes [21]) is less than 1 in 5,000,000 per reactor per year. This isn't accounting for any safety features designed into the EPR^{TM} which would mitigate the early or large release of radiation in the event of core damage. In context, this is equivalent to a meteorite with a diameter larger than 1km striking the earth leading to a catastrophic event [22].

In summary, the purpose of the safety case is to do the following throughout the life of the station:

a) Ensures that all potential hazards and faults have been identified
b) Demonstrate that the risks associated with operating the power station are either eliminated or where that is not possible, suitable and sufficient controls are in place such that the risks have been reduced to a level that is ALARP

The "As Low As Reasonably Practicable" (ALARP) Principle

The "ALARP" principle (a requirement of the Health and Safety at Work act [23] is fundamental to nuclear safety in the UK – in simple terms it is a requirement to take all measures to reduce risks associated with a hazard where reasonable.

Throughout the life of the station, it is necessary for the operator to demonstrate that they are continuing to meet the ALARP principle: by identifying, analysing potential hazards and risk, learning from operational experience; and keeping abreast of developments in knowledge which may impact the ALARP argument.

4.2.2.3 Environmental Permitting

The environmental safety of nuclear installations in the UK is primarily secured through the three previously mentioned operational environmental permits, and the conditions attached to them. All of which must be obtained and retained in order to legally operate a nuclear power plant.

When assessing permit applications, the key themes for compliance relate to:

- Maintaining suitable capability, resources and arrangements within the operator at each stage of the plant lifecycle.
- Proposed activities at the site and the relevant environment case; ensuring radiological or conventional impacts on people and the environment are eliminated or optimised in line the Best Available Technique (BAT) principle (see below).

Throughout the life of the plant, the EA will rigorously check compliance with the permit conditions by performing inspections and continued assessments of management arrangements, operational discharges and application of BAT. If the operator is found to be non-compliant with any agreed permit conditions (i.e., insufficient organisational capability, discharging more than what is agreed in the permit) the EA will provide advice and guidance to assist re-compliance with the permit. However, they may take enforcement action which may start with advice and guidance to assist returning to a compliant position. If not addressed in a timely fashion or the event was sufficiently serious in the first place can include further enforcement including the issue of a formal caution; prosecution; the service of a notice; and/or the suspension or revocation of the permit in accordance with the EA's Enforcement and Sanctions Policy [24].

Environment (BAT) Case

A summary of the Environment Case was submitted during the RSR permit application, which must be maintained throughout the life cycle of the power station. It is used to describe and justify the application of BAT within the HPC design and operator throughout the lifetime of the project.

This document highlights the designs, techniques, and materials used to reduce the amount of radioactive waste that is created and disposed of to the environment; and where disposal is unavoidable, any further techniques to ensure that the impact of such disposals are As Low As Reasonably Achievable (ALARA). These designs, techniques and materials are divided amongst overarching claims which focus on:

Reducing the amount of radioactive waste requiring discharge or disposal;

Reducing discharges to the atmosphere and to the sea;

Reducing the impacts from discharges to air and water; and,

Efficient management of solid wastes.

Below these claims sit a number of arguments, sub-arguments and evidence to support the justification that BAT is being applied in the design of the power plant.

Additionally, in relation to the Environment Case and explicitly mentioned in the RSR permit conditions, is the requirement for a Waste Management Plan (WMP) and a Site-Wide Environment Safety Case (SWESC). These must further demonstrate that the radioactive waste will be managed over the whole lifetime of the site, and how the site will be brought to a condition where it can be released from regulation.

Best Available Technique (BAT)

BAT for RSR environmental permit:

The concept of BAT has been formally defined as part of the RSR environmental permit:

"The latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste. In determining whether a set of processes, facilities and methods of operation constitute BAT in general or individual cases, special consideration shall be given to:

- *Comparable processes, facilities or methods of operation which have recently been successfully tried out;*
- *Technological advances and changes in scientific knowledge and understanding;*
- *The economic feasibility of such techniques;*
- *Time limits for installation in both new and existing plants; and,*
- *The nature and volume of the discharges and emissions concerned."*

The "best available technique" for a particular process will change over time in the light of technological advancements, and changes to economic and social factors.

The BAT principle is applicable to specific elements of all three of the operational environmental permits however is demonstrated in different ways depending on the permit.

BAT for CA environmental permit:

The concept of BAT is implicit within the conditions of the CA environmental permit and is defined in the Environmental Permitting (England and Wales) Regulations 2016 (as amended):

"best available techniques" means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole, where—

- *"techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;*
- *"available techniques" means those techniques developed on a scale which allows implementation in the relevant industrial sector, under economically and technically*

viable conditions, taking into consideration the costs and advantages, and which are reasonably accessible to the operator; and

- *"best" means most effective in achieving a high general level of protection of the environment as a whole.*

This definition of BAT is derived from the definition presented in Article 3(10) of the Industrial Emissions Directive.

BAT for WDA environmental permit:

Due to the way in which nuclear power stations are permitted through the Environmental Permitting (England and Wales) Regulations 2016 (as amended), permits for discharges of cooling water and trade effluents are issued and regulated under Schedule 21 (Water Discharge Activities) rather than Schedule 1 (Installations). The concept of BAT is not applicable under Schedule 21 activities. Regardless of this, the concept of BAT described for the CA permit (above) is applied to all activities under the WDA permit by both the operator and the regulator.

4.3 Radiological Impacts to People and the Environment

The atoms of some elements found in nature, or produced artificially, are slightly unstable and to achieve greater stability, they emit ionising radiation. These atoms are referred to as radioactive.

Radioactivity occurs in the natural environment, it is encountered every day through the consumption of food and water, and the inhalation of air. It is also in building materials and items commonly used in everyday life as well the natural environment and cosmic radiation.

As part of the operation of HPC, radioactive materials will be both used and generated by the nuclear reaction. This will result in small quantities of radioactive substances (gases, liquids and aerosols) being discharged during the normal operation of HPC. These emissions may result in a small contribution to the daily radiological dose (measure of radiation exposure) from other sources to human and non-human organisms in the local area surrounding the power station. In addition, those who work at the HPC plant may also receive a small daily radiological dose.

It is important to note that radiation emitted from the normal operation of HPC is 1000 times lower than the average background radiation from living in the UK from natural sources [25].

4.3.1 Dose Impact to Workers

This section concerns annual dose to personnel on the HPC site. The impacts to HPC workers will be regulated under the Ionising Radiations Regulations 2017 (IRR) [26]. These implement the European Council Directive 2013/59/Euratom of 5 December 2013 [27] laying down basic safety standards for the protection against the dangers arising from exposure to ionising radiation.

The anticipated radiation exposure to workers have not yet been quantified for HPC. On this basis a value has been estimated based on those staff who work at operational Nuclear Power Stations in the UK. The UK Health and Safety Executive has reported an average dose to a Classified Worker (those likely to receive the highest radiation exposures) in the UK Nuclear Industry, as 0.5mSv/yr [28].

In terms of upstream fuel production, as HPC is not yet operational and will also be purchasing uranium from the market, it will not be possible to determine facility specific dosages in mSv directly from the future HPC specific fuel supply chain. For the purposes of this report, various annual dosage to personnel for the assumed key upstream sites as per the LCA have been collected from publicly available reports from the respective companies and organisations. These values are given in Table 11. It should be noted that available values sometimes referred to a specific location, and sometimes appear to refer to across the organisation's activities in general. The year to which values referred to also varies based on availability.

