



Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

Milestone 9.1

Preliminary Sustainability Plan

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Authors	Nicolas Arnaud, Maria Marsella, Francesca Spagnuolo, Disha Sawant Paul Laycock, Elisabeth Hauzinger, Monica Marzario, Robert Galler, Daniel Schneider, Francesca Scipione
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Executive Summary

The Preliminary Sustainability Plan (PSP) is a milestone of ET-PP project Work Package 9 (WP9) towards “Sustainable Development Strategy”. This report describes how sustainability, including economic, environmental and societal impacts will be addressed by the research infrastructure of the Einstein Telescope. It presents the methodology and tools that will be used to study the impacts of the ET infrastructure and outlines the specific goals and targets of the future RI.

A Final Sustainability Plan (Milestone No. 19) will be released by the end of the ET-PP project, to include a more mature analysis of the ET Environmental Impact Assessment & Mitigation Strategy (D9.2) and CO₂ Footprint Assessment & Mitigation Strategy (D9.3).

List of acronyms and abbreviations

ACS	Analysis Capture System
CERN	European Organization for Nuclear Research
CFD	Contract for Differences
CRU	Computing Resource Usage
ESFRI	European Strategy Forum on Research Infrastructures
ET	Einstein Telescope
ET-PP	Einstein Telescope - Preparatory Phase
EU	European Union
FCC	Future Circular Collider
FSP	Final Sustainability Plan
GHG	Green House Gasses
GPU	Graphical Processing Unit
GW	Gravitational Wave
IGWN	International Gravitational-Wave Observatory Network
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
OECD	Organization for Economic Co-operation and Development
PPA	Power Purchase Agreement
PSP	Preliminary Sustainability Plan
RI	Research Infrastructure
SDGs	Sustainable Development Goals
UNGA	United Nations General Assembly
UN DESA	United Nations Department of Economic and Social Affairs
WLCG	Worldwide LHC Computing Grid
KPI	Key Performance Indicator

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Context

In today's times, scientific research infrastructures should not only be foundational to innovation, societal progress, but also be the models built for attaining sustainable development goals. Ensuring that these infrastructures are financially, socially, digitally, and environmentally sustainable across their decades-long lifecycles is increasingly recognized as crucial by institutions like ESFRI¹ and the OECD²; whose frameworks support intergenerational solidarity, operational resilience, open access, and resource efficiency³. Recent advances highlight how infrastructure sustainability is being embedded in both policy and practice: for instance, the new research station at Bodmin Moor - Europe's first dedicated Atlantic temperate rainforest facility - integrates locally sourced wood, community-driven fundraising, and carbon-sink science in a biodiversity hotspot⁴. Such initiatives underscore why embedding lifecycle governance, ecological design, and funding diversification into research infrastructure planning isn't just aspirational - it's a strategic imperative for scientific excellence and planetary stewardship.

Indeed, according to the Sixth Assessment Report (IPCC SYR, 2023) of the IPCC⁵, there is a rapidly closing window of opportunity to secure a livable and sustainable future for all. Actions implemented by governments, civil society and the private sector in this decade will have impacts for thousands of years and can enable or hinder a *climate resilient development* (the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development). Climate impacts exacerbate vulnerability and socio-economic inequities, which undermine efforts to achieve the Sustainable Development Goals (SDGs)⁶ set out by the 2030 Agenda for Sustainable Development (UNGA, 2015)⁷. The negative impacts of climate change, together with other crises (effects of Covid 19 pandemic; conflicts and other global challenges), reduce the ability of public and private actors to adopt effective adaptation measures and limit opportunities for sustainable development (see, e.g., UN DESA, 2023-24⁸). Contributing to the achievement of sustainable development is a shared responsibility of government institutions, the private sector and communities, including the scientific community. Research Infrastructures (RIs) such as should aspire to be multidisciplinary and are essential to advancing research across all scientific fields. They account for a significant portion of research investment and play a crucial role in tackling complex socio-technical challenges (OECD). As such, enhancing their organisation, sustainability, and impact has become a top priority for research funders and policy-makers. Very large research infrastructures also shape the

¹ ESFRI: "Why Sustainability Matters for Research Infrastructures" (June 4, 2025) [link](#)

² OECD: Importance of sustainable funding, governance & open policies for research infrastructure [link](#), [link](#)

³ OECD Toolkit on sustainable infrastructures for research data, interoperability, long-term preservation: [link](#)

⁴ Guardian: New Atlantic temperate rainforest research station in Cornwall (April 2025): [link](#)

⁵ AR6 of the IPCC: [link](#)

⁶ UN Sustainable Development Goals (UN SDGs): [link](#)

⁷ 2030 Agenda for Sustainable Development: [link](#)

⁸ DESA 2023 - 2024 Report: [link](#)

region where they are located and impact on the environment, the economy, and society at large (ESFRI⁹).

The Einstein Telescope (ET) is one such large underground Research Infrastructure that is proposed to host a third-generation, gravitational-wave observatory. It builds on the success of current, second-generation laser-interferometric detectors Advanced Virgo and Advanced LIGO, whose breakthrough discoveries of merging black holes (BHs) and neutron stars over the past 5 years have ushered scientists into the new era of gravitational-wave astronomy. The Einstein Telescope will achieve a greatly improved sensitivity by increasing the size of the interferometer from the 3km arm length of the Virgo detector to 10km, and by implementing a series of new complex technologies.

Assessing the research infrastructure of ET on the lines of Environmental Impact and GHG emissions is crucial from two aspects: first, attempting to improve the infrastructure of the facility so that the long-term scientific advancements go hand in hand with environmental sustenance and second, setting up a roadmap for the scientific community on prioritizing sustainability in planning of scientific facilities.

Based on existing studies and models, including the current strategy for sustainability at CERN¹⁰; this Preliminary Sustainability Plan prioritizes some sustainable development goals for the future RI, e.g. increase resource-use efficiency; reduce travel footprint; strengthen the sustainability of advanced computing infrastructures; provide open and equal access to researchers.

The Einstein Telescope (ET), as a pioneering underground research infrastructure, represents a major step forward in European and global scientific advancement. Given its scale, complexity, and anticipated environmental footprint, the development of a **comprehensive and integrated sustainability plan** is challenging but essential to ensure that the ET sets a benchmark for environmentally responsible large-scale research facilities.

