EUROPEAN RESEARCH EXECUTIVE AGENCY (REA)

REA C – Future society

C4 – Reforming European R&I and Research Infrastructure

GRANT AGREEMENT
PROJECT 101079696 – ET-PP - HORIZON - INFRA - 2021 - DEV - 02

ET–PP INFRA-DEV ANNUAL MEETING 2026

ET–PP WP9

Sustainable Development Implementation Strategy:

ET Environmental Impact, ET CO2 Footprint

(D9.1, D9.2, D9.3)

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May 5 – 7, 2026
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ET-PP WP9 Sustainable Development Strategy Team





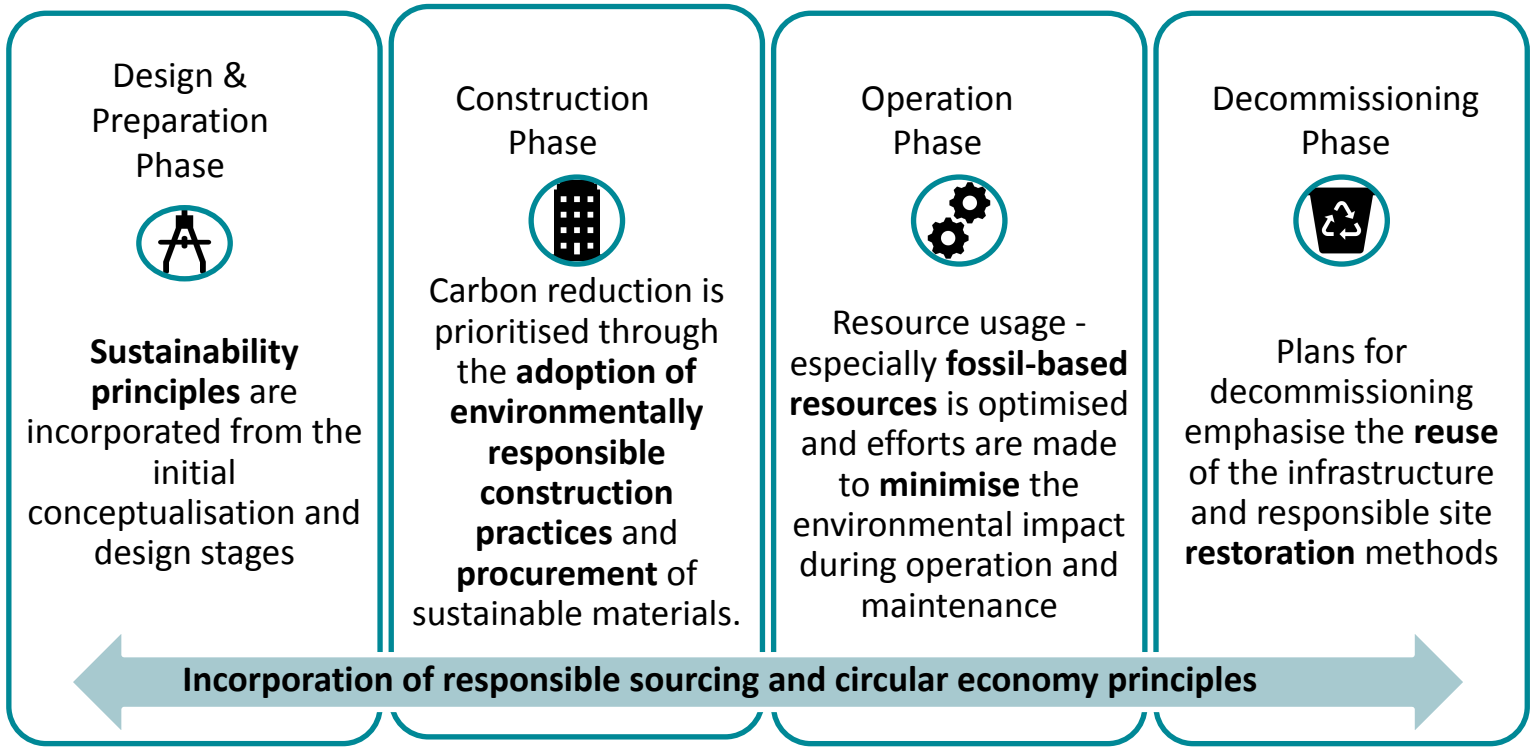



Vision

ET-PP is committed to fulfilling

- Long-term operational requirements while minimising environmental impact
- Adhering to EU and national sustainability directives, as well as international best practices
- Develop a strategy for the realization of a **long-term sustainable research infrastructure - 3 Deliverables**

- **D9.2:** Environmental Impact Assessment & Mitigation Strategy including - Annex: Strategies for excavation and material reuse
- **D9.3:** CO2 Footprint assessment and mitigation roadmap
- **D9.1:** Sustainable Development Implementation Strategy



Ref: Horizon Europe Framework Program for Research & Innovation, Strategy Report on Research Infrastructure Roadmap by *European Strategy Forum on Research Infrastructures

ET Sustainability Development Implementation - Challenges

It is an underground infrastructure (second only to KAGRA in Japan)

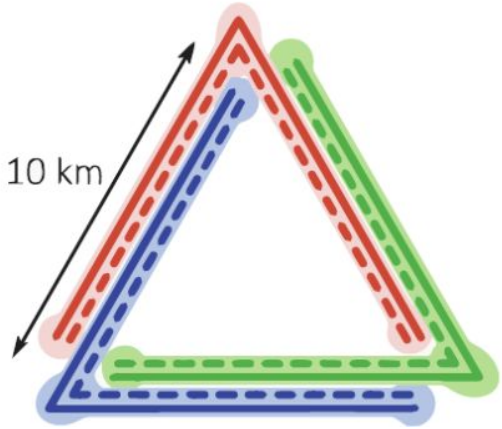
Geometry and characteristics are still under definition, with many assumptions currently in place

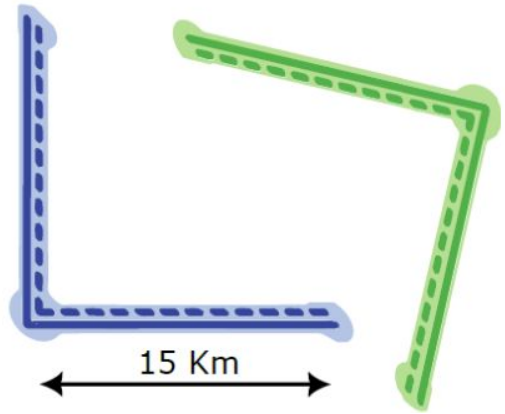
Ongoing activities include site selection and geometry definition, with a strong focus on sustainability considerations

Preparatory phase of ESFRI roadmap - pre-feasibility studies managed by candidate sites to prepare technical and economic proposal for candidacy