Table 11: Summary of average dosage to personnel for the assumed upstream locations and facilities

LC stage	Facility	Average annual dosage to personnel (mSv)	Year
Underground mining	Cigar Lake Mine, Saskatchewan, Canada [29]	0.57	2019
ISL mining	Muyunkum and Torkuduk mines, Kazakhstan [30]	1.47	2018
Open cast mining	Rossing mine, near Swakopmund, Namibia [31]	1.4	2019
Conversion	Malvési [32] and Pierrelatte (Tricastin) facilities, France [33]	0.039 & 0.03	2019
Enrichment	Orano facility, Pierrelatte, France [33]	0.03	2019
Fuel fabrication	Framatome facility, Romans-sur-Isère, France [34]	0.75†	2019

† Average occupational dose for Framatome employees

4.3.2 Dose Impact to the Public

Estimated annual dose for the candidate representative person (CRP) for HPC is shown in Table 12 separated into the contributions from each exposure pathway. A CRP is “defined with habits that might potentially result in them receiving the highest dose” [25]. The CRP in the case in Table 1 is for the highest dose to a member of the farming family subject to terrestrial and marine exposures. These data are taken from Table 15 of the HPC RSR Permit application submitted in July 2011 [25].

Table 12: Annual dose to members of the public HPC (mSv)

Terrestrial Pathways	Marine Pathways	Direct Radiation	Total
0.0044	0.0001	0.000001	0.0045

As shown, the direct radiation exposure to the CRP and other members of the public will be negligible due to the shielding design of HPC reactor and waste storage buildings (which uses components and materials to prevent radiological spread) [35].

The majority of the dose comes from small radiological discharges to the atmosphere and to the marine environment during operation, however these are still well below that of the annual dose limit for members of the public under IRR’17, and well within the relevant constraint of 0.3mSv/y set down by the Environmental Permitting (England and Wales) Regulations [36]. Dosage from discharges from HPC total dose is a very small proportion (approximately 0.015%) when compared to this constraint.

Another potential contributor of dose to the public which must be considered is in the dose resulting from the disposal of solid radioactive waste and spent fuel off-site at appropriately permitted facilities in the future. Low Level Waste (LLW) will be disposed of at facilities such as the LLWR in Cumbria. HPC has obtained disposal in principle agreements from a number of radioactive waste service providers to demonstrate that these wastes are compliant with current waste acceptance requirements and can be disposed against current standards. These facilities are required to comply with the same requirements in the Environmental Permitting regulations with regards public doses. These facilities will also be subject to the same stringent regulation. These disposal facilities will also have an environmental safety case in place to demonstrate the safety to the environment over the long term. The radioactive waste from HPC represents a very small proportion of the overall waste disposed of at these facilities. As part of their permitting requirements these facilities have also demonstrated that they will operate under the dose constraints outlined in the regulations. It is not possible to specifically split out HPC contribution to the dose. All fuel generated at HPC, once used in the reactor and considered ‘spent’, is removed and stored in a passively safe state in an on-site interim storage facility. It will remain there until long term storage becomes available in the UK, in the form of a geological disposal facility (GDF).

Radioactive Waste Management (RWM) is a subsidiary of the Nuclear Decommissioning Authority (NDA), and was established as the government organisation responsible for planning and delivering geological disposal in the UK. As part of this process, RWM has created a generic Disposal System Safety Case (DSSC), a set of documents that considers the safety and environmental implications of the geological disposal of radioactive waste. One of the supporting documents of the DSSC is the operational environmental safety assessment (OESA).

Illustrative calculations of dose to members of the public from gaseous emissions have been undertaken as part of the OESA based on the entire inventory of all waste and spent fuel disposed of in the GDF.

Annual doses to members of the public (local resident family receptor group) resulting from peak gaseous emissions to the atmosphere during the operational period in the base scenario are calculated to be 0.17mSv/yr [37], however a large proportion (approximately 65%) of this comes from naturally occurring radon. RWM also looked at a bounding case which it recognises ”is not likely to reflect reality” which resulted in a dose of 0.28mSv/y. RWM also noted that the dose estimated of 0.17mSv also "incorporate significant conservatisms”.

The OESA calculations and report will be updated, in line with updates to the DSSC, as part of each major stage of the GDF development programme, as design choices evolve. Discharges are also very site specific so their management will need to be adjusted according to the chosen site.

4.3.3 Dose Impact to Non-Human Biota

Through its permitting process, the EA demonstrates that it has met it obligations under the Conservation of Habitats and Species Regulations 2017, as amended by the Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019 to ensure that no EA permitted activity results in an adverse effect, either directly or indirectly, on the integrity of Natura 2000 sites.

As part of HPC's permit application in 2011 an assessment was undertaken using the internationally established ERICA tool, with the exception of noble gas releases which were modelled using the EA’s Research and Development Report (R&D) 128 Methodology.

The assessment considered a number of reference organisms which are considered to be representative of the HPC ecosystem. The selection of reference organisms is based on habitat and feeding habits.

The assessment considered predicted discharges from HPC and also these discharges in combination with discharges at permitted limits from Hinkley Point A and B (HPA and HPB) power stations.

- 40µGy h^{-1} for terrestrial animals;
- 400µGy h^{-1} for terrestrial plants;
- 400µGy h^{-1} for freshwater and coastal organisms;
- 1,000µGy h^{-1} for deep ocean organisms.

As such, based on the international recognised models used in HPC Co’s assessment, the output of which are below the most stringent assessment levels (10µGy h^{-1}), it can be concluded that there would be no significant effects on any Natura 2000 site. Likewise, no significant effects are predicted on any other ecological receptor or designated site, such as Sites of Special Scientific Interest (SSSI) and nature reserves that are within or adjacent to the assessed habitats [38].

4.3.4 Upstream risks

Upstream risks are related to the processes associated with the planned nuclear fuel source chain. HPC is not due to be operational, and thus require nuclear fuel, until 2026. For this reason, HPC has no current stock of nuclear fuel and the future nuclear fuel route is not determined. For the purposes of this study, it has been assumed that fuel fabrication will be carried out by Framatome in France and enrichment by Orano in France. The upstream environmental risks associated with the fuel are likely to be similar to the upstream risks of currently operational nuclear power plants. Furthermore, HPC may consider fuel routes that reduce or remove the amount of virgin converted uranium product (for example by using reprocessed spent fuel or underfeeding at the enrichment stage). For the purposes of this document, a summary of the risks has been provided below:

4.3.4.1 Mining

In many respects, uranium mining is similar to other forms of mining. The OECD has reported that uranium mining is *'now the most regulated and one of the safest forms of mining in the world* [39].*'*

Mined uranium is typically extracted from underground and open pit mines. Although uranium is naturally radioactive, it is not highly radioactive in its natural state; therefore, it is not deemed to pose a radiation health risk from exposure. The main health risk of natural uranium is in its chemical toxicity, which can cause kidney damage if inhaled or ingested in sufficient quantities. Therefore, the wastes from uranium mining require careful handling and treatment to avoid adverse impacts on the local environment of the mine. Once the uranium has been extracted, the residual materials – the tailings – will be deposited in pits or dams.

Risks from mining that can lead to contamination of the environment, with adverse effects on flora and fauna can include inadequate cleaning of water, accidental emissions to air, spillage/leakage of chemicals and radioactive elements, and leakage from landfills and sludge pools. However as long as stringent controls are in place and maintained these risks can be controlled.

4.3.4.2 Conversion

Two different processes are typically used for this step: in one, yellowcake is converted to uranium trioxide, and then to uranium hexafluoride (UF_6) and uranium dioxide (UO_2); in the other, natural uranium is first converted to uranium tetrafluoride (UF_4) and then to UF_6.