The Sustainability Assessment of ET is being developed in strong alignment with **the EU Sustainability Frameworks**, aiming to ensure environmental responsibility and long-term coherence with European policy goals. Central to this approach is the prioritization of the **United Nations Sustainable Development Goals (UNSDGs)**¹¹ and alignment with **the 8th Environmental Action Programme**¹², which underpins the **European Green Deal**¹³. This includes integrating considerations from key EU legislative and strategic instruments such as the **EU Climate Law**¹⁴, **Fit for 55 Package**¹⁵, **Zero Pollution Action Plan**¹⁶ and the **Circular Economy Action Plan**¹⁷. The ET's infrastructure planning also addresses sustainable resource use through frameworks like the **Ecodesign for Sustainable Products Regulation**, **Waste from Electrical and Electronic Equipment Directive**, and the **Biodiversity and Soil Strategies for 2030**. By embedding these principles, the ET project not only advances scientific excellence in gravitational wave detection but also contributes to a resilient, low-carbon, and environmentally sound research infrastructure model within the EU.

⁹ ESFI Roadmap 2026: [link](#)

¹⁰ Environmentally responsible research at CERN: [link](#)

¹¹ UN SDGs: [link](#)

¹² 8th Environmental Action Program: [link](#)

¹³ European Green Deal: [link](#)

¹⁴ EU Climate Law: [link](#)

¹⁵ Fit for 55: [link](#)

¹⁶ Zero Pollution Action Plan: [link](#)

¹⁷ Circular Economy Action Plan: [link](#)

At the heart of this plan is a strategic **Environmental Impact Assessment (EIA) framework**, designed to align with the European Union’s EIA Directive (2011/92/EU, amended by 2014/52/EU) and guided by international best practices, such as those implemented at CERN. This framework ensures that sustainability is embedded across all phases of the project - from **design to construction, operation, and decommissioning**. Key pillars of the EIA strategy include scoping and baseline assessment, evaluation of alternatives and mitigation measures, robust public participation, and continuous monitoring and follow-up. Through these measures, the EIA supports the early identification of environmental and social risks, the protection of ecosystems, and the tracking of sustainability performance via clearly defined Key Performance Indicators (KPIs).

In parallel, the preliminary sustainability plan introduces a **dedicated Carbon Assessment and Management Strategy**, which provides a structured approach to measuring and mitigating greenhouse gas emissions across the ET’s entire lifecycle. The strategy encompasses critical components such as underground construction, buildings, equipment, and machinery, and aligns with global, EU, and national frameworks relevant to potential EU sites. It integrates cross-cutting sustainability themes, including the **management of critical raw materials** and the adoption of **circular economy principles**, reinforcing a systems-based approach to carbon reduction.

Together, the EIA and carbon strategies establish a robust foundation for the ET’s sustainability vision - ensuring that scientific excellence is pursued in tandem with environmental stewardship, regulatory compliance, and societal responsibility. This preliminary plan positions the Einstein Telescope as a **model of sustainable research infrastructure development** for future generations. The PSP is fully aligned with the European Union’s sustainability frameworks and integrates the principles of Environmental, Social, and Governance (ESG) standards. By embedding ESG indicators into the project’s design and operational strategies, the Einstein Telescope aims to deliver measurable environmental performance, transparent governance, and equitable socio-economic benefits.

Sustainability Workshop Summary

The Sustainability Workshop¹⁸ (Milestone No 18 of the ET-PP project) was organized on the occasion of the 2nd Annual Meeting for Einstein Telescope, at Université Paris-Saclay on Nov. 16 - 17, 2023.

The details are given in Appendix section 1.

Description of Deliverables and Final Milestone

The following section outlines the key deliverables produced within WP9 throughout the project, detailing their purpose, scope, and alignment with the project’s objectives. Additionally, the final milestone is presented, marking the completion of the WP9 work.

- **Environmental Impact Assessment & Mitigation Strategy (EIA) (D9.2)**

It involves high level environmental impact preassessment of the project's potential significant effects on the environment. It broadly examines elements such as biodiversity, land, water, air, climate, and human health, considering both direct and indirect impacts. The process also addresses cumulative effects, possible risks from accidents or natural disasters, and the project's susceptibility to climate change. Through this systematic analysis, the EIA

¹⁸ The Indico page of the workshop is available at the following URL: [link](#)

ensures that environmental factors are thoroughly incorporated into planning and decision-making.

- **Carbon Footprint Assessment & Mitigation Strategy (D9.3)**

It consists of carbon assessment and management in the Einstein Telescope project, drawing on existing global, EU, and national frameworks. It covers key project components such as underground infrastructure, buildings, equipment, and machinery, and integrates critical areas like carbon governance, mitigation, and circular economy principles. The strategy aims to ensure comprehensive, lifecycle-based carbon management aligned with regulatory standards and sustainability goals.

- **ET Sustainable Development Implementation Strategy (D9.1)**

The implementation strategy for the Einstein Telescope is grounded in the principles of sustainable development, setting out to define steps towards comprehensive Environmental Impact Assessment to systematically evaluate ecological sensitivities and ensure compliance with applicable environmental regulations, combining the outcomes from D9.2 and D9.3. The high-level carbon footprint, encompassing design, construction, and operational phases, forming the basis for identifying mitigation measures and reduction pathways, is developed in D9.3. In alignment with European sustainability objectives, the strategy integrates renewable energy solutions, prioritizes the use of low-carbon and resource-efficient materials, and embeds circular economy practices throughout the project lifecycle. To ensure accountability and continuous improvement, a robust monitoring, reporting, and adaptive governance framework ought to be established, thereby safeguarding long-term environmental performance and advancing the objective of climate neutrality, as developed in D9.2.

- **M19 Final Sustainability Plan**

The Final Sustainability Plan for the Einstein Telescope integrates comprehensive environmental and carbon management strategies to ensure responsible project development. It incorporates findings from the Environmental Impact Assessment, addressing potential impacts on biodiversity, land, water, air, climate, and human health, while also considering cumulative effects, disaster risks, and climate vulnerability. Aligned with global, EU, and national frameworks, the plan includes a detailed carbon management strategy covering all major project components—such as infrastructure, buildings, and equipment—and emphasizes lifecycle-based assessment, mitigation, and circular economy principles. Together, these elements form a holistic approach that embeds sustainability at the core of project planning and decision-making.