KAGRA GW Site - Kamioka mines, Hida city - Japan

EGO-VIRGO GW Site - Cascina (Pisa) - Italy





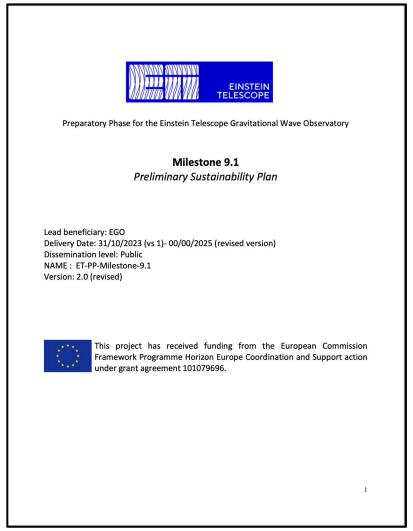
ET Sustainable Development Strategy - Reports

ET Environmental Impact Assessment & Mitigation Strategy

- Scoping and Baseline Assessment
- Alternatives and Mitigation
- Public Participation and Transparency
- Monitoring and follow-up

ET CO2 Footprint Assessment & Mitigation Strategy

- Compute the key Carbon and Environmental Impacts
- Findings and Mitigation Strategies
- Highlight the most critical insights and recommendations for decision-makers


Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

Milestone 9.1
Preliminary Sustainability Plan

Lead beneficiary: EGO
Delivery Date: 31/10/2023 (vs 1)- 00/00/2025 (revised version)
Dissemination level: Public
NAME : ET-PP-Milestone-9.1
Version: 2.0 (revised)

This project has received funding from the European Commission Framework Programme Horizon Europe Coordination and Support action under grant agreement 101079696.


D9.2 Report Environmental Impact Assessment and Mitigation Strategy

Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

Deliverable 9.2
Environmental Impact Assessment and Mitigation Strategy

Lead beneficiary: INFN
Delivery Date: 10 Dec. 2025
Dissemination level: internal
NAME : ET-PP-Deliverable-D9.2.
Version: V9.0

This project has received funding from the European Commission Framework Programme Horizon Europe Coordination and Support action under grant agreement 101079696.

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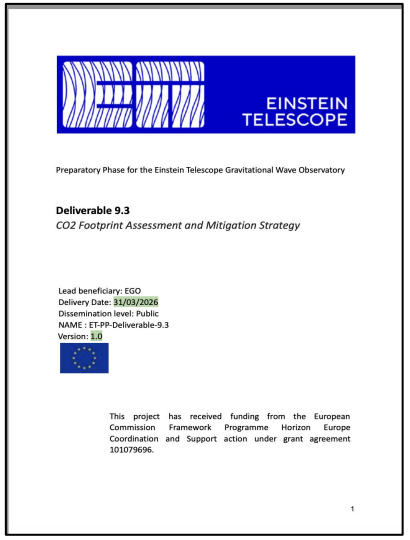
Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

Deliverable 9.2. Annex I
Management of Excavated Materials

Lead beneficiary: Montanuniversität Leoben (MUL)
Delivery Date: Nov. 2025
Dissemination level: internal
NAME : ET-PP-Deliverable-D9.2. Annex 1
Version: 1.2

This project has received funding from the European Commission Framework Programme Horizon Europe Coordination and Support action under grant agreement 101079696.


Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

Deliverable 9.3
CO2 Footprint Assessment and Mitigation Strategy

Lead beneficiary: EGO
Delivery Date: 31/03/2026
Dissemination level: Public
NAME : ET-PP-Deliverable-9.3
Version: 1.0

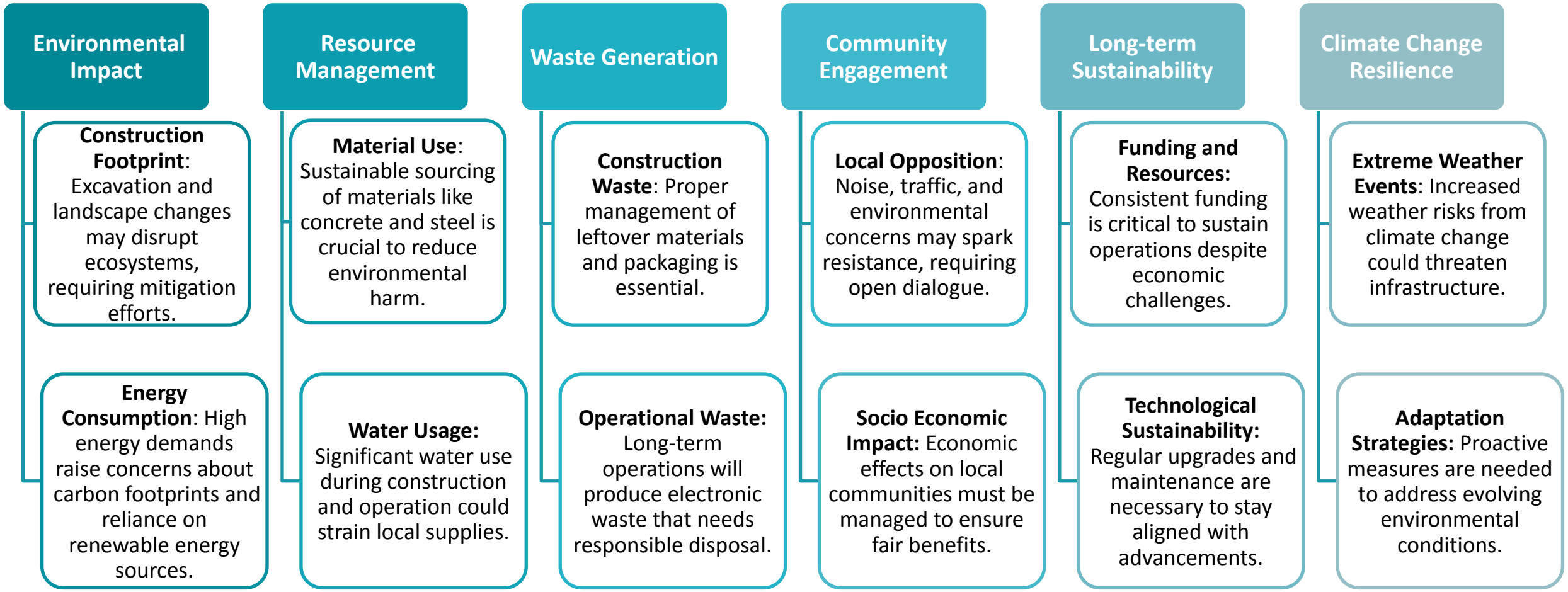
This project has received funding from the European Commission Framework Programme Horizon Europe Coordination and Support action under grant agreement 101079696.