The leakage of UF_6 and of hydrogen fluoride (HF), when exposed to moisture, are the main risks associated with these processes, as UF_6 is highly corrosive, as is HF, which is also highly toxic and volatile. From a human health perspective, the chemical toxicity of HF is more adverse than the radiation dose from the UF_6.

4.3.4.3 Enrichment

During the enrichment process, gaseous uranium hexafluoride – UF_6 (natural U-235 concentration) – is separated into two fractions: the tails, of which has a depleted concentration of U-235, and the enriched fraction which contains a higher concentration of U-235.

There are a few different types of enrichment process. A common method of enriching UF_6 is the gaseous centrifuge process. In this process, the pressure in almost all areas of the centrifuge plant is kept below atmospheric to ensure any leaked UF_6, will not escape externally. For the remaining places where high pressure is needed, double containment is required. Any escaped emissions and venting gases are collected for appropriate treatment.

Suppliers of enrichment services are expected to assess enrichment process risks including spillage, leaks and emissions of UF_6, oil and other chemicals and substances, in due course. Uranium enrichment is an extremely sensitive area that is subject to strict international control, in order to prevent nuclear proliferation activities.

4.3.4.4 Fuel fabrication

Fuel fabrication is the final step of the nuclear fuel preparation and involves activities which convert the enriched fuel into a format that can be used in the nuclear power plant, i.e., into nuclear fuel rods. Nuclear fuel rods are grouped into assemblies and form the major part of the nuclear reactor's core. The three main steps are [40]:

1) Conversion of UF_6 into UO_2 powder
2) Processing of powder to make pellets
3) Assembly of pellets and other materials into fuel rods

Strict quality control measures are in place at each step of the way, to ensure traceability of the components. Major safety concerns are associated with the handling of fluoride and with inadequate handling or placement of fissile materials, resulting in a critical event.

4.4 Radioactive Waste Management

4.4.1 Spent Fuel and Radioactive Waste Management

All sources of energy generation produce some form of by-product or waste, whether it is carbon dioxide from fossils fuels, hazardous chemical wastes from photovoltaics (solar panels), and in the case of nuclear power, radioactive waste and spent fuel.

It is important in all these cases is to ensure that the generation and disposal of any wastes is minimised regardless of whether that is radioactive, chemically hazardous or inert, and that the waste is managed in a safe manner, protecting the workers, public and the environment.

As part of the RSR permit application, HPC must demonstrate to the Environment Agency that the radioactivity and volume of radioactive wastes to be generated and disposed of have been minimised in line with principle of Best Available Techniques (BAT) and the Waste Hierarchy[4].

As a Generation 3+ reactor technology the EPR^{TM} reactor planned to be built at HPC has been designed from the outset with waste minimisation in mind. This includes the careful selection of materials, surface finishes, and design of the systems in order to prevent, or if prevention is not possible, reduce the volume and level of radioactivity any waste generated throughout the plants entire lifecycle from construction to decommissioning.

Any radioactive waste or spent fuel that will be generated is captured within HPC's integrated waste strategy, ensuring that all wastes streams throughout the life cycle of HPC are appropriately managed and have an assigned and agreed disposal route as shown in Figure 16. It should be noted that the figure is a simplified overview. Radioactive wastes are classified with the following definitions:

- **Low Level Waste** (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters, etc., which contain small amounts of mostly short-lived radioactivity (not exceeding 4 giga-becquerels per tonne (GBq/t) of alpha activity or 12 GBq/t beta-gamma activity). LLW does not require shielding during handling, storage, transport and disposal. In the case of HPC, LLW comprises ~95% of the total volume of all radioactive waste.
- **Intermediate Level Waste** (ILW) is more radioactive than LLW and typically comprises resins, chemical sludges, and metal fuel cladding, as well as contaminated materials from reactor decommissioning. Due to its higher level of radioactivity ILW requires some form of shielding during its handling, storage, transport and disposal. In the case of HPC, ILW comprises ~5% of the total volume of all radioactive waste.
- **High Level Waste** (HLW) is sufficiently radioactive that the heat generated by its radioactivity increases the temperature of the waste (> 2kW/m^3) and its surroundings to a sufficient level that is requires both cooling and shielding. In the case of HPC, HLW comprises ~0.25% of the total volume of all radioactive waste. This includes a small portion of non-fuel components used in the reactor core and the reactors heavy reflector. Both these systems are designed to become radioactive, to perform its safety function, or in the case of the latter prevent the components outside the core becoming radioactive, significantly reducing the volume of radioactive waste. After a period of onsite interim storage, it is anticipated that some HLW will decay to ILW prior to offsite disposal.

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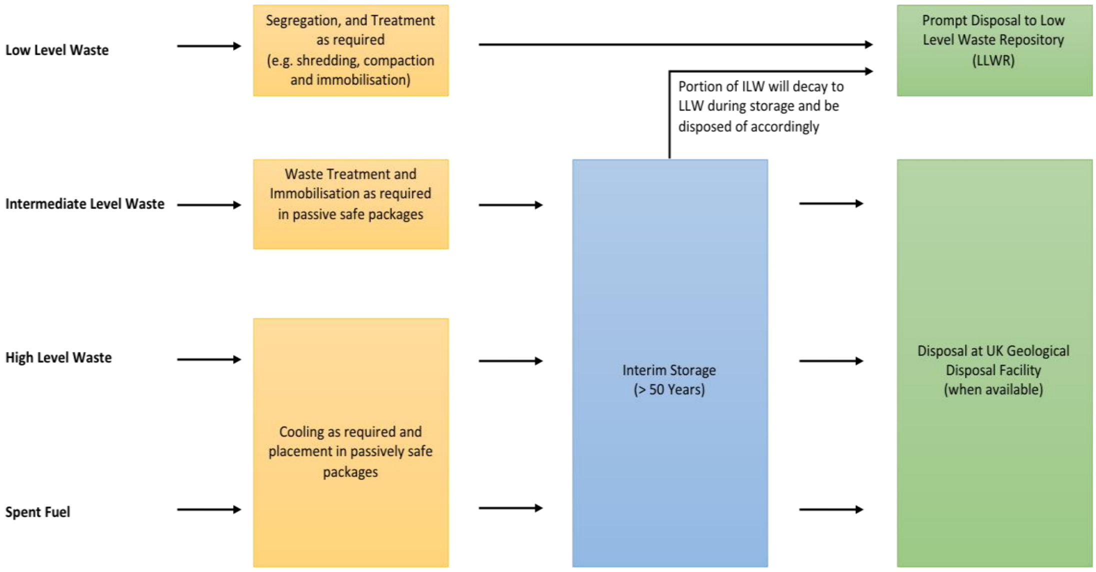
[4] The waste hierarchy sets out the priority order for managing waste materials based on their environmental impacts. In simple terms, the preference is always to avoid producing waste in the first place. Opportunities to safely reuse or recycle materials are preferable to disposal.

Figure 16: HPC Radioactive Waste Management Strategy



Any radioactive waste and spent fuel will be treated according to their classification. Whilst all LLW can be accepted and disposed of in the UK's LLWR at Drigg, at the point at which LLW will be disposed on from HPC, this waste will be split over a number of waste disposal destinations, including incineration. ILW, HLW and Spent Fuel will be packaged into passively safe containers and placed into interim storage on the HPC site. These packages will ensure that the radioactive waste and spent fuel remains fully contained throughout its interim storage and requires no active management.