Brief Overview of the Goals

Incorporating sustainability into the development process of a large research infrastructure project is essential to ensure its long-term success, compliance with regulations, and positive environmental and social impacts. A well-rounded sustainability strategy not only supports adherence to EIA

requirements but also strengthens the project's alignment with global sustainability objectives and initiatives.

The preliminary sustainability plan for the Einstein Telescope emphasizes alignment with **EU Sustainability Frameworks** to enhance consistency, guided by the core principles of the EU Taxonomy and its environmental objectives.

On these lines, each sustainability strategy should be accompanied by a relevant theme description that pertains to the ET RI project:

- **Decarbonization and Energy Efficiency** support the reduction of carbon emissions and the integration of renewable energy solutions in both design and operational phases. Key areas to address include sustainable energy strategies, carbon footprint, and air quality. While an Environmental Impact Assessment (EIA) does not mandate the evaluation of embodied carbon in scientific equipment, dedicated attention will be given to this aspect at the appropriate stage, within the broader context of lifecycle assessment.
- **Climate Resilience** attempts to guarantee that the infrastructure is resilient to future climate-related risks by incorporating climate risk assessment and adaptation measures.
- **Efficient Data Management** helps quantify the energy consumption and carbon footprint associated with digital operations in scientific research infrastructures. This allows sustainability assessments to identify optimization opportunities, such as reducing redundant processing, improving data center efficiency, or adopting low-carbon cloud services.
- **Resource Management and Circular Economy** encourage efficient use of materials, waste minimization, and a lifecycle approach. This should ideally include descriptions of material selection, circular economy practices, and sustainable procurement strategies.
- **Biodiversity & Landscape Preservation** protects local ecosystems and integrates green spaces into the project footprint. The relevant sustainability themes should focus on nature positive approach (e.g. natural habitats and biodiversity preservation) and visual impact assessment.
- **Water Management** assesses water use, conservation, and protection of local water bodies. This should contain water management and water resources description.
- **Project Governance** supports transparent, inclusive, and accountable decision-making across all stages of the project. Key themes to consider include governance structures and sustainable data management.
- **Socio-economic Impact Assessment** gauges the project's impact on local communities, employment, and regional development, with the goal of ensuring fair and inclusive benefits. Key sustainability themes to address include stakeholder engagement, equity and inclusion, and economic impact assessment.
- **Carbon Assessment** comprehensively summarizes the main carbon and environmental impacts, key findings, and proposed mitigation measures; a synthesis of the most critical insights and recommendations for decision-makers; and an emphasis on the significance of carbon and resource management in research infrastructures.

Sustainability Action Plan

The proposed sustainability framework is based on **EU Taxonomy**¹⁹. Keeping in mind the European Commission’s **Do No Significant Harm (DNSH) principle**²⁰ and relating it with ET RI’s potential sustainability objectives, these Key Parameter Indicators (KPIs) ensure consistent evaluation across diverse locations using common sustainability and impact criteria. This approach promotes a transparent and robust assessment process, aligned with the needs of large-scale research infrastructure projects, and supports informed, flexible decision-making.

Strategic Key Performance Indicators provide a standardized framework for assessing the environmental suitability of potential locations. The Einstein Telescope Preparatory Phase is currently in the process of assessing three potential construction sites: Sardinia (Italy), Saxony (Germany) and EMR (partially in Belgium, Germany & The Netherlands).

Specific KPIs are developed to refine project design and guide future enhancements in mitigation and monitoring strategies. These tailored indicators address the unique aspects of the project, allowing for effective progress tracking and adaptive management.

This plan envisages connecting each **target area** to **strategic Key Parameter Indicators (KPIs)** that are relevant for a local analysis and **specific KPIs** that are essential for project-level optimization, forming a roadmap that WP9 and associated teams can implement across the design and construction stages. **This plan stays site agnostic and focuses on the infrastructural aspects to assess environmental impact.**

These KPIs also contribute to broader **ESG compliance** and provide international visibility of ET as a next-generation **green scientific infrastructure**.

1. Low-Carbon and Energy-Efficient Infrastructure

This framework supports a structured approach to designing and operating low-carbon, energy-efficient research infrastructure, enabling continuous improvement and informed decision-making.

Targets	Strategic KPIs	Specific KPIs
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¹⁹ EU Taxonomy: [link](#)

²⁰ EU DNSH: [link](#)

• Minimize air quality negative impacts to ensure health and environmental protection • Minimize carbon footprint to address climate change • Maximize renewable energy usage and reduce overall energy demand, promoting long-term energy sustainability and efficiency	• Baseline air quality and predict future impact zones • Alignment of the current and planned energy infrastructure with sustainability goals • Energy supply potential, including renewable sources, to support future energy planning	• Life-cycle carbon footprint, covering Scope 1, 2, and 3 emissions (expressed in tCO₂e/year) <i>Details of Scopes are mentioned in section 2 of the Appendix.</i> • Renewable energy usage percentage and generation capacity (in MW units) • Energy use breakdown by subsystem (e.g., cryogenics, HVAC, data centers), offering insight into the most energy-intensive components
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Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- **Perform energy modeling** for critical systems such as cryogenics and ventilation across different infrastructure designs (e.g., tunnel options).
- **Establish a baseline greenhouse gas (GHG) profile** using recognized standards such as **PAS 2080** and **ISO 14067**.
- **Integrate life cycle assessment (LCA) screening** into **technical specifications** during the procurement phase to ensure sustainability criteria are met from the outset.

2. Climate Change Resilience

This framework supports a structured approach to develop and implement adaptive strategies to enhance infrastructure resilience against climate-related risks through risk assessment, design adaptation, and emergency planning.

Targets	Strategic KPIs	Specific KPIs
Future-proof the site and infrastructures from climate-related events	Climate Risk Screening and Vulnerability Assessment	• Resilience measures implementation (e.g. flood protection, fire zones) • Stress test system performance under temperature, drought, or power disruptions • Adaptation policy integration

Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- **Future-proof the site and infrastructures** from climate-related events
- Map **climate hazards** (heat waves, water scarcity, flooding)
- **Coordinate** with civil WP (WP6) to embed resilient design (e.g. backup energy, water reuse, passive cooling)

3. Efficient Data Management & Processing

Computing requirements for the Einstein Telescope will be significant and, as detailed in a separate Deliverable (D8.1), can be effectively met using state-of-the-art solutions from the LHC. This approach avoids redundancy in the short term and leverages collaborative efforts to address future computing challenges over the medium and long term.