Environmental Impact Assessment & Mitigation

- Analytical process for identifying and assessing the potential environmental impacts of a project in its different phases (construction, operation and decommissioning)
- Includes an Environmental Management Plan (EMP) laying out how such measures should be implemented and monitored
- Strategy adheres to the requirements of EU EIA Directive (2011/92/EU as amended by 2014/52/EU) and is articulated in:
  - Scoping and baseline assessment
  - Alternatives and mitigation
  - Public participation and transparency
  - Monitoring and follow-up

WP9 Deliverable D9.2

Environmental Impact Assessment & Mitigation - Key aspects

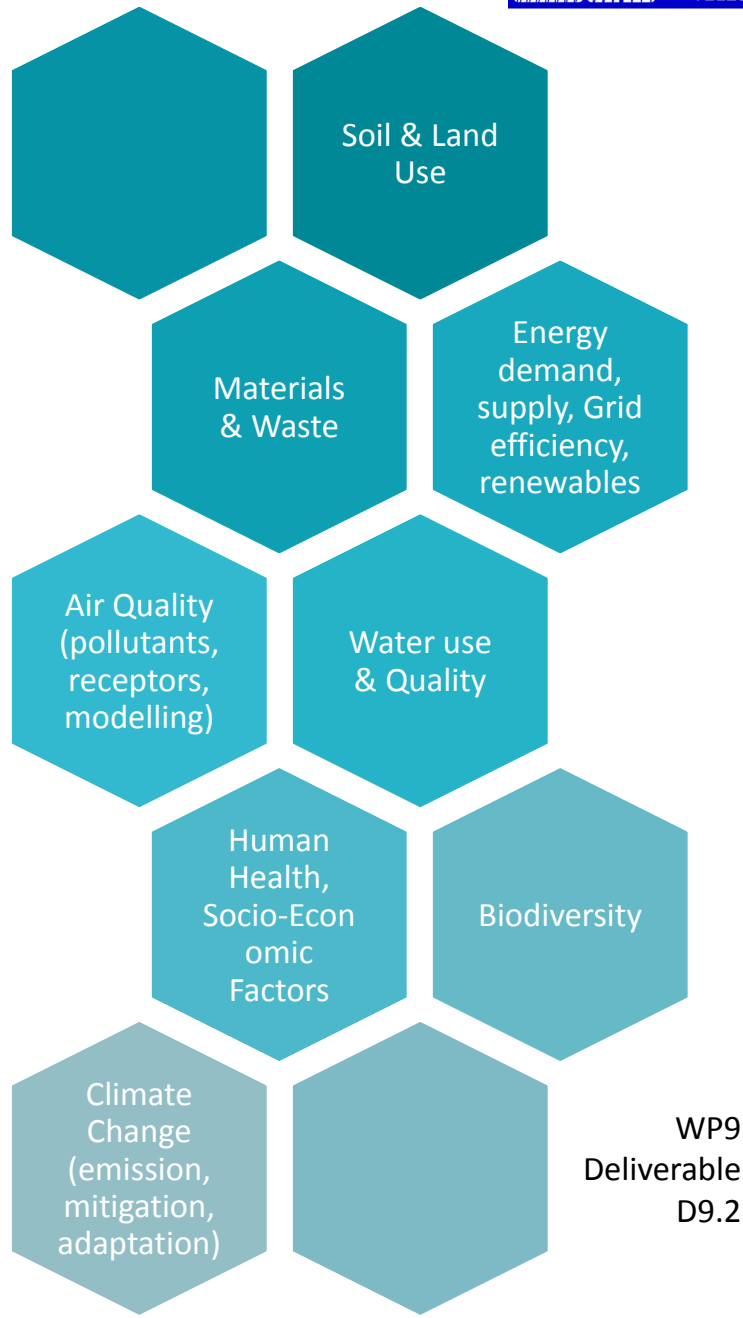


WP9 Deliverable D9.2

Environmental Impact Assessment (EIA) - Workplan

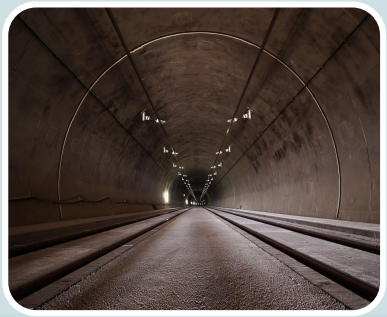
- Define Sustainability Strategy with environmental, social, and economic themes
- Establish **Baseline conditions** using site-specific data (air, water, soil, noise, biodiversity, etc.)
- Conduct detailed **Impact assessments** for both construction and operational phases
- Develop and implement **Strategic KPIs*** (for site comparison) and **Specific KPIs** (for mitigation & performance tracking)
- Identify and evaluate **Alternatives and Mitigation Measures** across EIA themes
- Analyse and define an overall strategy for reclamation, reuse and recycling of excavated materials

***KPI: Key parameter Indicators**



WP9
Deliverable
D9.2

Reclamation, Reuse and Recycling of Excavated Materials



Technical

Tunnel advancing method, dimensions

Site organisation

Material yield parameters

Material analysis

Processing technology

Geological

Geological situation

Chemistry/ Mineralogy/ Strength properties of excavated materials

Project specifications

Processability

Legal

Ownership

Regional Waste law

End of waste character

Economic

Supply and demand

Raw material price vs. Landfilling costs

Transport route/ -range between end points

WP9 Deliverable D9.2 Annex

CO2 Footprint Assessment & Mitigation Strategy

Part 1: Carbon Management approach (designed to span across all project phases)

Establishes clear roles and responsibilities, supported by regular performance reviews.

Preparatory and Design stages

- Management approach
- Setting carbon reduction targets
- Establishing a robust baseline
- Integrating material efficiency, circularity, and nature-based solutions into design decisions
- Procurement to favor suppliers with strong environmental credentials
- Embedding carbon and sustainability requirements into tender documentation

Construction and Operation stages

- Low-carbon construction practices
- Maximizing renewable energy use
- Continuous monitoring and transparent reporting of carbon performance through digital tools

