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Milestone 9.1

Preliminary Sustainability Plan

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EXECUTIVE SUMMARY

This document, M9.1-Preliminary Sustainability Plan, is a milestone of the ET-PP Project, which is funded by the European Commission Framework Programme Horizon Europe Coordination and Support action under grant agreement 101079696.

The Preliminary Sustainability Plan is the first milestone of Work Package 9 “Sustainable Development Strategy”. This report describes how sustainability, including economic, environmental and societal impacts will be addressed by the Einstein Telescope. It presents the methodology and tools that will be used to study the impacts

of the ET infrastructure, from design and preparation to the dismantling phase (in the very long term), and outlines the specific goals and targets of the future RI.

A Final Sustainability Plan (Milestone n. 19) will be released by the end of the ET-PP project (at M36), to include a more mature analysis of the ET environmental impact (D9.2) and CO2 footprint assessment (D9.3). The Final Sustainability Plan of the Einstein Telescope will also include the main elements of the ET Sustainable Development Implementation Strategy (D9.1) and CO2 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
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

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1. Introduction

Research infrastructures (RIs) are built to remain operative, effective and competitive for a long time. The long-term sustainability of a RI (OECD, 2017) requires considering not only the evolving needs of the relevant scientific community, but also the environmental and socio-economic impacts and value of the infrastructure.

To address the main sustainability aspects affecting the design of the Einstein Telescope, the ET-PP project organized a workshop at the Université Paris-Saclay (the content and results of the workshop are described in M9.2 - ET Sustainability Workshop¹). The workshop was the occasion for the ET-PP community to develop topical discussions about the main dimensions of long-term sustainability within a very large research infrastructure (Fig. 1); and to exchange with the experience of other research institutions in the field of High Energy Physics, Cosmology, and Astroparticle Physics.

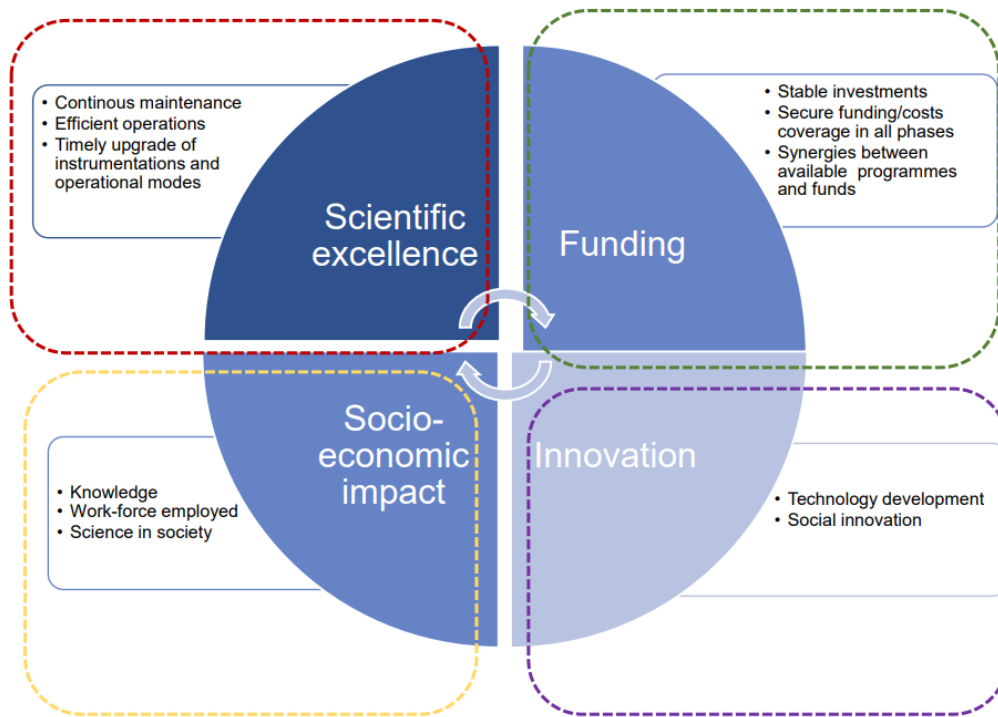


Figure 1- “The four main dimensions of RI’s long-term sustainability”

¹ The Indico page of the workshop is available at the following URL:
<https://indico.ijclab.in2p3.fr/event/9686/timetable/#20231117>

Based on existing studies and models, including the current strategy for sustainability at CERN², 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.