Targets	Strategic KPIs	Specific KPIs
• Minimize Computing Resource Usage (CRU) • Optimize software for efficiency • Eliminate redundancy using Analysis Capture System (ACS) • Attract, train, and retain computing experts for long-term sustainability	• CRU per workflow and energy consumption per CRU • % of optimized Processing Units workloads • Efficiency gains from reused computations via ACS • Development of expert retention and training methods	• CO₂e per CRU based on energy source • User-level CRU footprint vs ET average • Emissions avoided via shared infrastructure use (e.g., WLCG) • Reductions from computation reuse (ACS - enabled) • Optimization of software by pool of dedicated computing staff

Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- Establish **monitoring of CRU** with expert support.
- Establish a **software testing and validation** infrastructure using modern best practices.
- Establish **close collaboration with WLCG computing experts**.

4. Resource Management & Circular Economy

This approach focuses on promoting circular economy principles by prioritizing material reuse, recycling, and recovery throughout the infrastructure lifecycle.

Targets	Strategic KPIs	Specific KPIs
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• Promote circular use of materials and minimize waste • Foster reuse of excavated material • Ensure sustainable procurement	Circularity potential across materials and infrastructure packages	• Recycled content and reused content (in %) • Construction waste recovery rate • Embodied carbon in materials and operational systems • Embodied energy for high-impact materials (concrete, steel, copper) • Reuse of excavated earth in landscaping, fill, or internal concrete blends
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Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- Create a **Material Flow Analysis (MFA)** linked to excavation and procurement plans
- **Prioritize** suppliers with **EPDs (Environmental Product Declarations)**
- **Collaborate** with WP6 and site contractors for real-time excavation volume tracking

5. Biodiversity and Landscape Preservation

This approach works towards protecting local ecosystems and blending green spaces, focusing on a nature-positive approach and visual impact assessment.

Targets	Strategic KPIs	Specific KPIs
Nature positive approach (Protect and enhance local ecosystems and landscape integrity)	• Area of habitat or number of species potentially affected evaluation • Landscape impact assessment • Interference with high ecological value areas • Interferences with cultural or heritage sites	• Habitat area restored/preserved • Vegetation cover (number of plants per unit area) • Net biodiversity gain/loss • Ecosystem services assessment

Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- Conduct **landscape and biodiversity impact assessments** before construction
- **Avoid or minimize** disruption to high-value ecological areas
- Design **restoration projects** for disturbed habitats

- **Monitor vegetation and biodiversity change** over time
- Preserve **cultural/heritage site integrity** within project boundaries

6. Soil Preservation and Excavation Reuse

An important contribution, to minimize the impact of ET project on the natural environments and promote its integration into the surrounding landscape, involves the treatment and reuse of a large amount of excavated material. During the construction of large-scale infrastructures, a huge quantity of excavated material is generated. This material is increasingly less considered as mere waste to be landfilled, representing, instead, a potential resource. In fact, as indicated in the EU Soil Strategy 2030²¹, the excavation material should be reused in the same or another appropriate location.

The steps cover implementation of sustainable soil management practices to preserve soil quality and minimize erosion during construction and to encourage the reuse of excavated material on-site or nearby to reduce waste, transport emissions, and resource consumption.

Targets	Strategic KPIs	Specific KPIs
• Minimize soil consumption • Maximize excavated material reuse	Subsurface soil conditions (porosity, permeability, stability)	• Excavated soil reuse rate (%) • Reduction in impermeable surface areas • Integration of Nature-Based Solutions (NBS) to restore or enhance land use

Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- Conduct detailed **geo-characterization studies** (WP6 input)
- Develop **Excavated Material Reuse Matrix** (already broadly proposed by WP9)
- **Monitor reuse performance** by contractor during construction phase

7. Water Use and Quality Protection

The section focuses on adopting efficient water use strategies to optimize consumption and ensuring responsible sourcing throughout the project lifecycle.

Targets	Strategic KPIs	Specific KPIs
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²¹ Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, EU Soil Strategy for 2030. Reaping the benefits of healthy soils for people, food, nature and climate, COM (2021) 699 final: [link](#)

• Ensure sustainable water usage • Protect surface and groundwater quality	• Groundwater and surface water availability • Availability and capacity of existing water infrastructure • Local water stress analysis (seasonal and annual)	• Water balance: accounting for all inflow/outflow including construction and operational use • Discharged water quality (in line with national discharge limits) • Water usage effectiveness • Efficiency of water consumption (m³ per technical unit or operation)
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Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- **Map water usage demand** for cryogenic systems, cooling, sanitary use, and construction activities
- **Establish water sourcing strategies** with minimal ecological drawdown (e.g., rainwater harvesting, recycled sources)

8. Maximizing Socio-Economic Benefits

Sustainable development enhances socio-economic benefits by promoting inclusive growth, job creation, and poverty reduction. Assessing sustainability involves evaluating how projects contribute to community well-being, equity, and long-term economic resilience.

Targets	Strategic KPIs	Specific KPIs
Maximize positive local impacts (jobs, knowledge, training)	• Potential economic impact across local, regional, national levels • Projected occupational footprint (direct and indirect employment) • Inclusion of community voices in decision-making (e.g., residents, associations, local authorities) and wider stakeholders (e.g., institutions, scientific partners, industry)	• Local employment rate (% of project-related jobs hired locally) • Number of training initiatives launched (STEM or vocational) • Apprenticeship and early-career researcher program stats • Insights from public forums, workshops, or surveys to be integrated into decision-making

Relevant Tasks

Practical steps to implement the strategy and meet the targets:

- Integrate **sustainability clauses into tendering**

- **Develop partnerships** with nearby universities, polytechnic institutes, and NGOs
- **Track and report job creation and skills transfer** through WP

Challenges with Sustainability Assessment of Einstein Telescope

Site Selection

The most significant aspect in commencing environmental and carbon assessments for any infrastructure is the construction site. The planning, excavation profiles, energy supply networks, and environmental baselines differ substantially based on site location and environment. This can limit the consolidation of a unified Product Breakdown Structure (PBS), which are essential for performing high level Life Cycle Assessments (LCA) or carbon budgeting under ISO 14067 or EN 15978 frameworks.