End of Life stage

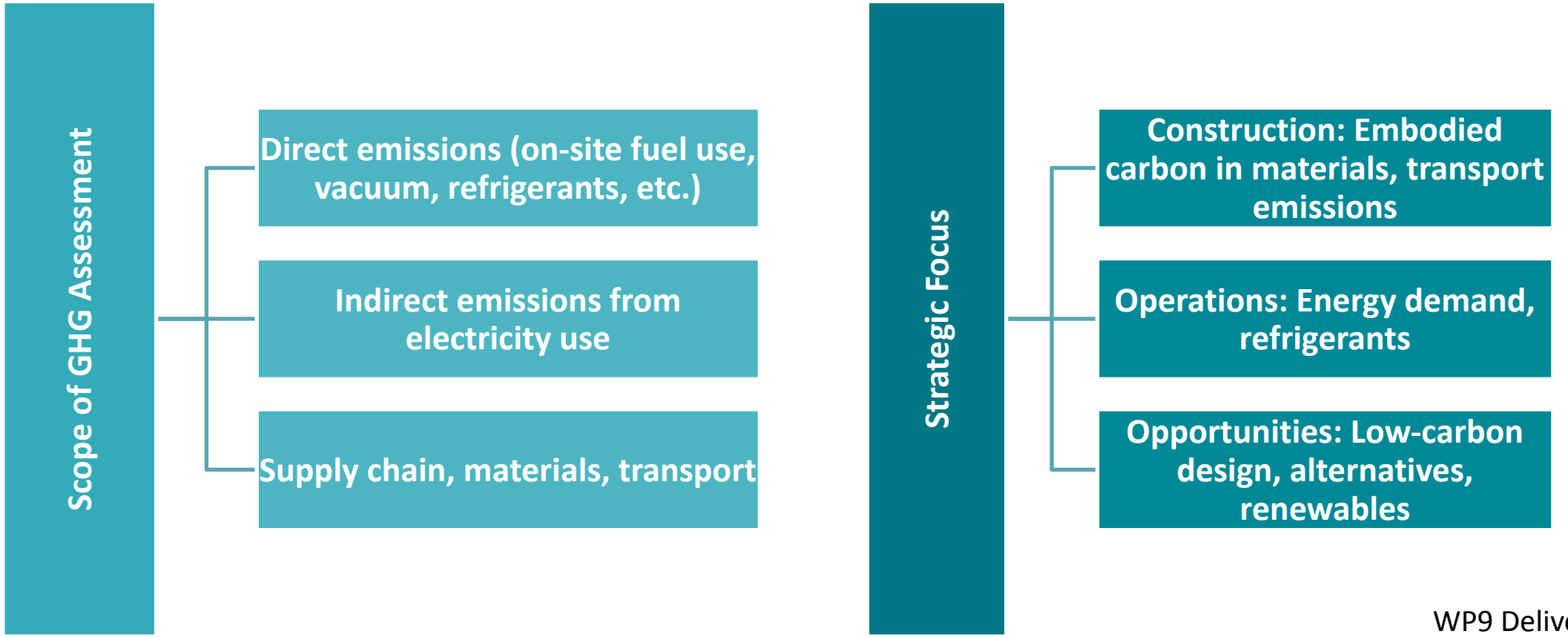
- Prioritize reuse, responsible site restoration, and the minimization of land-use change

WP9 Deliverable D9.3

CO2 Footprint Assessment & Mitigation Strategy

Part 2: Baseline Whole Life carbon Assessment (undertaken at preparatory phase)

Provides a high-level quantification of CO2 footprint of ET's (civil + scientific) infrastructure



WP9 Deliverable D9.3

CO2 Footprint Assessment & Mitigation Strategy - Roadmap

TASKS

1. CARBON MANAGEMENT & MITIGATION STRATEGY

2. HIGH-LEVEL CARBON ASSESSMENT OF CIVIL & SCIENTIFIC COMPONENTS

KEY OUTCOMES

- Methodology for Carbon Assessment
- Carbon Management and Governance
- Integration of Management into Project delivery

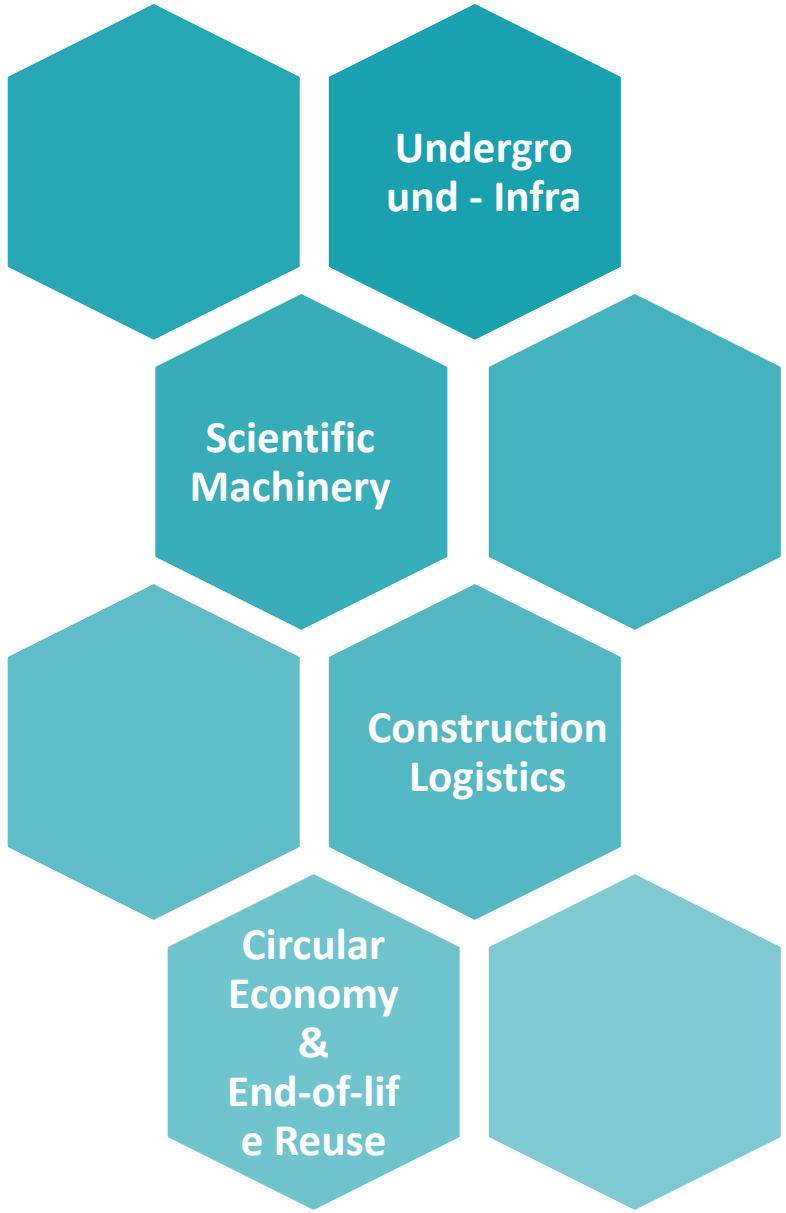
- Carbon Quantification for Major Components
- Main Carbon Hotspots
- Main Mitigation Opportunities

WP9 Deliverable D9.3

Life Cycle based CO2 Assessment & Mitigation Strategy – Workplan

- Define system boundaries for buildings, underground works, scientific equipment, etc.
- Apply LCA* Methodology in alignment with global standards#
- Perform Carbon Budgeting, hotspot analysis & scenario planning (conservative vs circular reuse models)
- Align Scope 1, 2, 3 emissions with GHG Reporting Protocols
- Suggest integrating Low-Carbon Strategies into design, procurement, construction & operations

*Life Cycle Assessment methodology defined by European commission
#PAS 2080:2023, ISO 14040:2006, ISO 14044:2006, EN 15804:2012+A2:2019



WP9 Deliverable D9.3

ET High-level CO2 Assessment of Civil Engineering components

WP9 Deliverable D9.3

Goal

- Determine a high-level whole life carbon assessment for the major components of the civil infrastructure of 2 ET configurations (triangle and L-shape).
- The carbon footprints will be used as a baseline before more granular and site-specific carbon assessments are undertaken by the design teams.