Figure 17: HI-STORM MIC spent fuel cask in place in Sizewell B power station Store. Radiation is contained to a level that it is safe to work around and even touch the casks. (Image: Holtec)

The robust shielding built into the HLW and Spent Fuel Packaging and the ILW waste store utilises layers of thick concrete and steel to reduce any radiation from the waste and spent fuel to a level which poses no risk to the workforce, public or environment. The shielding is so effective that it is safe to touch the outside of the shielded package or store (see Figure 17). The additional radiation exposure to a member of the public living near the HPC interim waste stores when full will be 1,000 times less than that from natural background radioactivity, and less than that from drinking a cup of coffee a day. It should be noted that during interim storage of HLW, the HLW will decay to ILW prior to offsite disposal.

A benefit of the interim storage on the HPC site is that it allows a portion of the ILW to decay to LLW. This waste will be disposed of to the UK's LLWR reducing the total volume of waste to be disposed of as ILW at the GDF although treatment and recycling will be prioritised where possible.

In line with UK Government Policy the remaining ILW and SF will be transferred from the interim stores to the UK's Geological Disposal Facility when it becomes available. Radioactive waste and SF are transported in containers that are tested against established international standards and are so robust as to withstand reasonably foreseeable events including dropping, intense fires, and even train collisions [41].

4.4.2 The Low Level Waste Repository (LLWR)

The UK's LLWR is located near Drigg, in Cumbria and is controlled by LLWR Ltd. It has been in operation since 1959 so has been safely disposing of the UK's for over 60 years. Where possible, waste is compacted after which most will be grouted in metal containers. These containers are then disposed of within engineered concrete vaults.

The environmental safety of the LLWR is demonstrated in its Nuclear Safety Case (NSC) and Environmental Safety Case (ESC). Nuclear Safety is regulated by the Office for Nuclear Regulation and the EA regulates the environmental safety. It is defined by the EA as "a set of claims concerning the environmental safety of disposals of solid radioactive waste, substantiated by a structured collection of arguments and evidence." An ESC demonstrates to the EA how the site can operate safely. Issues examined in the ESC include geology, hydrogeology, waste characterisation, waste processing, engineering of the waste vaults, potential radiological impacts, and coastal erosion.

LLWR's existing ESC was submitted and accepted by the EA in 2011 [42] and their Environmental Permit required the site to submit an updated ESC to the Environment Agency by 3/5/2021.

4.4.3 The Geological Disposal Facility (GDF)

The GDF will be a nuclear-licensed facility and will therefore have to meet the same strict safety standards and inspection regime as a nuclear power station, research lab, or any other nuclear facility. Geological disposal involves isolating radioactive waste deep underground in a suitable geology in order to prevent harmful quantities of radioactivity from reaching the surface. The type of radioactive waste which will be disposed of in the GDF will be HLW and ILW waste with a small amount of LLW which is unsuitable for surface disposal.

GDF disposal uses a multi-barrier approach [41]

1. **The Waste Form**: first the radioactive wastes are packaged, with some wastes vitrified to solid form whilst others will be encapsulated in cement. This solid matrix prevents leakage or spillage of any dangerous liquids.
2. **The Waste Container**: the encapsulated waste will then be packaged into metal containers such as cast iron, copper or steel, or in concrete containers. This packaging has been designed to last from hundreds to thousands of years, providing another protective barrier.
3. **The Buffer**: once the containers are placed hundreds of metres below the surface in stable rock formation, in a series of highly engineered tunnels, the space between the containers and the vault walls are backfilled with clay, cement or crushed rock. This buffer protects and prolongs the life of the containers, allowing the waste to decay safely whilst prevent radioactivity from reaching the surface.
4. **Seals**: just before a GDF is to be closed, all remaining space will be backfilled and access pathways to humans sealed. These seals will limit the escape of radioactivity along tunnels and shafts when other engineered barriers have degraded.
5. **The Rock Barrier**: by placing the radioactive waste deep underground within stable rock types, another barrier to radioactivity is introduced. The depth of the rock will shield people on the surface from radiation once other barriers begin to degrade (far into the future). It also protects waste from future sea level changes and ice ages.

4.5 Prevention of Accidental Releases: Safety Objectives and Principals

Nuclear plants operate using a 'defence in depth' [43] approach to maintain nuclear safety. Under this concept, nuclear plants have in place multiple diverse, independent and redundant safety measures or 'barriers' to prevent radiological release and maintain nuclear safety. Put simply, the defence in depth approach means that in the unlikely event that one of the plant's safety barriers or systems fails:

- There are multiple ‘back-ups’ to mitigate the failure (this is redundancy);
- Back-ups are independent of each other (physically separated or electrically isolated from each other); and
- These back-ups are provided by different technologies/equipment/methodologies to reduce the risk of a common cause of failure affecting all back-ups (diversity).

There are three basic safety function which are fundamental to prevent the release of radioactive products to the environment. These three ‘Cs’ are key aspects of nuclear safety at HPC:

- Control: Control the nuclear reaction (or shut down the reactor when required).
- Cooling: Maintain cooling of the nuclear fuel so it retains its integrity (including after the reactor has been shut down); and
- Containment: Maintaining physical barriers between radioactive substances and the environment.

For the planned HPC plant, there are several independent barriers and safety systems to achieve the three safety functions above and apply the defence in depth concept. Examples of these are given below:

Control

Control rods are a series of rods which fit into the reactor core and absorb neutrons (slowing the reaction down when inserted deeper in the core and speeding the reaction up when retracted from the core). The rods can be fully inserted into the core very quickly, at which point the reaction is terminated entirely. This means that the nuclear reaction can be shut down in a matter of seconds either as a result of an automatic safety system being triggered (for example in response to an earthquake) or as a result of an operator action.

Cooling

Although the reactor can be shut down in seconds, the reactor will continue to produce ‘decay heat’ (heat produced by radioactive products in the reactor). This is much lower than the amount of heat produced at full power (a few percent) but is sufficient to damage the fuel or the core structures if cooling (circulation of colling water) does not continue to be supplied after shutdown. In turn, this would mean barriers to contain radiation (see below) are compromised.

It is crucial to maintain power during and after an accident so that safety systems which require electricity can continue to operate and pumps can continue to pump water through the core to maintain cooling of the nuclear fuel.

The EPR has several segregated and diverse ways of continuing to provide cooling embedded in its design (applying the defence in depth concept). These include:

- Four, physically separated safeguard buildings for each reactor unit [44]. Each will contain safeguard systems to control and remove decay heat from the reactor in the event of an accident. Each building can perform all the required safety functions independently. Each safeguard building has an Emergency Diesel Generator to power the safety equipment and systems.
- To ensure that power is available to power the safety systems at all times, including during loss of connection or supply from the National Grid, there are two further back-up diesel generators located on the nuclear island, known as the Ultimate Diesel Generators.
- An additional emergency access road is planned so that in case of an emergency, an alternative route for emergency vehicles to reach HPC is available.

In the worst-case scenario that cooling is lost, the EPR has the ability to do a controlled core melt using its Core Catcher, and although this will mean the asset is not recoverable ensures that the radioactivity remains contained, and people and environment are protected.

Containment barriers

There are three very significant containment barriers which prevent the release of radioactivity – any of which on their own is enough to prevent the release of radioactivity to the environment. The barriers are:

- Nuclear fuel itself: the fuel pellets, which are stacked inside ‘rods’ are stable up to very high temperatures and contain radiation;
- Reactor pressure vessel and primary circuit: a thick-walled steel structure;
- Containment building: A thick pre-stressed concrete structure, reinforced with gastight steel plates and strong enough to withstand significant internal and external forces (for example an airplane crash).