Project Scope Evolution

The Einstein Telescope project is undergoing technical evolution, especially in optics, cryogenic systems, and tunnel configurations (triangle-shaped vs. L-shaped layouts). These design variations directly affect:

- Material volume estimates
- Power and cooling demands
- Construction schedules and transport logistics

Expert Involvement

The preparatory phase involves collaboration between multiple national agencies and researchers, and involves engineering consulting stakeholders. Coordination across Work Packages (WPs) and with Einstein Telescope Organization (ETO) adds logistical complexity in terms of data fragmentation and quality.

Furthermore, the analysis included in key deliverables (D9.1, D9.2, D9.3) is depending on inputs from WP6 (infrastructure), WP8 (data), and WP4/5 (cryogenics and optics) as described in the following:

- Given the multi-sectorial complex infrastructure of ET, inputs from WP4 and WP6 are crucial. Several aspects such as changes in land use, resource consumption, emissions will be essential for the assessment and will be also helpful to eventually evaluate the possible disturbances to local ecosystems and communities.
- Based on the information shared by WP8 about the requirement and design of online/on-site data center, the estimation of the required resources; WP9 team will be able to broadly gauge the computation-based emissions by ET.
- Specific resource information from WP5 about the scientific machinery utilized in ET (for maintenance of cryogenic temperatures, operation of optical equipment, etc.) can shed light on particular components' emissions. Book-keeping these numbers would be instrumental as often such scientific technologies advance over time and studying current scientific instruments for emissions can provide baselining for future assessments.

Moreover, the complexities associated with centralized data ownership and project-wide traceability tools, carbon footprint estimation becomes a distributed task with cohesion challenges.

Data Collection and Accuracy

With many site studies ongoing, WP9 must rely on provisional data or extrapolated metrics, which can compromise the granularity required for ISO-aligned LCA. Moreover, evolving legal and EIA requirements per country can affect acceptability of the baseline data as per the EU regulators and funders.

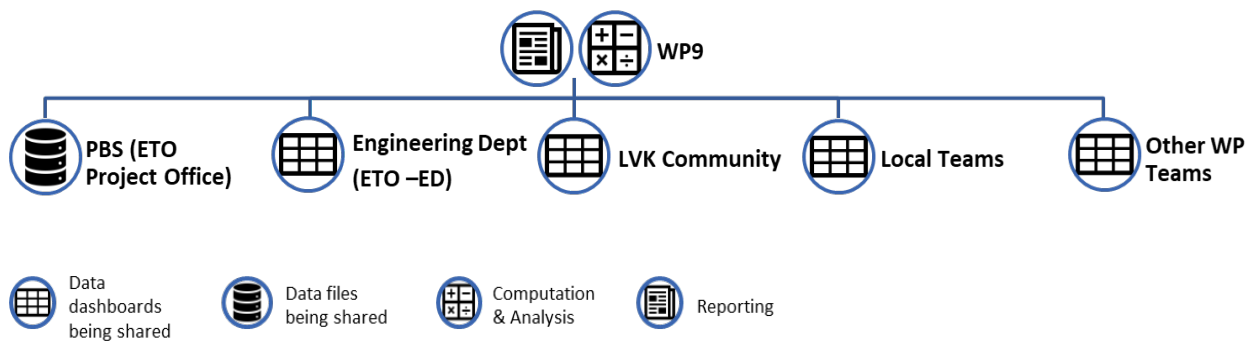
WP9 is committed to delivering the assessment by actively collaborating with other WP teams to obtain relevant data, drawing upon the latest available literature and documentation, and applying carefully considered extrapolations within realistic ranges to enable a comprehensive evaluation of the carbon footprint and environmental impact. *The broad approach for initiating the interaction for such data requisites and glimpses of data collection frameworks are mentioned in the next section and in Appendix Section 3.*

Integration with domain experts/ Governance for Assessment

Sustainability assessment and carbon footprint measurement within a large-scale scientific infrastructure like the Einstein Telescope demand a high degree of coordination among diverse working groups. These assessments are **inherently complex, requiring consistent methodologies and clearly defined parameters across teams that often have varying technical focuses and regional scopes**. Each group—whether focused on construction, operations, or procurement—must align on what constitutes relevant environmental data and how it is collected, categorized, and reported. **Without this shared understanding, discrepancies in data interpretation can undermine the integrity of the entire sustainability evaluation process.** Ensuring that everyone is working from the same definitions, units, and reporting standards is essential to producing a carbon footprint measurement that is both credible and actionable.

The challenge is compounded by the dynamic and collaborative nature of the Einstein Telescope project, which spans multiple countries and disciplines. Rigorous follow-ups are necessary to track progress, verify data inputs, and adapt to emerging sustainability requirements or evolving project scopes. This calls for continuous engagement, transparency, and a strong feedback loop among stakeholders. **Effective sustainability assessment is not a one-time exercise but a continuous process that hinges on mutual accountability and shared commitment to environmental goals. In such a multidisciplinary and multinational context, fostering a culture of openness and precision around data is just as crucial as the technical measurements themselves.**

Initiation



The **Sustainability team (WP9)** of ET has initiated collaboration with members of the **Einstein Telescope Organisation (ETO)**, particularly the ETO Project Office and Engineering Department, to gain a clearer understanding of the components and scope involved in the construction phase of the Einstein Telescope. **These early interactions aim to gauge the type and the depth of information available, in order to identify key personnels, map out the types of materials, construction activities, and infrastructure requirements that are likely to influence the project's environmental footprint.** *The glimpses of such data requisites and formats are illustrated in Appendix section 3.* By engaging directly with representatives involved in technical planning, WP9 is trying to lay the groundwork for more detailed assessments in the near future.

Scaling Up the Interface

Once the baseline data collection framework is established and the network starts functioning, WP9 will initiate structured engagement with other WP teams to ensure seamless integration and effective data acquisition. This interaction will begin with targeted coordination meetings to communicate the framework's scope, the expected data formats, and reporting timelines. WP9 will collaborate closely with technical WPs—such as infrastructure, optics, and cryogenics—to clarify environmental and sustainability data needs, offering guidance on aligning their existing data pipelines with the sustainability assessment metrics. Where necessary, WP9 will provide data collection templates, support tools, and interactions to improve the consistency and quality of the data being gathered across disciplines.