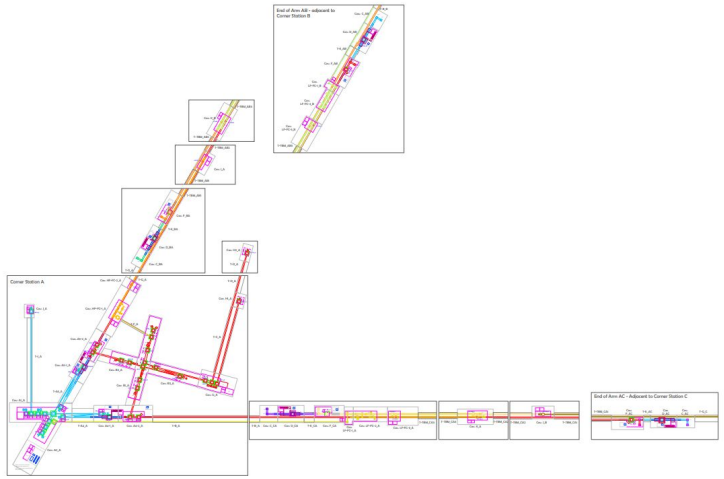


Figure 60: Element Names - Triangle (retrieved from **TD.2**)

Scope and system boundaries

- Top-down carbon assessment of the civil infrastructure of 2 configurations (triangle and L-shape)
- The carbon benchmarks/factors/LCA assumptions are not site specific.
- Whole life carbon assessment including construction, maintenance, operation, and end of life.

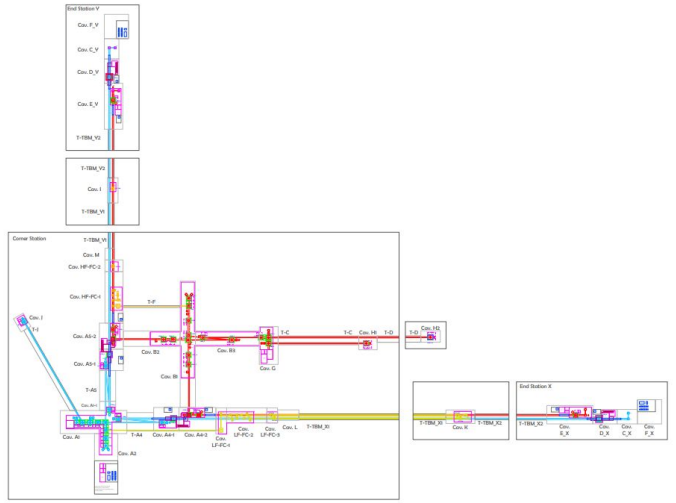
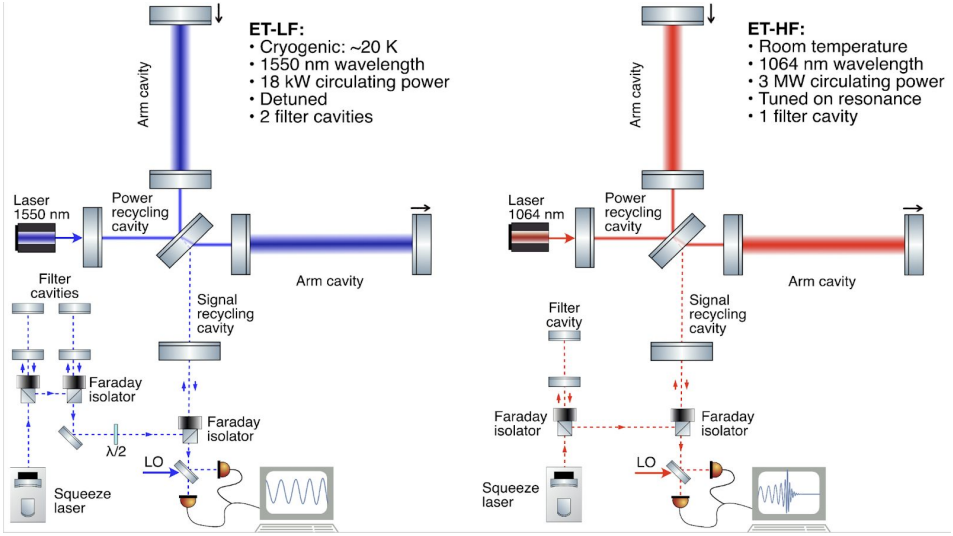
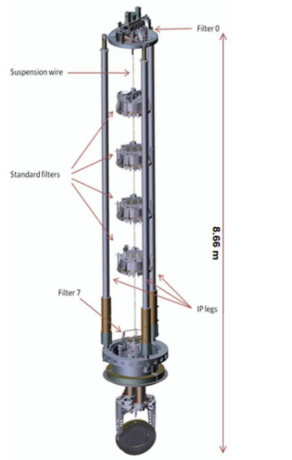


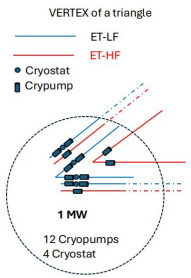
Figure 61: Element Names - L (retrieved from **TD.2**)

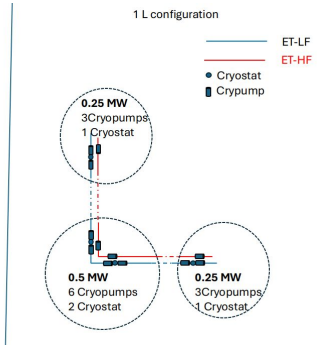
ET High-level CO2 Assessment for Scientific components

- Civil engineering components of the ET infrastructure (for both the triangular and 2L-shaped layouts):
  - Conventional tunnels
  - TBM (tunnel boring machine) tunnels
  - Shafts (access tunnels)
  - Caverns
  - Excavated material from construction of underground infrastructure
  - Surface buildings, including basic MEP (Mechanical, Electrical, Plumbing) services
  - Operational energy use of the whole ET facility
  - Operational water use of the whole ET facility
- Scientific instrument components of the ET infrastructure (for both the triangular and 2L-shaped layouts):
  - Interferometer (including Optics)
  - Noise Mitigation (including Sensors)
  - Suspension Systems
  - Vacuum Systems
  - Cryogenics Systems
  - Computation Models (Electricity consumption)