As described above, multiple safety systems are in place to maintain cooling and protect the integrity of the containment barriers.

As a consequence of the physical and regulatory aspects described in the sections above, the probability of the containment barriers being breached and there being an unintended release of radiation to the environment is extremely remote.

4.6 Other Environmental Risks

As part of the planning application for HPC, a series of assessments were undertaken on the potential risks to the environment from construction and operation of HPC. Section 4.6 highlights some of the risks to the environment as assessed for the HPC project so far.

4.6.1 Major Accident & Disaster risk

For the management of risk for all non-radiological chemical substances, HPC is expected to fall within lower tier controls of the COMAH (Control of Major Accident Hazards) regulations. The purpose of the COMAH Regulations is to prevent major accidents involving dangerous substances and limit the consequences, to people and the environment, of any accidents which do occur. HPC must account for all dangerous substances present on site and limit risk of accidents by the way these chemicals are stored, handled and used. For example, some chemicals may be restricted by inventory limits. The overall objective of the regulation is to provide a high level of protection in a consistent and effective manner [45].

For the MA&D assessment, a major accident is considered to be an uncontrolled event caused by a man-made activity that may result in serious damage to an environmental resource or receptor. A disaster is defined to be a naturally occurring event such as an extreme weather event or a ground-related hazard event, with the potential to cause serious damage to an environmental resource or receptor. Serious damage is considered to be potential loss of life or permanent injury, and/or permanent or long-lasting damage to such a receptor that cannot be restored through either minor clean-up or restoration efforts.

For both the construction and operational phases, the majority of identified hazards or threats identified, are deemed not to be MA&D events. For those which are, relevant mitigation measures were prescribed. These events are considered to be tolerable or ‘TifALARP’ (Tolerable if As Low as Reasonably Practicable), meaning the proposed mitigation measures and/or compliance with relevant regulations (such as the Construction Design and Management (CDM) Regulations 2015 [46]) and licence conditions, are considered effective in risk reduction. No risks identified under either phase are considered to be intolerable or significant.

4.6.2 Flood Risk

Sea level changes, storm surges, and intense precipitation events are all factors which could lead to potential flooding at the HPC main site and associated development areas. An assessment of existing flood risk from all sources of flooding for the main and other development sites for the planned HPC power station was conducted under a Flood Risk Assessment (FRA) [47]. The risk of future flooding to the site (considering climate change) was also described alongside possible changes in flood risk to off-site receptors as a result of the development plans.

Risk from all sources of flooding up to the 1 in 20-year return period event were assessed in the FRA, while more extreme events are considered as part of the safety case assessment. Extreme events are considered to be those such as the 1 in 10,000-year and 1 in 100,000-year events.

The FRA included a Sequential Test to ensure that the primary mitigating measure undertaken would be avoidance. This test ensures that development is steered towards areas of lowest probability of flooding first and, if no suitable sites are available, sequentially to zones of increasingly higher probability of flooding.

Following the completion of the Sequential Test, an Exception Test was applied where development must occur in areas more at risk of flooding. This ensures that new developments in flood areas would only occur where flood risk is clearly outweighed by other sustainability drivers.

Flood risk mitigation measures will be implemented at HPC, including raising the principal land platform and constructing a new sea wall to protect the land platform from erosion. Full details of the FRA can be found in the Overarching Flood Risk Assessment Report [47].

4.6.3 Climate change risk

Climate change has the potential to affect a range of receptors on site. To understand such risks, assessments were undertaken to understand and respond to three aspects of climate change: hotter summers, wetter winters and rising sea levels [48]. Furthermore, reasonably foreseeable climate change is considered as part of the development of the HPC design and safety case. This is carried out through the characterisation and assessments of hazards which could affect the site over its life. This will result in a substantiated demonstration that HPC is robust to hazards.

4.6.3.1 Consideration for Climate Change Adaption

HPC's design takes into account the potential impacts of climate change to ensure that the operation of the site will not be disrupted by climatic events.

With regards to drought due to increased summer temperatures, the UK Government identifies a key risk of reduced availability of cooling water for inland power stations. It should be noted that as HPC's main cooling water supply will be from the sea, this risk is somewhat reduced, however the station will still require mains supplied water for a variety of purposes. The site's water supplier, Wessex Water, has supplied its Climate Adaptation Report [49], from which it proposes a number of contingency plans up to 2040. Other risks from hotter summers, fire and subsidence, are of limited risk to HPC, as there is little landscaping within the security permitter which will limit the spread of any fires, and because the building design and foundations require significant groundwork which restricts subsidence risk.

It is expected that future winters will see increased risks from flash flooding events. Several design features have been included to mitigate the risks of these events, including drainage infrastructure and cooling water outfalls to ensure that rainwater is diverted offsite. Additional underground drainage measures will ensure the integrity of the site's foundations.

Further water risks to the site involve rising sea levels. HPC's design has been developed in accordance with the Overarching National Policy Statement (NPS) [50] and Nuclear NPS [51], which demonstrates that the site is consistent with the upper projections for sea level rise in UKC09. In addition, the design of the sea wall is able to be adapted to take account of any sea level rise.

4.6.4 Habitats Regulation Assessment (HRA)

As the HPC project is situated in close proximity to sites of European and international nature conservation importance, it has the potential to affect one or more such sites. EDF Energy. is, therefore, required to provide information to allow a Habitats Regulations Assessment (HRA) to be undertaken by the competent authority in support of the DCO and of the Environmental Permit applications.

The reports, referred to as 'Shadow HRA', have been produced to facilitate consultation with the competent authority on the information required to enable it to undertake an 'Appropriate Assessment (AA)' proposed for the Hinkley Point C Project.

The HRA information was prepared based on a three-stage process. It essentially identifies potentially relevant European sites on which the proposed project is likely to have a significant effect on qualifying features (either alone or in-combination with other plans and projects). If a likely significant effect has been identified, then the potential effects of the project on the qualifying interest features and associated conservation objectives is carried out. If it is concluded that an adverse effect on site integrity would be possible, then mitigation measures are assessed and proposed to address these effects. If, taking into consideration these mitigation measures, the potential for adverse effect still remains, the HRA progresses to the next stage, where alternative methods are identified and examined as ways for achieving the overall objective of the project whilst having lesser effect. If there are no suitable alternative measures, then a case of progression of the project under a case of Imperative Reasons of Overriding Public Interest (IROPI) would be made and compensatory measures agreed and implemented.

The Shadow HRA carried out for the HPC project summarised that the construction and operation of the HPC site (including associated development) would not have an adverse effect upon the integrity of the relevant designated European and international sites for nature conservation importance.

A full explanation of the HRA methodology and assessment can be found in The HPC Shadow HRA Report [52].

4.6.5 Non-Radiological Operational Discharges to Water

Comprehensive assessments have been undertaken by EDF of the environmental risks posed by cooling water and trade effluent discharges from HPC and to demonstrate that these risks have been appropriately addressed by the design and operation of the power station [53].

Findings concluded that: The impact of the thermal plume will not be significant; ammonia discharges are likely to have a negligible effect; hydrazine discharges will be low and of minor impact, as will be the impacts of seasonal chlorination.

These assessments were used to produce the Water Discharge Activity Permit application submitted to the Environment Agency under the Environmental Permitting (England and Wales) Regulations 2010 (as amended), for the operational phase of the project. Within the application, HPC Co has committed to the development of an integrated management system for the control and disposal of liquid effluents as well as numerous management plans including the minimisation, control and monitoring of these discharges.