Indeed, according to the Sixth Assessment Report (IPCC SYR, 2023) of the IPCC, 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 (that is 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) set out by the 2030 Agenda for Sustainable Development (UNGA,2015). 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). Contributing to the achievement of sustainable development is a shared responsibility of government institutions, the private sector and communities, including the scientific community. Very large research infrastructures (OECD, 2023), such as the Einstein Telescope, shape the region where they are located and impact on the environment, the economy, and society at large (ESFRI, 2017). The next sections introduce the main sustainability figures of merit (Section 2) and the methodology used to outline the sustainability goals of the Einstein Telescope (Section 3). ET Sustainability (preliminary) objectives, targets, responsibilities and timing are presented in Section 4.

2. Sustainability figures of merit

As highlighted by several publications on research infrastructures (OECD, 2023; 2019; 2017; ESFRI, 2017; 2024; European Commission, 2017), the main sustainability issues to be addressed within the ET-PP project concern the emissions of carbon dioxide and other greenhouse gas emissions (CO₂eq); the requirements for sustainable data management and storage of very large amounts of data; the adoption of affordable, reliable and sustainable energy systems; the sustainable management of excavated soil; the preservation of natural habitats and biodiversity in the area surrounding the future

² For further information, consult: <https://home.cern/about/what-we-do/environmentally-responsible-research>

RI; stable and secure funding; the promotion of a safe and secure working environment.

2.1. Greenhouse gas emissions

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 Protocol³. 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;
- **scope 2** refers to indirect emissions related to the generation of electricity, steam, heating or cooling purchased for an organization’s own use;
- **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.

Given that the ET infrastructure is still in the design phase, a preliminary estimate of its potential greenhouse gas emissions can be derived by comparing data and operational approaches from similar research infrastructures, such as those of the LIGO-Virgo-KAGRA (LVK) collaboration (Fig. 2). One of the primary sources of emissions directly associated with the ET is power consumption, which adds to the contributions from computing and travel to the ET site/meetings.

At this stage, no definitive estimate of the Einstein Telescope’s (ET) power consumption exists, as key components—such as the cryogenic system and the cooling and ventilation requirements—have not yet been finalized. A dedicated deliverable is forthcoming to provide a first assessment based on comparable existing infrastructures. In the meantime, some considerations can be drawn from the energy consumption of similar observatories. For example, existing gravitational wave observatories report annual power consumptions of approximately 2 GWh for KAGRA, 3 GWh for Virgo, 5 GWh for LIGO-Livingston, and 7 GWh for LIGO-Hanford. The overall carbon footprint associated with this electricity usage will largely depend on the local energy mix. For instance, a stark contrast can be observed between the two LIGO sites: Hanford sources approximately 80% of its electricity from

³ The GHG protocol is a comprehensive global standardized framework for measuring and managing greenhouse gas (GHG) emissions. Details here: <https://ghgprotocol.org>

hydroelectric power, 10% from nuclear, and 5% from wind, thereby exhibiting a significantly lower carbon footprint compared to Livingston, which relies almost entirely on fossil fuels—mainly natural gas and coal—reflecting regional energy availability (Holz, 2023).