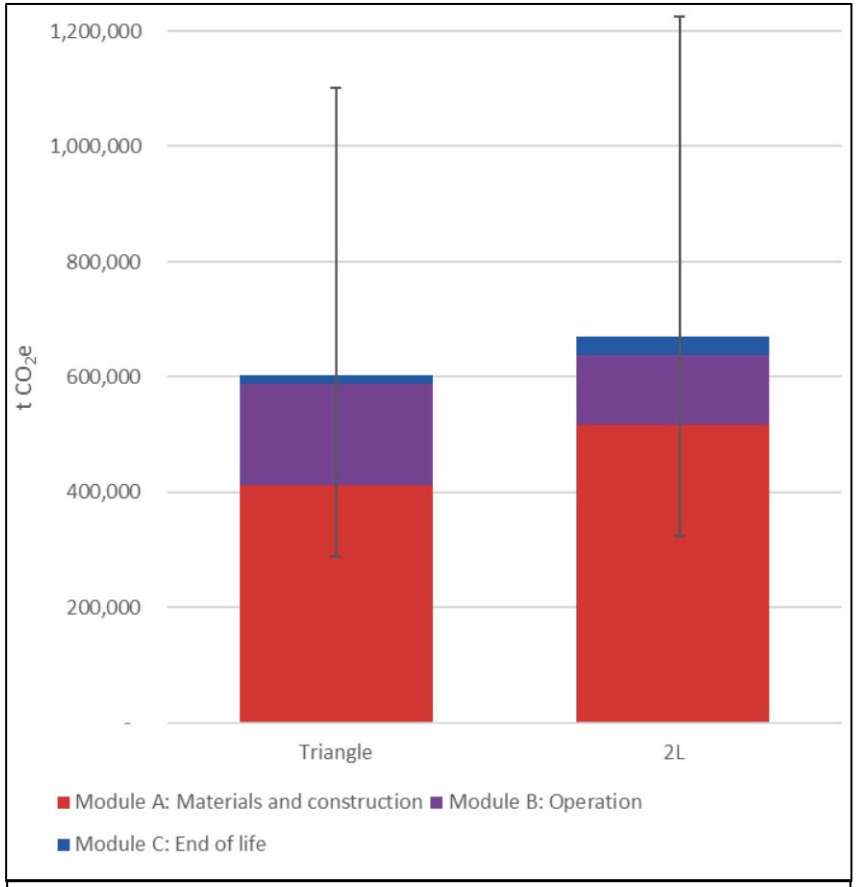




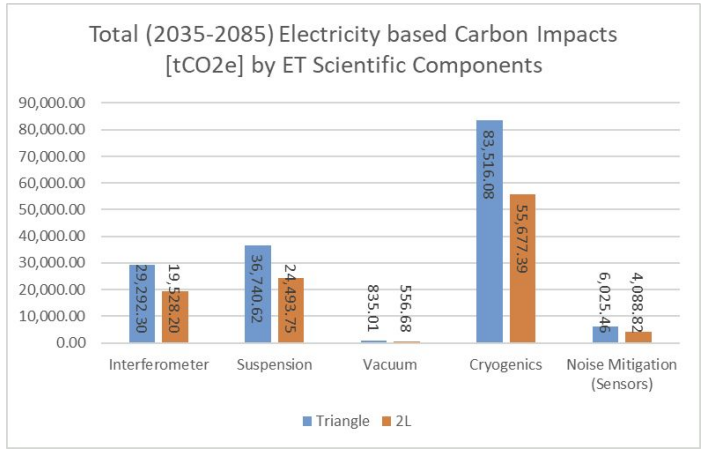


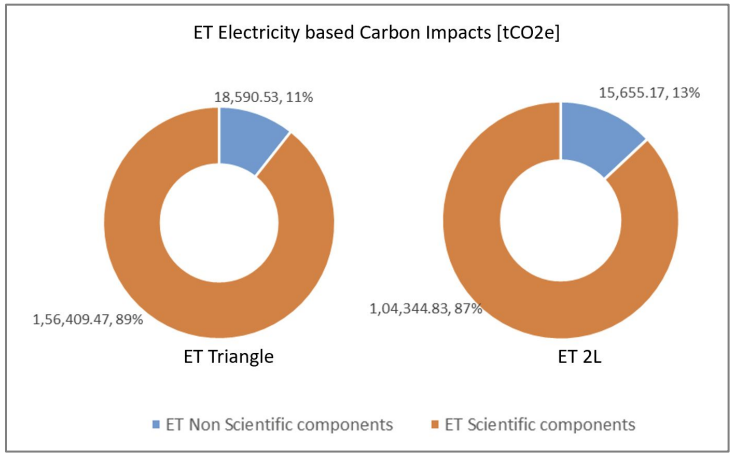
WP9 Deliverable D9.3

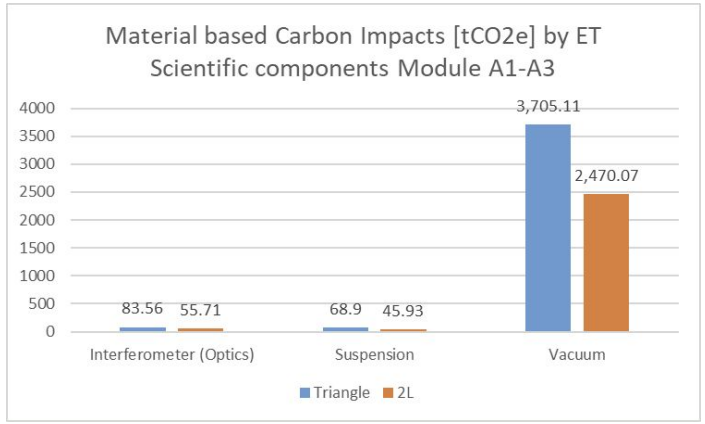
Baseline Whole Life Carbon Assessment

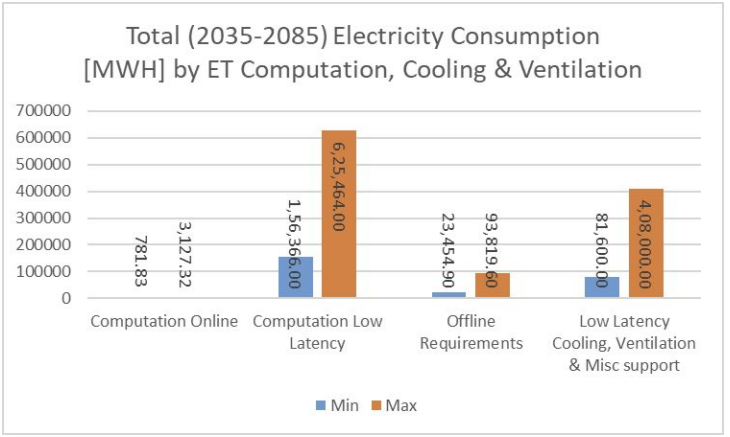


Carbon impacts of ET underground and surface infrastructure including uncertainty