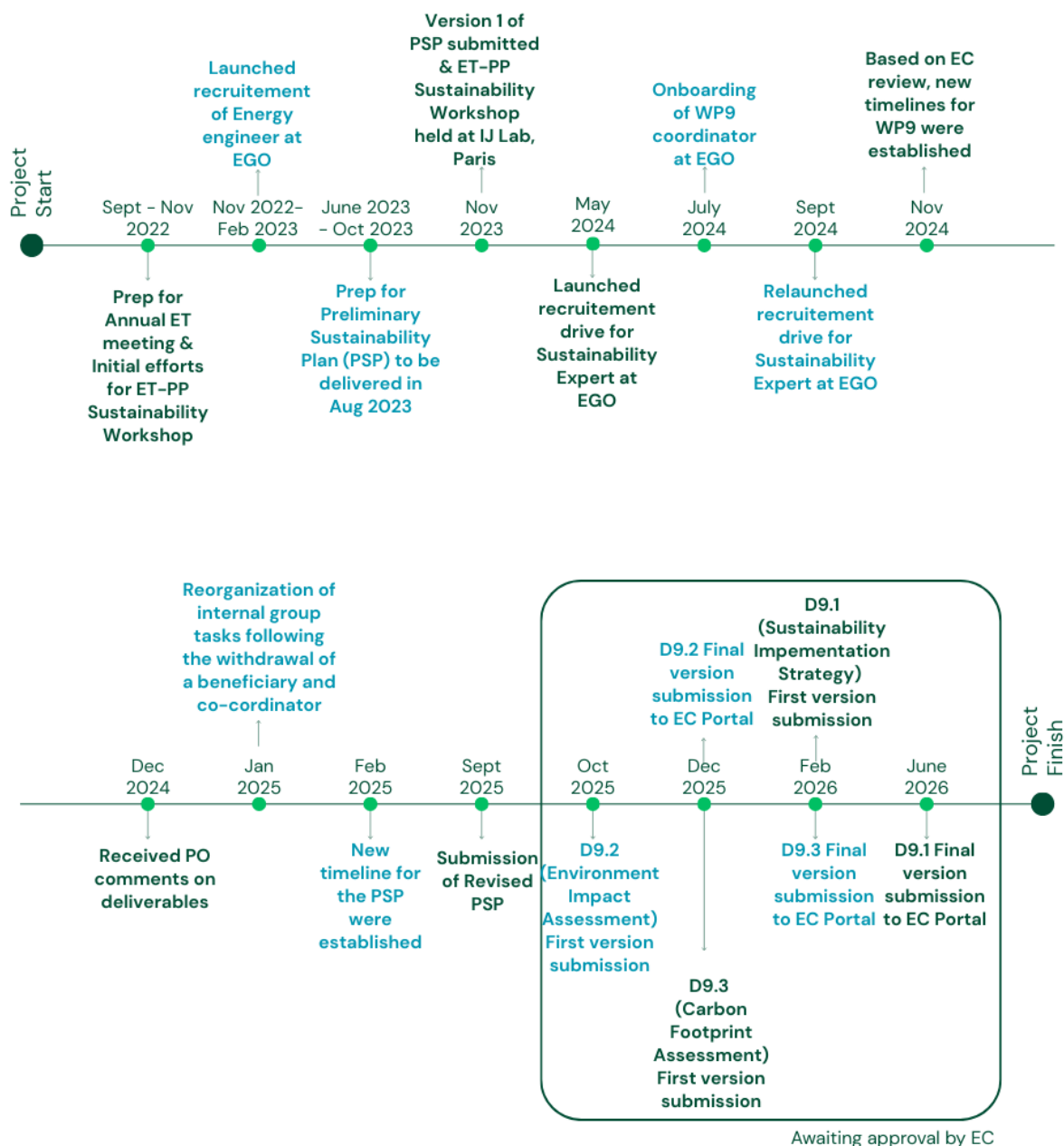
Following initial alignment, WP9 will implement a cycle of feedback, review, and refinement with the WP teams to validate the effectiveness of the data collection strategy in practice. Continuous follow-ups will be scheduled to monitor progress, troubleshoot bottlenecks, and ensure data integrity. Through these interactions, WP9 will identify gaps or inconsistencies in reporting, adapt the framework to suit evolving needs, and scale up efforts to cover a broader scope of environmental and CO₂ - related metrics. These rigorous follow-ups will not only help improve the granularity and accuracy of sustainability assessments but will also foster a culture of accountability and collaboration across the entire Einstein Telescope consortium, ultimately ensuring that sustainability goals are robustly embedded into the project's lifecycle.

WP Involved	Type of Interaction	Purpose of Interaction
WP4: Site Preparation	Environmental Baseline Data	Collect baseline data on biodiversity, emissions, land use, and environmental impact.
WP5: Project Office/Engineering Dept.	Technical Planning	Integrate low-carbon technologies, sustainable materials, and eco-design into infrastructure planning.
WP6: Technical Design	Design Inputs	Assess lifecycle emissions and influence design decisions (e.g., materials, energy systems).
WP7: Transfer of Technology	Sustainable Innovation	Promote transfer of green technologies and best practices for reducing emissions.
WP8: Computing and Data Access	Data Infrastructure	Set up carbon accounting systems, sensor data collection, and environmental monitoring dashboards.
WP10: Education, Outreach, Citizen Engagement	Awareness & Feedback	Communicate environmental strategies and gather public feedback; promote behavioral change.

A dedicated organizational structure for sustainability will be fully included into the future ETO organization and this framework will be elaborated in the Final Sustainability Plan.

Timelines & Deliverables

WP9 is responsible for producing three major sustainability deliverables (D9.1, D9.2, D9.3), involving a structured process of coordination, data collection, analysis, and reporting over 12 months. The workflow is tightly sequenced to align with EC Portal submission deadlines, ensuring quality through internal and external reviews.



Justification for Flexibility and Delay Mitigation

Given the dependencies on external data providers (including civil works teams, procurement, and technical WPs), the need for synchronized definitions and measurement criteria, and the often-fragmented maturity of sustainability-related information across large scientific infrastructures, reviewers of the preparatory phase should consider that **delays are likely and should be reasonably allowed**. Coordination between WP9 and other WPs or local partners often encounters bottlenecks such as differing data standards, incomplete information, and scheduling conflicts. Therefore, built-in flexibility and contingency allowances are essential to maintain the credibility and completeness of the sustainability assessment process without compromising its scientific and operational integrity.