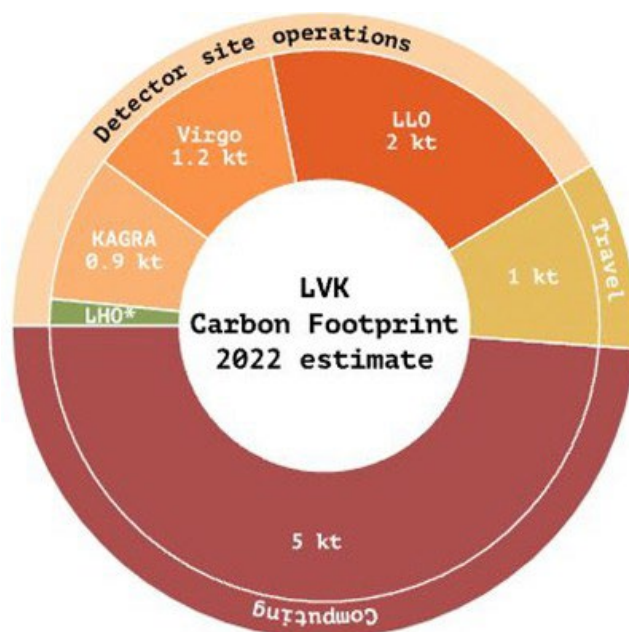


Figure 2- “Estimated carbon emissions from LIGO-Virgo-KAGRA in 2022⁴”

The case of Virgo is different, as the EGO site, which is powered by the national electricity grid, is sourced half through fossil fuels and the other half through renewables (15% hydroelectric; 12% solar; 9% wind; 6% bio waste; and 2% geothermal power)⁵. It is worthwhile to note also that 6% of the global energy requirement is self-produced by EGO through photovoltaic plants.

However, the predominant contribution of fossil fuels to the carbon footprint by country is confirmed by the analysis of data on Global Carbon Budget (2023)⁶ shown in the following map (fig.3):

⁴ Image credit: pie chart by Anna Green, Deputy Editor-in-Chief, Ligo Magazine.

⁵ Data provided by the Infrastructure Department of the European Gravitational Observatory, Technical System Service.

⁶ For further information regarding the Global Carbon Budget (2023)⁶ shown in the following map (fig.3): <https://globalcarbonbudget.org/carbonbudget2023/>

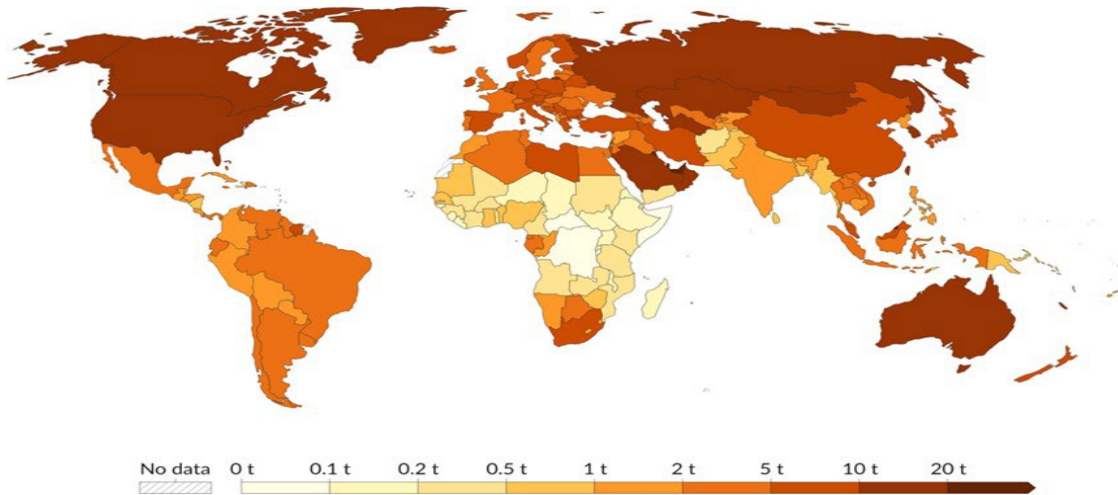


Figure 3- “Carbon dioxide (CO₂) emissions from fossil fuels and industry”

This scenario is further supported by data of the Energy Institute - Statistical Review of World Energy (2023)⁷, with major processing done by Our World in Data, which show that the primary energy consumption worldwide is mostly based on the use of fossil fuels (Figure 4):