4.6.6 Non-Radiological Operational Discharges to Air

The HPC development plans include Emergency Diesel Generators (EDGs). The role of the EDGs is to supply electrical power needed to shut down the reactor safely when off-site power is lost. The EDGs sequentially supply all safety classified loads required to bring the plant to, and to maintain, a safe shutdown state. The Ultimate Diesel Generators (UDGs) do the same thing but for station black out and total loss of AC power (i.e., including the loss of the EDGs). A Loss of Offsite Power (LOOP) event is only expected to occur a limited number of times during the lifetime of the plant so emissions to air from the diesel generators would be limited to occur only during such events and during operational maintenance purposes to ensure their functionality.

A Combustion Activity Permit has been granted by the Environment Agency under the Environmental Permitting (England and Wales) Regulations 2010 (as amended). The EA concludes that the impacts determined in the assessment are reasonable and within acceptable ranges [54]. HPC's Environmental Statement (ES) also includes analysis of other discharges to air within the commissioning and operation stages, and in general find most discharges to be negligible, minor, or temporary [55].

4.6.7 Other conventional risks

HPC has assessed myriad of non-radiological risks including carbon equivalent emissions of refrigerant gases, and as a result will be reducing risks by using lower GHG emitting refrigerants.

It has also assessed emissions coming from use of diesel generators and are in process of obtaining and Industrial Emissions Direction (IED) permit.

4.7 Electromagnetic Fields

Electromagnetic Fields (EMF) exist wherever there is a positive or negative electrical charge. Whilst they can exist naturally, fields are also generated by human made sources, such as in the vicinity of electrical power lines and electrical equipment. As increased electricity usage has grown, so has exposure to EMF. Whilst research indicates that short-term exposure to low-level EMF causes no visible detrimental effects, exposure to high-level EMF can have harmful impacts on health, and these levels are restricted by national and international guidelines. [56].

Recommendations of limits applying to EMF have been published by the International Commission on Non-Ionising Radiation Protection (ICNIRP). These recommendations have been adopted by the voluntary Code of Practice (CoP) document (published by the former Department of Energy and Climate Change (DECC)), which details the recommended approach for demonstrating compliance with EMF exposure limits. The ICNIRP guidelines give a Basic Restriction level of 2 $mA.m^{-2}$ for general public exposure over 50 Hz, which indicates the level of current in the central nervous system, above which, acute effects on the central nervous system could occur [57]. Reference Levels for public exposure of 100 µT and 5 kVm^{-1} for magnetic and electric fields, respectively, are also given This is a guideline above which investigation may be required as to whether induced current exceeds the Basic Restriction.

The grid connection for the planned HPC development will align with the existing infrastructure. Once operational, any changes to site transmission infrastructure will comply with the recommendations of limits suggested by the ICNIRP. As a consequence, the exposure guidelines for public exposure scenarios would be set to prevent any consequential health outcome. EDF concluded that any adverse effect from the planned HPC development, in terms of EMF, will be negligible and therefore not significant.

4.8 Noise

4.8.1 Noise limit legislation and policy

Excessive noise can result in a wide range of impacts on the quality of human life and health, as well as on the environment and ecological receptors.

There are a number of national policies which refer to acceptable noise limits, both in general, and for nuclear power stations within the UK. The UK government’s policy on noise is set out in the overarching National Policy Statement for England. It defines three different levels of acoustic effects: No Observed Effect Level (NOEL), Lowest Observed Adverse Effect Level (LOAEL), and the highest level, Significant Observed Adverse Effect Level (SOAEL). SOAEL is the level above which significant adverse effects on human health and quality of life occur. To take into account any potential noise pollution effects on a planned development (including construction of it), the potential noise exposure needs to be assessed as to whether it would be above or below the LOAEL and the SOAEL [58]. There are a number of factors that will determine the effect of noise from a proposed development (for example) and whether it breaches this level, including (but not limited to) noise exposure, duration of noise and time of day at which the noise occurs. Therefore, there is no single objective noise-based measure, for example a fixed number of decibels (dB) which defines these levels, so planned developments must be assessed in a more flexible manner, on a case-by-case basis.

While in general, normal operation of a new nuclear power station is unlikely to give rise to significant noise, vibration or air quality impacts, there may be local impacts associated with transport and construction activities. With proper mitigation steps, the effects of noise and vibration from the associated transport and construction effects will be minimised. These steps include good design, in terms of location, as well as the use of appropriate technologies and barriers [50].

If there is the potential for noise impacts to occur from a proposed development, a noise assessment is required to be undertaken. A noise assessment was undertaken for the planned development of HPC nuclear power plant [59] which is summarised below.

4.8.2 Noise Assessment

A formal Environmental Impact Assessment (EIA) was undertaken with the Infrastructure Planning Commission (IPC) to determine the noise impacts of the proposed development. This included an assessment of potential impacts, the significance of effects, requirements for mitigation, and residual effects of the planned HPC nuclear power plant. The EIA methodology considers whether impacts of a proposed development could have an effect on any receptors or resources within the boundary of the site and a 600m off-site area.

The noise assessment for the construction period identified any likely significant effects that were deemed likely to occur after taking into account the proposed design of the HPC development. Primary mitigation measures were established and incorporated into HPC's design and construction plan, with consideration of the British Standard BS 5228 Part 1, which gives detailed information on good construction practice for minimising the effects of construction noise.

Additional secondary mitigation measures have been committed to by EDF to further minimise any identified significant adverse effects.

The overall noise impact of operation of the HPC power station has been assessed as being of minor adverse significance: at the nearest receptor dwellings to the development site, on Knighton Lane, and in the nearby villages of Shurton and Wick, the average noise level is predicted to be between 29.6 and 36.6dB depending on wind direction as noted in Table 11.20 of the HPC ES. As a result, no additional mitigation measures are considered necessary.

Condition MS12 of the Hinkley Point C Development Consent Order sets a limit of 45dB LAeq 1hr for operation of the power station between 23:00 and 07:00. Whilst this predicted noise levels should not exceed this under normal operation, there may be routine tests and operations required as part of the safety case which could exceed this if undertaken during the period specified. In this case a noise assessment will be undertaken and if it is deemed possible that the operation would exceed this limit then it would either be undertaken between 07:00 and 23:00 or additional mitigation installed.

During the construction of HPC, secondary nuisance impacts caused by workforce travelling to and from and staying in accommodation within local communities have been managed through a strong focus on community and the implementation of a Code of Conduct with strict terms and conditions for people working on site and living in nearby communities. During operation, the workforce is likely to be less transient in nature, however it is still envisaged that communities will remain a priority and the Code of Conduct will remain to support this.

The full noise assessment and discussion of mitigation measures is found in Chapter 11 of Volume 2 of the ES of the HPC Development Site [60].

4.9 Land Use

The expected change in land use classification for the HPC development is shown in Table 13. Note that marine waters, the use of which is not expected to change, has not been included.

Beyond the HPC development site, it has not been possible to estimate land classification on all relevant facilities due to lack of information. In the cases where the "before" land classification information is not known, the areas have been reported as "unspecified". Most "after" land classification for non-HPC facilities has been reported as some type of "artificial" type. This is relevant to some of the upstream facilities assumed for the purposes of the LCA and report as well as for the core offsite radioactive waste facilities. Likewise, the number of years for which the upstream facilities will occupy the land for is not given as such data was not readily available. Note that infrastructure for core off-site facilities for recycling, incineration, and landfilling waste have not been included.