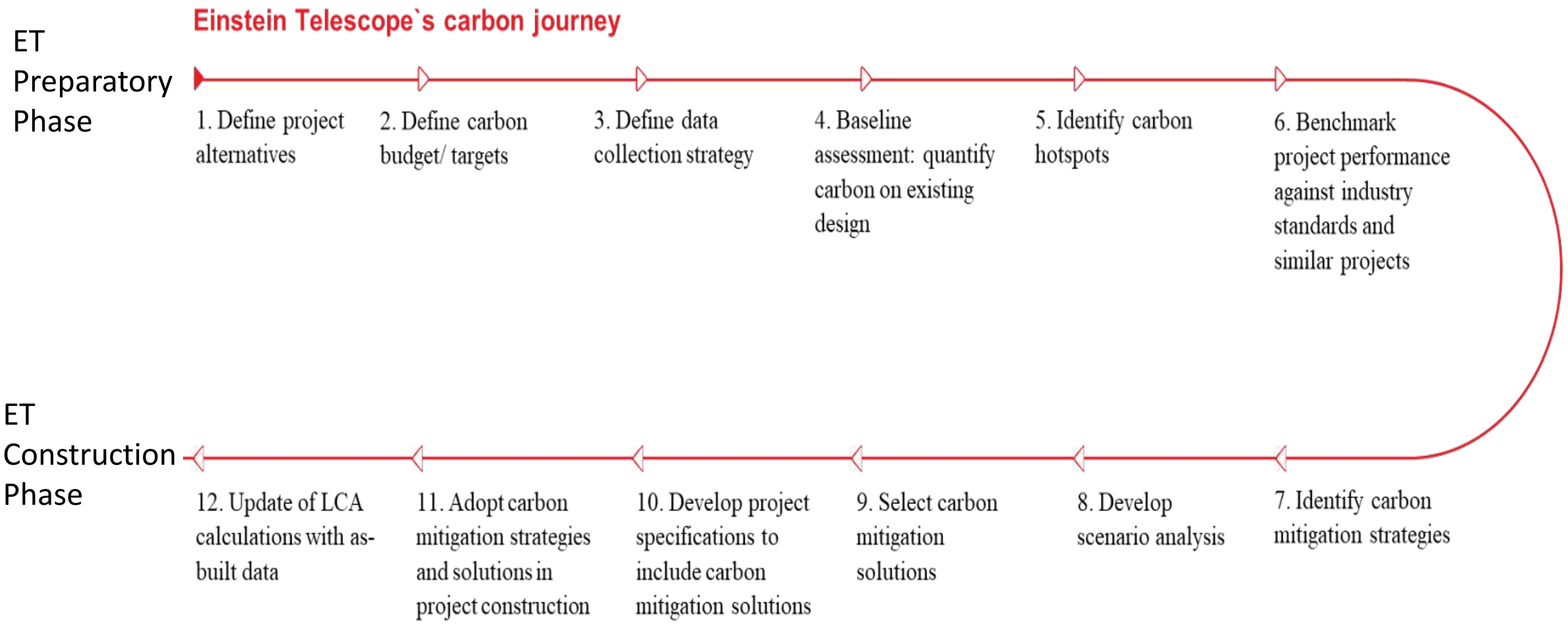






WP9 Deliverable D9.3

Key Steps for the Life Cycle Assessment during ET Phases



How to enhance the analysis to be included in D9.1 and M19

D9.1: D9.1 ET Sustainable Development Implementation Strategy

M19: Final Sustainability Plan

Action
Defining responsibilities
Assess feasibility
Establishing realistic timelines
Strengthen stakeholder collaboration through comprehensive cooperation and capacity-building plans
Enhancing digital integration through software tools and dashboards for real-time monitoring and reporting

KPIs for a high-level and flexible framework to support the Environmental pre-assessment

Energy KPIs	Purpose
Baseline: Presence of energy infrastructure, Possibility of local grid from renewables, Energy reuse potential (heat recovery)	Assess site readiness, Identify circular opportunities, etc.
Construction: Estimated energy consumption per unit construction activity, Use of low emission machinery, Renewable energy generation capacity	Quantify demand, evaluate sustainability, etc.
Operations: annual energy consumption, share of renewables, energy/ TB	Evaluate sustainability

KPIs for a high-level and flexible framework to support the Environmental pre-assessment

Air KPIs	Purpose
Baseline: Air quality, PM_{10} concentration, NO_2 concentration	Assess baseline particulate levels
Construction: PM_{10} concentration, NO_2 concentration, O_3 concentration	Risk screening
Operations: $PM_{2.5}$ concentration, NO_2 concentration, other pollutants	Evaluate long term effectiveness of control measures

KPIs for a high-level and flexible framework to support the Environmental pre-assessment

Climate change KPIs	Purpose
Baseline: Climate risk screening, Average annual temp and precipitation	Assess climate hazard exposure, Characterize climatic trends

Waste KPIs	Purpose
Baseline: Availability of circular opportunity (3Rs)	Evaluate the efficiency of waste segregation and recycling practices

KPIs for a high-level and flexible framework to support the Environmental pre-assessment

Water KPIs	Purpose
Baseline: Ground and surface water availability, Annual water consumption	Establish baseline water quantity, Assess site readiness
Construction: Water quantity and quality of source, annual consumption	Promote sustainable water management
Operations: annual consumption, Share of non potable water use	Evaluate long term effectiveness of control measures

KPIs for a high-level and flexible framework to support the Environmental pre-assessment

Nature, Biodiversity & Landscape KPIs	Purpose
Baseline: No. of species potentially affected, Interference with high ecological value areas	Guide avoidance, mitigation and compensation measures in line with biodiversity conservation purposes
Construction: Habitat area affected by site clearance	Quantify direct habitat loss and support mitigation design

Human Health KPIs	Purpose
Baseline: Population potential exposure to noise, vibrations, pollutions	Understand the magnitude of potential impacts
Construction & Operation: Population potential exposure to noise, vibrations, pollutions	Ensure the safety of workers and nearby residents

KPIs for a high-level and flexible framework to support the Environmental pre-assessment

Socio-Economic & Territorial Assessment KPIs	Purpose
Baseline: Assess economic structure, and possible cultural and social factors relevant for the project, possible and existing stakeholder engagement	Understand socio-economic profile, Ensure transparency and prevent conflict
Construction & Operation: Socio economic impact generated (including new jobs, temporary and permanent)	Understand socio-economic profile and contribution to local development

Reclamation, Reuse and Recycling of Excavated Materials

Assessment approach

1. Site-specific geochemical and geotechnical characterization (Mechanical strength, mineralogy, petrography,…)
2. Cross-border environmental compliance and contamination screening (Thresholds, …)
3. Define potential reuse pathways, prioritize high-volume, on-site or near-site options (Match material properties to realistic technical as well as legal applications)
4. Assess processing and logistics requirements, integrate material characterization and processing into construction concept
5. Perform sustainability evaluation
   Quantify environmental impact in line with ETs scientific mission