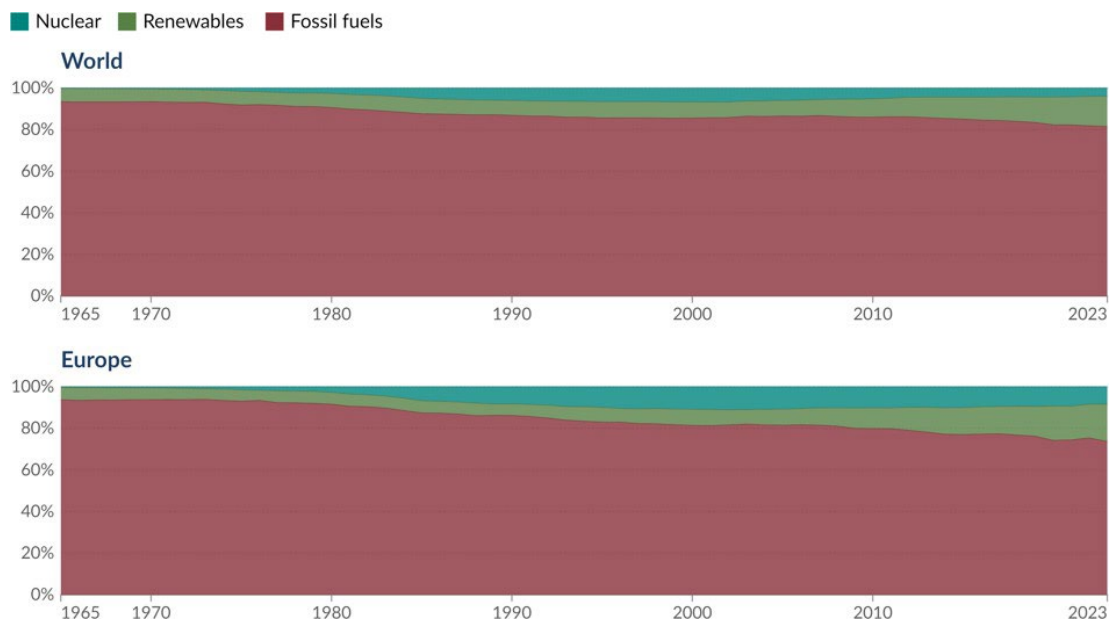


Figure 4- “Primary energy consumption in Europe and the World from 1965 to 2022”

⁷ Statistical Review of World Energy: <https://www.energyinst.org/statistical-review>

Taking these various considerations into account, the power usage and supply for the ET infrastructure will be mainly addressed by reducing the use of fossil fuels to the maximum extent possible by implementing energy-saving measures, developing more energy-efficient technologies and adopting renewable energy solutions (Section 2.3).

2.2. Computing

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. ET will also align with advancements in the broader GW science community, which plans to utilize the current computing model of the International Gravitational Wave Observatory Network (IGWN) and benefit from advancements in particle physics facilitated by the Worldwide LHC Computing Grid (WLCG). ET will leverage the WLCG associate partner status of Virgo to ensure close alignment with advances in the domain.

Two main challenges arise when harnessing existing solutions for ET's computing needs. Firstly, while critical components for large-scale computing are in place, they are complex and require a dedicated team of experts for maintenance and operation. An example is the Rucio data management system, which has proven to work at scales well beyond those needed by ET, but requires continuous maintenance and improvements by the Rucio community. The same applies to all LHC computing solutions, necessitating expertise and effort to operate and being maintained.

Secondly, ET faces the challenge of integrating increasingly diverse computing resources, often shared with other scientific communities to leverage economies of scale and ensure near-full resource utilization. For example, GPUs are increasingly used in data centers due to their efficiency for certain operations. Software must generally be adapted to run on a GPU, often requiring a vendor-specific API. The emergence of TPUs (tensor processing units), designed for better performance in AI/ML workflows, suggests that heterogeneity will increase in the future.

The strategies defined in D8.1 by ET computing experts will help address these challenges. Accurate collection of Computing Resource Usage (CRU) information will be a key part of the ET sustainable computing model. The CRU infrastructure will need to collect information from every computing architecture used across all ET computing facilities. ET software will need to be managed as part of an ET software framework, allowing optimization of workflows. A dedicated team of experts who

support the porting of algorithms to new architectures is needed. The ET continuous integration service will provide validation of results and avoid wasting computing cycles, while an extensive testing suite will offer insights on algorithm efficiency and overall ET workflows. These tools will allow ET to predict and optimize its computing needs, ensuring the ET CRU footprint is no larger than necessary to achieve its scientific goals.