The summary of these values of land use area by Corine Land Cover class for the key stages of relevance can be seen in Table 13. Note that for the m^2 values, there is a difference in the before and after total values due to rounding.

Site preparation for HPC began in 2010/2011. Construction of key HPC structures began in 2018 and will take a total of approximately eight years to construct and commission. Most land will be occupied from the start of this period. During the construction phase, a number of temporary infrastructures supporting the construction of the main site will be built, used, and then deconstructed. These include Junction 23 and Cannington P&R facilities, HPC/Sedgemoor Campus, the Jetty and miscellaneous areas next to permanent works, to facilitate construction. These temporary structures will be built on arable land and after their removal, EDF will return this land to its previous state. The land for these temporary structures has been accounted for within the Corine Land Classification table.

Land occupied by more permanent infrastructure erected during the construction period will be occupied during the HPC operational period of 60 years or longer, and during the decommissioning period to follow. Land in which onsite waste repositories are planned, and that are expected to be required beyond the estimated 60-year operation of the plant, is likely to be occupied from end of operation for at least another 55-65 years.

The largest land use change resulting from the HPC development, as seen in Table 13 is the decrease in arable land. This land change is due mainly to a gain in artificial surfaces from the main development site and associated infrastructure but also the gain in forest and semi-natural land area due to restoration of the land used temporarily for construction and compensatory measures. There is also an increase in ‘unspecified’ land type.

Land use areas for the assumed mining and conversion sites have been obtained from various publicly available documents which makes analysis of the land type more approximate. For example, for the assumed ISL mining sites, the area value was taken from a mining permit area although it is possible that there are more mining permits covering further land [61]. It was assumed that all the ‘after’ land type is artificial (mine, dump and construction sites) but in reality, due to the way in which ISL technology operates, only a small percentage of this land would be actually be affected on the surface.

For the conversion site, the land use value was taken from Orano’s website [62] and is believed to also include facilities and areas beyond those specifically for uranium conversion. For the assumed enrichment and fuel fabrication sites, satellite images from Google Maps have been used to record an approximate estimate for the visible area occupied by artificial infrastructure. Activities relevant to HPC which occur on these upstream sites are outlined in the ‘Upstream Risk’ section.

Any land use changes due to interim spent fuel and radioactive waste repositories that are on the HPC site are included in the “HPC site” column. With regards to offsite radioactive waste repositories, an estimated value for the current site at Drigg LLWR has been given although the land use type ‘before’ and ‘after’ operations have been assumed as “unspecified” and “artificial”, respectively. The expected lifetime of Drigg is unclear with numerous site changes occurring since conception but it was established in 1959 [63] and recent plans refer it being delicenced in 2135 [64].

An estimated surface area land use for the future UK GDF (not built yet) has been given and the ‘before’ land use type listed as “unspecified” and the ‘after’ land use type listed as “artificial surfaces”. The anticipated lifetime of the GDF is not known but is expected to be a long time, perhaps up to 160 years [4].

Table 13: HPC land use specified according to Corine Land Cover Classes for the before (pre-construction) and after periods

		Key life cycle facility							-	
Time	**Class**	**Extraction**	**Conversion**	**Enrichment**	**Fuel Fabrication**	**HPC site**	**Drigg LLWR**	**UK GDF**	**Total (ha)**	**Total (m2)**
Before	1. Artificial	-	-	-	-	37		-	37	373,300
	2. Agricultural	-	-	-	-	194	-	-	194	1,942,900
	3. Forest & semi-natural	-	-	-	-	6	-	-	6	55,600
	4. Wetlands	-	-	-	-	0	-	-	0	2,300
	5. Water bodies	-	-	-	-	-	-	-	-	-
	Unspecified	3,190	650	90	39	1	100	150	4,220	42,203,400
		3,190	650	90	39	238	100	150	4,458	44,577,500

		Key life cycle facility								
Time	**Class**	**Extraction**	**Conversion**	**Enrichment**	**Fuel Fabrication**	**HPC site**	**Drigg LLWR**	**UK GDF**	**Total (ha)**	**Total (m2)**
After	1. Artificial	3,190	650	90	39	95	100	150	4,314	43,137,800
	2. Agricultural	-	-	-	-	90	-	-	90	904,200
	3. Forest & semi-natural	-	-	-	-	15	-	-	15	148,120
	4. Wetlands	-	-	-	-	2	-	-	2	20,000
	5. Water bodies	-	-	-	-	-	-	-	-	-
	Unspecified	-	-	-	-	36	-	-	36	362,400
		3,190	650	90	39	239	100	150	4,457	44,572,520

4.10 Impact on Biodiversity

4.10.1 Core – HPC site

EDF's objectives for the HPC project in relation to biodiversity are "to avoid adverse impacts on the integrity of wildlife sites of international and national importance, …priority habitats and species including European protected species…[and] valuable ecological networks and ecosystem functionality" [65]. More specific biodiversity impacts and objectives are set out in the 'Sustainability Statement' as well as Volume 2 of the ES of the HPC Development Site [66]. Ecological studies have been carried out to determine the potential impacts of the construction and operation of HPC on the terrestrial, marine and coastal ecology and are reported in the ES and the ES addendum.

EDF recognises the importance of the natural environment of the HPC site and surroundings, and the project has been designed to minimise negative effects on biodiversity as much as possible. Although the project has been planned to limit impacts on ecologically valuable land and habitat as much as possible, some land take has been unavoidable. The majority of this lost land is agricultural so its impact on biodiversity is not very significant, but EDF has committed to measures to further reduce any impacts felt [65].

The Bridgewater Bay SSSI, along with the Severn Estuary SPA and Ramsar Site, is home to many internationally important wetland birds, meaning that the impacts of the HPC development could be significant. EDF has committed to ensuring that construction methods are chosen to reduce the disturbance to these bird species [67].

The Bridgewater Bay SSSI also faces risk from the cooling water infrastructure. Temperature increases in the marine environment as a result of this infrastructure could have a negative impact on marine biodiversity, so the infrastructure is sited sensitively to minimise this impact [68].

In addition to these mitigation measures, during the construction phase, EDF will create a number of new habitat areas bordering the development area and off-site to minimise biodiversity and habitat loss, including:

- Approximately 21ha of broad-leaved woodland/grassland habitat mosaic, and a further adjacent wetland area of 0.2ha
- 25ha of arable land and/or pasture seeded with a native wildflower mix
- A bat barn to provide alternative and enhanced roosting habitat for bats, to be retained throughout the site's development [67]

As a result of these measures, it is considered that the impacts on ecological receptors will be limited to 'minor' and it is not anticipated that the impacts of HPC will affect the 'favourable' conservation status of the surrounding areas.

In order to achieve a high biodiversity landscape after the completion of the construction phase, the following measures have been proposed:

- At the end of the construction phase, the restoration of the construction areas will result in 17.7ha of calcareous grassland, almost 15 times the area lost during construction, resulting in a moderate gain to biodiversity by year 30
- A total of 39.7ha of broad-leaved woodland will be planted on restored areas using species that are typical of ancient semi-natural woodland in the surrounding area, resulting in a minor beneficial impact after 30-50 years
- The restoration of the construction phase will create a new habitat network of hedgerows, woodland, and grassland, improving habitat connectivity within 5-10 years and supporting low value populations of breeding and wintering birds, resulting in a minor beneficial impact [67]

4.10.2 Core – Waste repositories

The LLWR site in Drigg is located in Cumbria and covers approximately 100 hectares [69]. Whilst the site itself is not designated for nature conservation purposes, there are valuable ecological features within the site such as areas of woodland and scrub, Drigg Stream and the acid grassland habitats. A range of flora and fauna have been observed on the site, including the plants Pillwort and Yellow Bartsia, protected animals (including Great Crested Newt, bat species, Badger, Natterjack Toad and Adder), and protected birds (including Barn Owl and Kingfisher). Protected and notable habitats and species are also known to be present in the wider surrounding area. The planning of major projects onsite is informed by specific surveys and appropriate mitigation is specified as necessary. Method statements and restrictions of work are applied to guide work in sensitive areas. Works that may affect nesting birds are subject to seasonal restrictions to comply with relevant legislation [70].