Category	Properties	Testing procedure	Unit
Geotechnical Parameters	Bulk density	Gas pycnometer	[m/s]
	Abrasivity	CERCHAR	
	Abrasivity & breakability	LCPC	
	Abrasivity	LA-Index	
	Impact fragmentation	SZ	
	Tensile strength	Brazilian Test	[MPa]
	Strength index	Point Load Test	[MPa]
	Uniaxial compressive strength	UCS	[MPa]
	Static E-Modulus	Es	[GPa]
	Grain shape index	SI	
	Flatness index	FI	
	Resistance against polishing	PSV	
	Resistance to crushing	CS	
	Water absorption after 24 h	Enslin-Neff	[%]
	Frost resistance	Freeze-thaw resistance	
	Alkali-Silica Reactivity	ASR	[‰]
Mineralogy	Mineral phases	Optical microscopy	[%]
	Mineral phases	QEMSCAN, Raman, XRD	[M-%]
Geochemistry	Major elements	ICP-MS, XRF, LIBS	[mg/kg]
	Trace elements	ICP-MS/OES	[mg/kg]
	Leaching elements	ICP-OES	[mg/kg]
	Hydrocarbon Index	Gas chromatography	[mg/kg]
	Carbon content	Dry combustion	[mg/kg]
	Water-soluble chloride	XRF	[M-%]
	Acid-soluble sulphate	XRF	[M-%]

Refinements in information

Underground Civil Components	Current status	Data Requisites
Mechanical, Electrical and Plumbing (MEP) services	Only operational emissions considered	Construction, maintenance and End-of-life data on Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Heating, Ventilation, Cooling, Safety infrastructure	No data considered	Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Infiltration of water and Waterproofing	Only water consumption based on Virgo requisites considered	Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Offsite construction activities	No data considered	Processes, transport, Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Any site waste other than excavated soil, concrete and steel	No data considered	Materials (type, mass), Disposal methods (Recycling, Incineration, Energy from waste, to Landfills)

Refinements in information

Surface building Civil Components	Current status	Data Requisites
Temporary buildings during ET facility construction	No data considered	Dimensions, Material constituents (type, mass) and power requisites, expected lifespan
Fittings and furnishings	No data considered	Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
External works	No data considered	Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Parking facilities	No data considered	Material constituents (type, mass) and power requisites
Technical rooms	No data considered	Dimensions, Material constituents (type, mass) and power requisites, expected lifespan
Mechanical, Electrical, and Plumbing (MEP) services	Only operational emissions considered	Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Packaging of building materials and components	No data considered	Materials (type, mass), packaging methods

Refinements in information

Scientific component	Current status	Data Requisites
Interferometer	Only the sensors mitigating the external stochastic noise are considered	Granular Material constituents (type, mass) and power requisites, expected lifespan
Suspension Systems	Only broad contributions such as material and power requisites are considered	Granular Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Vacuum System	Only broad contributions such as material and power requisites are considered	Granular Material constituents (type, mass) and power requisites, expected lifespan, replacement rates
Cryogenics	Only broad contributions for power requisites are considered	Granular Material constituents (type, mass) and power requisites

Moving forward

Leveraging ET-PP outcomes for site-specific assessment to carry out environmental assessment and carbon baseline

Action
Assess low carbon energy availability: on-site generation, impact on existing electricity grid, green procurement
Assess logistics for material transport and workforce
Assess transport connectivity for goods for operation and maintenance and commuters/ visitors
Assess local/regional/national availability of low carbon options for key structural materials, e.g. concrete and steel
Assess biodiversity and land-use impacts of land conversion
Conduct whole life carbon assessment for the three candidate sites – control and influence carbon
Organize stakeholder workshops on lowest carbon scientific facilities
Document decisions and actions
Publish and update KPIs

Clarifying baseline applicable to the selected site and layout for planning and permit documentation

Action
Assess energy demand implications for the two layouts
Conduct whole life carbon assessment (baseline) for the two layouts
Identify carbon hotspots for the two layouts
Compare carbon baseline against existing benchmarks
Organize stakeholder workshops to brief and gather information for the quantification
Document decisions and actions
Publish and update KPIs

Clarifying baseline applicable to the selected site and layout for planning and permit documentation

Action
Assess carbon and environmental regulatory requirements for the selected site (local, national, international)
Demonstrate compliance with EU and national climate targets
Set carbon performance or reduction target in line with the regional, national and international decarbonization obligations
Set carbon baseline performance for the selected site and layout
Prepare mitigation measures for planning documents
Assess carbon and environmental regulatory requirements for the selected site (local, national, international)
Demonstrate compliance with EU and national climate targets

Organizing advanced data collection to improve quality and granularity

Action
Identify attributes, feasible data sources, reference documents
Identify interaction and follow- up strategy

Meeting Carbon Monitoring & Management Targets

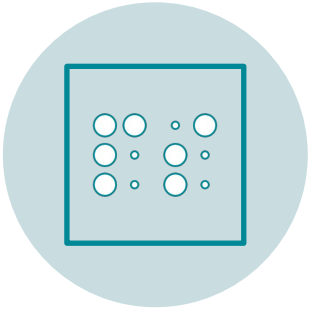
Action
Identify carbon reduction opportunities following the carbon reduction hierarchy across energy efficiency, energy generation, construction materials, circular economy applications, earthworks management, construction plant and transport strategies
Prioritize and implement carbon reduction opportunities into developing design
Review and update carbon assessment regularly
Regularly review the design’s carbon performance against targets
Organize training and knowledge sharing on low-carbon design options and measures
Publish and update KPIs
Specify low-carbon materials and carbon limits in tendering documents

Meeting Carbon Monitoring & Management Targets

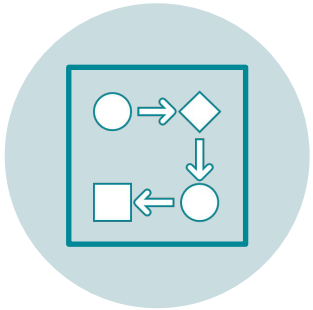
Action
Conduct regular reviews and audits
Provide a reference carbon footprint for the project as the basis for monitoring performance of the procurement contracts
Define carbon performance requirements for the procurement contracts, aligned with the established carbon targets
Establish an incentive/sanction contractual mechanism linked to achieving or missing carbon targets
Follow carbon management requirements

ET Sustainable Development Implementation Strategy - Opportunities

Addressing the path toward sustainability is crucial and can be prioritized proactively rather than reactively.



It can serve as a guide for decision-making in various sectors.



An iterative process is being conducted to determine the technologies to be used, sizing, geometry, financial aspects, and environmental impact.

We are in a preparatory phase (ESFRI roadmap), which involves pre-feasibility studies managed by candidate sites as part of the preparation of the technical and economic proposal for candidacy.