ET will need to capture complete workflows with an Analysis Capture System (ACS) that takes relevant information from the ET software framework, CRU infrastructure, data management, and metadata systems. This facilitates reproducibility, avoids wasting researcher time and computing resources, and prevents unnecessary work duplication. For example, if Researcher 1 is unaware that Dataset A has already been processed by Pipeline X to produce Dataset B, the ACS will inform them, presenting Dataset B directly.

The collection of CRU information for every ET collaboration member will allow ET to present individuals with a comparison of their CRU footprint against the ET average, encouraging them to seek optimization help from ET computing experts. The heaviest users would automatically be flagged as potentially needing expert assistance. A similar approach has been trialed by the ATLAS collaboration, as shown in the first ever WLCG workshop on sustainability which ET computing experts also participated in⁸.

All the software and computing requirements previously highlighted can only be achieved through the employment of a dedicated team of experts working for ET and properly trained to optimize computing use. However, it's important not only to hire existing experts and train new ones but also to retain them, as they are often dissuaded from working in academia due to poor career prospects. Since ET represents a unique opportunity, it could become a pioneering example of how a sustainable research infrastructure can offer professional and economic growth paths comparable to those in the industrial sector. This challenge is also recognized by the Joint ECFA NuPECC APPEC (JENA) computing initiative, whose report will be published very soon (in 2026).

2.3. Sustainable energy systems

A medium-term goal for the ET project should be to establish an energy management system in order

⁸ Details and additional material here: <https://indico.cern.ch/event/1450885/timetable/?view=standard>

to get the ISO 50 001 certification⁹. This certification outlines a set of requirements that will enable the ET infrastructure to:

- develop a policy for more efficient energy use by setting achievable targets and objectives;
- collect data to better understand and make informed decisions about energy use;
- measure the achieved results to assess the policy's effectiveness.

The adoption of an efficient energy management system will help the ET infrastructure to improve its energy performance, by maximizing the use of clean energy sources and reducing energy consumption, with a decrease in costs and environmental impacts. Although the certification has a three-year validity, annual audits will be conducted to verify the achievement of the set objectives and undertake any necessary actions to further improve energy performance.

In the perspective of a diversified and sustainable energy supply, the ET infrastructure will be able to utilize two mechanisms, provided by the European Union to incentivize the use of renewable energies and provide some long-term stability for both producers and consumers: the Power Purchase Agreement (long-term contracts at prices either fixed or with limited variations allowed); and the Contract for Difference, aiming at stabilizing market prices, limiting both financial losses and unjustified gains for the service provider¹⁰.

2.4. Sustainable management of excavated soil

Another 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 2030¹¹, the excavation material should be reused in the same or another appropriate location. If this is not

⁹ More on ISO 50001 Energy Management standard here: <https://www.iso.org/iso-50001-energy-management.html>

¹⁰ Details about Power Purchase Agreements, Contract for Difference and other mechanisms to accelerate renewable energy projects are available at the following URL: https://energy.ec.europa.eu/topics/renewable-energy/enabling-framework-renewables_en

¹¹ 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, 17.11.2021.

possible, e.g., due to unacceptable levels of pollution of either geogenic or anthropogenic origin, such material should be prioritized for recycling or some other form of recovery in line with the waste hierarchy which establishes an order of preference for managing and disposing of waste (Figure 5).



Figure 5- "The five-step "waste hierarchy" established in the EU waste Framework Directive"

One of the priorities of the ET project is to propose a large-scale re-use of excavated material. Depending on its properties and quality, different areas of application will be considered. For instance, as done for the FCC project, the excavated material could be used as primary and secondary building materials both onsite and offsite the construction site, e.g., the production of aggregates for concrete, support of public infrastructure, filler material and creation of technosoils. Based on composition of the material, the production of new types of building materials with a lower carbon footprint than conventional building materials that are still being researched, like AAM (alkali activated materials), must also be considered. Reusing the excavation material on- or offsite not only prevents negative impacts from landfilling, which include degeneration of the countryside, environmental risks as well as low quality of life for surrounding residents, but also has positive effects such as CO₂ reduction through reduced transportation distances, conservation of regional raw material resources and financial savings in material management on the construction site.