As the location of the UK's GDF has not yet been decided, it is not possible at this point in time to assess the biodiversity impacts of the future site although this will be a key part of the assessment for the NDA as site selection is decided.

4.10.3 Upstream – Mining

Below, the key biodiversity impacts for the three assumed mines for this project, have been highlighted. This information has been taken from publicly available information online as referenced.

4.10.3.1 Cigar Lake Mine, Canada [71]

During operation of the mine, water and sediment concentrations of COPCs (constituents of potential concern) are predicted to increase. Once the site is no longer used, concentrations are expected to return to pre-operational conditions. It is predicted that the operation would have a limited influence on air quality and all COPC concentrations are predicted to return to near background levels within 5km of the operation.

Woodland caribou is identified as the only species potentially present in the general area with special status (threatened). Northern leopard frog and rusty blackbird are potentially present and are listed as of special concern.

It is not anticipated that there will be any radiological or non-radiological influence on either aquatic or terrestrial biota or vegetation.

4.10.3.2 Muyunkum and Torkuduk mines, Kazakhstan [72]

Although these mines are located in the middle of the desert and use less invasive techniques than most other mines, there is still a risk of impact to biodiversity. A detailed study was undertaken prior to construction to assess the base state of the local environment, and regular monitoring of water, air, soil and vegetation takes place on site.

A particular focus of this monitoring is the saxaul tree, which is vital for preventing soil erosion. KATCO plants and replants saxaul trees regularly around its sites. The company also recycles and treats contaminated soil to further reduce impacts to local species.

4.10.3.3 Rossing mine, near Swakopmund, Namibia [73]

Mining activities result in air pollution in the form of dust particles, which is monitored by Rio Tinto through its air quality monitoring programme. Mitigation measures are taken to ensure that exposure levels do not exceed the adopted occupational limits. Dust fallout that may impact local biodiversity is also measured and all measured deposition levels for 2019 were well below the selected regulation.

Saline water from the nearby river is abstracted to spray on roads to suppress dust, and no evidence has been found that trees in the study area are impacted by this. A study of groundwater samples found that chemical concentrations may have some impact on the local environment though this is confined within the zone of influence. The site's waste is also monitored with focus on radioactivity from waste rock or seepage water, asbestos, acidic drainage and residual nitrate.

In terms of biodiversity, several plant species of conservation value were identified onsite and replanted at the Namib Botanical Garden. The mine's power lines pose a risk to the avian population so three power lines are monitored on a quarterly basis. There is also monitoring of alien vegetation and feral cats.

4.10.4 Downstream – Grid infrastructure

The power grid also has an impact on biodiversity, but this is not specific to nuclear and no classification of land use areas have been made. The biodiversity impacts of National Grid infrastructure vary across the country depending on geographical context and local ecosystems.

The National Grid have developed an environmental value assessment method approach to meeting its biodiversity and environmental targets. This approach combines Biodiversity Net Gain (BNG) with Natural Capital assessment methodologies [74]. Further information can be found in the referenced document and from National Grid itself.

4.11 Visual Impacts

A Birdseye view of the planned main HPC site is show in Figure 18.

Figure 18: CGI of what the finished HPC main site will look like once completed

The HPC development site is located on the Somerset coast. Though there are no local landscape designations within the site, within the wider study area are a Historic Landscape, Green Wedge, three Historic Parks and Gardens, three Scheduled Monuments and a Conservation Area. Furthermore, the Quantock Hills Area of Outstanding Natural Beauty is located within 5km of the development site, and the site is visible from some locations within this area.

The main development site during the peak phase of construction consists of an area of approximately 176ha. Once construction is completed, land use will be dramatically reduced: the footprint of the operational site is approximately 67.5ha. The highest points of the development are the stack at 70m high and the reactor building at 64m high. EDF are aware of the significance and visual beauty of the area, and steps have been incorporated into the development designs in order to mitigate these impacts as much as possible. Some such measures are detailed below:

- In order to limit the visual impacts caused by the construction of HPC, a screening earth bund of between 2m and 8.5m has been created along the north-western and southern boundary of the development site. The bund which was created during site preparation works and planted with native coastal shrub on slopes, will not be able to screen all of the main construction work but will effectively limit the magnitude of visual and noise impacts during the construction and operational phase
- A number of planting and vegetation maintenance measures will ensure the safeguarding of existing vegetation and the creation of new vegetation to minimise visual impacts on the surrounding land. Further off-site planting proposals have been prepared to minimise the impacts on Pixies Mound, which are estimated to reach their full screening potential at year 15 of the operational phase.

Figure 19 demonstrates what the landscape might look like after restoration activities are complete.

Figure 19: CGI of the proposed restored landscape around HPC

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A1 Deviations from the Electricity PCR

Table 14: 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.	HPC 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.	HPC does not have access to data on 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."	As construction of HPC is not yet complete and it is not operational, it was not possible to use traditional specific data based on recent historical records. Operational data is based in detailed estimates by HPC Co and SZC Co. 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 HPC will go to UK LLWR, incineration, VLLW landfill and recycling. No specific data was available for these sites. Therefore, best fit generic ecoinvent datasets have been used. For 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 HPC 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 HPC Co 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 HPC Co (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) the most recent available annual mSv values to personnel for the upstream stages for the specific companies assumed for this LCA. These are for specific sites, which may or may not be eventually part of HPC’s supply chain. For the management of fuel residues, an estimated value was obtained based on plans for the UK GDF.
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 the "Risk Management" and "Regulation and Legislation".

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."	It has not been possible at this point in time (pre-operation) to address mishaps that happen less frequent than once in three years in this communication. It provides qualitative overviews of the findings of certain risk assessments, indicating whether risks were found to be tolerable and if not, what action is being taken . However, there is no quantification of the frequency of these potential risks or the outcomes. 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 available beyond the HPC site. However, approximations have been made based on several potential upstream supplier sources, by for example using estimation of area using Google Maps images and data from supplier reports on land area. This has also been done for offsite core infrastructure (e.g., the future GDF and the lower level waste repository). These are given as absolute values as opposed to allocated to HPC. For downstream, Ricardo does not consider it relevant to address such land use change. 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. Again, it has possible to obtain lifetimes of the relevant infrastructure and sites. Ricardo has used values for lifetime taken from public reports for the assumed sites (where available).
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 brief information as available online has been added to this document.

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Review of the LCA Report (Dated October 26th, 2021) "Life Cycle Assessment of the Hinkley Point C nuclear power plant development," and EPD-style document (Dated October 26th, 2021) "Life cycle carbon and environmental impact analysis of electricity from Hinkley Point C nuclear power plant development"

Prepared by Ricardo Energy & Environment, Ricardo-AEA Ltd.

Review Statement Prepared by the Critical Reviewer:

Julie Sinistore, PhD

October 27th, 2021

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 HPC LCA report- round 3 WSP review 27October2021."

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 October 26th, 2021, and not to any other versions, derivative reports, excerpts, press releases, or similar publications.

Julie Sinistore

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WSP USA Inc.