Deliverable	Relevant Tasks
9.2: Environmental Impact Assessment (EIA)	• Designing ET specific EIA and CO₂ Assessment Strategy • Literature Survey and assessment of data • Framing data collection formats • Assessing data with other WPs
9.3: CO ₂ Footprint Computation	• Designing ET specific EIA and CO₂ Strategy • Literature Survey and data assessment • Framing data formats • Assessment and computation
9.1: Final Sustainability Plan	• Defining and Finalizing Structure and Deliverables • Updating the ET-PP leadership • Developing the report

Appendix

Section 1: Sustainability Workshop Summary

Nov 16 - 17, 2023 at IJLab, Université Paris-Saclay²²

Workshop Objectives

- Raise awareness and responsibility within the ET collaboration regarding environmental impact. (apps.et-gw.eu, et-gw.eu)
- Frame sustainability strategies across infrastructure, instrumentation, computing, and outreach. ([Indico](#))

Presentations

Speaker & Theme	Key Takeaways
Francesca Spagnuolo (EGO) – Long-term infrastructure sustainability	Strategies for research infrastructure sustainability. (IJCLab Events Directory (Indico))
Mélissa Ridet (Labos 1point5) – Reducing lab carbon footprints	Effective best practices for energy, waste management, and travel reduction in academic labs.
Sonja Kleiner (CERN) – CERN's environmental strategy	Insight into how CERN achieves environmental responsibility in large-scale research.
Jacopo Ghiglieri (SUBATECH) – Perspective from HECAP+ research	Lifecycle analyses, carbon accounting and mitigation approaches for high-energy physics.
Jürgen Knödseder (IRAP) – Astrophysics infrastructure footprint	Case study on environmental impact of astronomy facilities and possible optimizations.
Daniel Holz (U. of Chicago) – LIGO-Virgo-KAGRA climate committee	Review of established models and collaboration efforts for sustainable gravitational-wave projects.

²² The Indico page of the workshop is available at the following URL: [link](#)

Interactive Discussions & Breakout Sessions

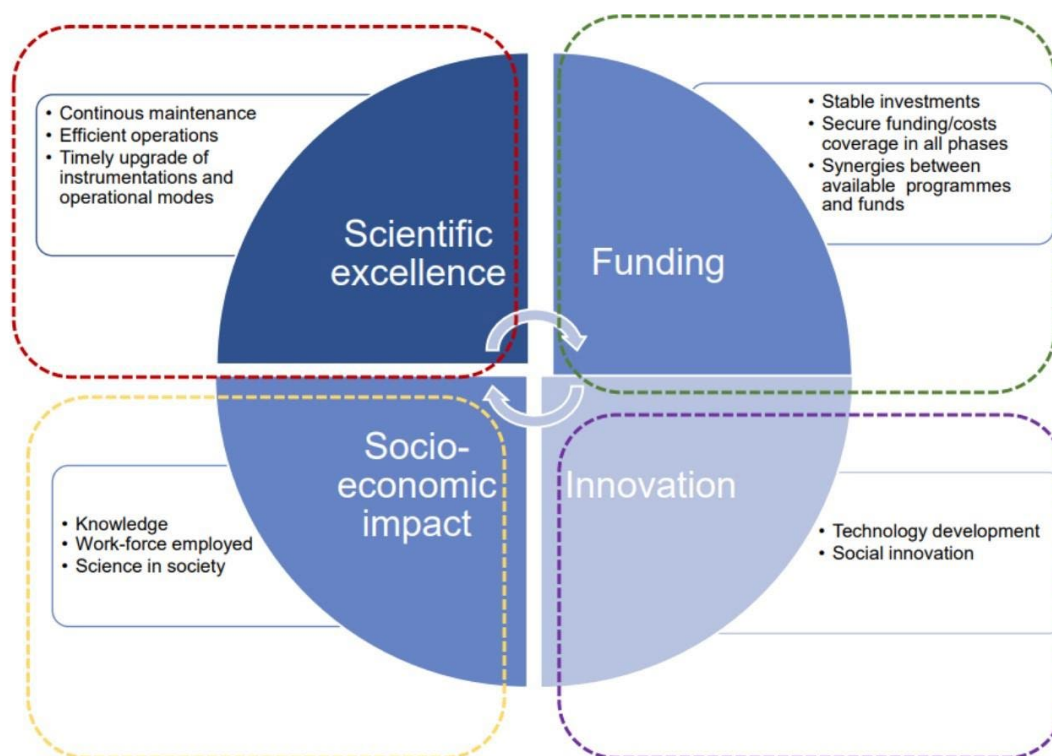
- **Day 1:** Explored how existing collaboration examples (CERN, Labos 1point5, LIGO-Virgo-KAGRA) can be adapted for ET.
- **Day 2:** Focused on core ET work packages:
 - **WP9 – Site Infrastructure:** Sustainable excavation, energy usage, and site operations.
 - **Instrument Design:** Materials lifecycle, cryogenics, vibration isolation efficiency.
 - **Computing:** Energy-demand modeling, data-center best practices, partnership with WLCG and ESCAPE. (apps.et-gw.eu, ego-gw.it, [Indico](#), [IJCLab Events Directory \(Indico\)](#), [IJCLab Events Directory \(Indico\)](#))
 - **Communication & Outreach:** Embedding sustainability messaging in public engagement efforts.

Next Steps & Deliverables

- Draft **Preliminary Sustainability Plan (Milestone 9.1)** prepared, to guide ET-PP toward detailed carbon footprint modeling. ([IJCLab Events Directory \(Indico\)](#), apps.et-gw.eu)
- Computing team developing energy-efficient framework, considering WLCG integration and low-carbon goals.
- Assigning clear ownership of sustainability goals across ET-PP work packages (WP9, instrumentation, computing, outreach).

Conclusions & Strategic Outlook

- The ET collaboration is aligning sustainability from the earliest design stage: both for underground infrastructure and computing facilities.
- Benchmarking off larger labs (e.g., CERN) and gravitational-wave networks ensures ET adopts proven and scalable measures.
- The workshop established a clear path: Formation of a sustainability plan leading towards integrating criteria into the design phase resulting in monitoring and optimization.



Workshop Outlook: “The four main dimensions of RI’s long-term sustainability”

Section 2: Scope 1, 2 and 3 in the context of the ET

The main sustainability figure of merit for a very large infrastructure like the Einstein Telescope concerns the emission of greenhouse gas (GHG). This can be expressed in CO₂eq and estimated in accordance with the internationally recognized methodology of the Greenhouse Gas Protocol²³. This protocol categorizes such emissions into three “scopes”:

- **Scope 1** refers to the direct emissions occurring from sources that are owned or controlled by an organization.
 - On-site stationary fuel combustion:
 - Boilers, generators, and heating systems (e.g., natural gas, diesel)
 - Cryogenic refrigeration units (e.g., using fluorinated gases)
 - Vehicle fleet emissions (if operated by the project):
 - Maintenance, logistics, or construction vehicles
 - Refrigerant leakage:
 - From HVAC systems, cryogenic systems, and cooling equipment
 - On-site construction machinery emissions (during building phase)
- **Scope 2** refers to indirect emissions related to the generation of electricity, steam, heating or cooling purchased for an organization’s own use. In case of ET, these can be emissions resulting from purchased electricity for:
 - Cryogenics
 - Data centers
 - Scientific instrumentation

²³ The GHG protocol is a comprehensive global standardized framework for measuring and managing greenhouse gas (GHG) emissions: [link](#)

- HVAC systems
- Tunnel lighting and operations

Moreover, assessment needs to consider emissions from:

- Heating or cooling from external providers (if applicable)
- Grid-mix energy source analysis (renewables vs. fossil-based share)
- **Scope 3** refers to all other indirect emissions occurring upstream and downstream of an organization's activities, such as business travel, personnel commutes, catering and procurement.

The elements can be:

- Production and transport of construction materials:
 - Concrete, steel, copper, rare earths, and specialized materials
 - Embodied carbon in equipment and infrastructure:
 - Scientific instruments, cryogenics systems, vacuum systems
 - Transport of goods and materials
 - Freight emissions (air, sea, road)
 - Business travel:
 1. Staff travel to/from site and for collaboration
 2. Employee commuting

Section 3: Preliminary Data requisites and Formats

Based on the induction carried out by WP9 for other WP experts from April 2025 till July 2025, preliminary framework and data requisite list have been developed. These formats are based on the latest ET document survey which consisted of ET Base Layout Design, Component hierarchy and Instrumentation breakdown. Detailed interactions with WP teams enabled WP9 to comprehend basic type, structure and depth of accurate data that can be shared in the coming days.

Environmental Assessment Considerations (Prototype Checklist)

A. Elements to consider in relation to Climate (ref. ESRS E1 disclosure requirements E1-1, E1-2, E1-3, E1-4, E1-5, E1-6, E1-7, E1-8, E1-9)		
	CHECKLIST OF POTENTIAL ISSUES under E1-1 Transition plan for climate change mitigation²	Potentially relevant? (YES/NO)
1	(17) Resilience in relation to climate change	
	CHECKLIST OF POTENTIAL ISSUES under E1-2 Policies related to climate change mitigation and adaptation	Potentially relevant? (YES/NO)
2	(22) Material impacts, risks and opportunities related to climate change mitigation and adaptation	
3	(23) Whether and how policies address the energy efficiency and renewable energy deployment	
B. Elements to consider in relation to Pollution (ref. ESRS E2 disclosure requirements E2-1, E2-2, E2-3, E2-4, E2-5)		
	CHECKLIST OF POTENTIAL ISSUES under E2-1 Policies related to pollution	Potentially relevant? (YES/NO)
13	14(a) Mitigating negative impacts related to pollution of air, water and soil including prevention and control	
14	14 (b) Minimising and substituting substances of concern and phasing out substances of very high concern	
15	14 (c) Prevention of incidents and emergency situations	
C. Elements to consider in relation to Water and marine resources (Ref. ESRS E3 disclosure requirements E3-1; E3-3)		
	CHECKLIST OF POTENTIAL ISSUES under E3-1 Policies related to water and marine resources	Potentially relevant? (YES/NO)
21	11(a) Water management including the use and sourcing of water and marine resources in own operations	
22	11(b) Product and service design in view of addressing water-related issues and the preservation of marine resources	
23	11(c) Commitment to reduce material water consumption in areas at water risk in its	

Example of Civil Engineering Components (Data Collection under progress)

Category	Existing data	Data source	Data request	Is this available? (Yes/ No)	Any remarks?
Conventional tunnels	Number, length, diameter, cross section	Supporting document for ET detector layout	Lining thickness, concrete grade, steel content		
TBM tunnels	Number, length, diameter, cross section	Supporting document for ET detector layout	Lining thickness, concrete grade, steel content		
Shafts	N		Number, depth, diameter, lining thickness		
Caverns	Number, length, width, height	Supporting document for ET detector layout	Lining thickness, concrete grade, steel content		
Surface buildings	N		Number, building footprint, typology (e.g. warehouse, office), structure type (steel/concrete)		
Excavated material	Y	Supporting document for ET detector layout	- Chemical and mineralogical composition - Geotechnical parameters - Potential mitigation strategies (e.g. reuse of soil)		

Operational energy	N		Operational energy consumption and source, operational life		
Operational water	N		Operational water consumption		
End of life strategy	N		Potential end of life strategies for civil engineering		
Other			Any other missing items		

Example of Scientific Instrumentation Components (Data Collection under progress)

Civil Subcomponent Category	Scientific Component Category	Scientific Component Subcategory	Data Source	Data requests	Is this available (Yes/No)?	Any Remarks?
Corner Cavern (A)	Optical Towers	Beam Splitter (BS)	ET Baseline Detector Layout & Supporting document for ET detector layout	Material Composition, Manufacturing details from vendor/s, Supply Chain and Transportation, Packaging, End of Life Disposal		
		Pre-Stabilized Laser Source System	ET Baseline Detector Layout & Supporting document for ET detector layout	Material Composition, Manufacturing details from vendor/s, Supply Chain and Transportation, Packaging, End of Life Disposal		

		Frequency Stabilization System	ET Baseline Detector Layout & Supporting document for ET detector layout	Material Composition, Manufacturing details from vendor/s, Supply Chain and Transportation, Packaging, End of Life Disposal		
		Mode Cleaner	ET Baseline Detector Layout & Supporting document for ET detector layout	Material Composition, Manufacturing details from vendor/s, Supply Chain and Transportation, Packaging, End of Life Disposal		
		Input Filter Cavity (1 mirror)	ET Baseline Detector Layout & Supporting document for ET detector layout	Material Composition, Manufacturing details from vendor/s, Supply Chain and Transportation, Packaging, End of Life Disposal		