In addition to the reuse of excavation material, ET's strategy will also focus on increasing the reuse and

recyclable rate for all types of waste that will be generated. An appropriate waste management system will be adopted following the “reduce, reuse and recycle” principle. This system will ensure safety for both people and the environment, and it will include an inventory of the waste departing from ET to guarantee waste traceability. Moreover, a pathway for the recuperation, reconditioning, and sale of reusable equipment such as furniture or electronic devices could be considered.

2.4.1 Sustainable procurement strategy

Achieving a sustainable procurement strategy will be a key objective for ET. This involves thoroughly reviewing purchase policies to minimize misspends and waste. It also requires a careful assessment of the infrastructure's needs and the adoption of procurement practices that prioritize green and sustainable principles. Important considerations include: Can we source locally? Do we have sufficient diversity among our suppliers? Will the purchase generate a return on investment in the country where it is made?

Another aspect worth analyzing in this regard is the procurement of goods, services and works with a reduced environmental impact throughout their life cycle, utilizing green responsible procurement practices. This involves considering if there are certificates and labels associated with the purchased products, assessing whether the production of the product generates pollution, determining its carbon footprint, and, in addition, examining any social impact associated with it. When goods and services are provided by ET members as in-kind contribution to the maintenance and operation of the infrastructure, the above considerations also apply.

A fundamental tool to optimize resource utilization is the Life-Cycle Analysis (LCA), a methodology aimed at assessing the environmental impact of a commercial product, process, or service throughout all stages of its life cycle. For such a significant research facility, applying LCA would encompass a wide range of activities, from the utilization of raw materials to final disposal or recycling. This entails evaluating aspects such as production, distribution, and usage within the facility itself, as well as the environmental impact generated by these activities. By comprehensively utilizing LCA, it's possible to identify areas for improving resource efficiency and reducing the overall environmental footprint of the research facility.

2.5. Preservation of the natural environment

In order to integrate biodiversity conservation in land-use-planning, several instruments have been

specifically developed. The European Commission, with its Biodiversity Strategy for 2030¹², has set a 30% minimum target for land to be protected, and defined other actions and commitments to put Europe's biodiversity on the path to recovery by 2030. The achievement of these goals is ensured by the EU's Environmental Impact Assessment (EIA) Directive (2011/92/EU)¹³, which requires major development projects to undergo thorough assessments of their potential environmental impacts, including biodiversity impact, before their start.

In accordance with the EU environmental policy, the ET project will plan specific measures to preserve natural spaces and enhance biodiversity across the entire infrastructure-affected area and its surroundings, including the definition of indicators to monitor the evolution of the ecosystem over time. For example, just as has been done at CERN sites, new trees could be planted both to compensate for those potentially felled due to construction work and to enhance biodiversity on the land managed by ET. Furthermore, conducting inventories of local flora and fauna is useful for characterizing the natural environment and identifying species of particular interest. In this way, once threatened or protected species are identified, it is possible to compare the data collected before and after the project's development and monitor the effect of changes in management and maintenance practices.

2.6. Stable and secure funding

To enabling effective planning, and monitoring, of design, preparation, implementation, construction, operation, major upgrades, decommissioning and termination of a very large research infrastructure, it is crucial to understand funding sources, establish a clear methodology for the calculation of the RI costs, and ensure an accurate long-term financial planning (ESFRI, 2024). To this end a coordinated effort is needed at multiple levels, with the involvement of regional, national and EU funding actors.

Aligning the Einstein Telescope with regional innovation strategies can ensure that the RI not only fosters scientific excellence, but also the economic growth and the social development of the hosting region, thus contributing to other sustainable goals, including decent work (SDG8¹⁴). In this respect, it

¹² Objectives, actions, implementation and timeline of the Biodiversity strategy for 2030 are detailed here: https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

¹³ Current consolidation version: <https://eur-lex.europa.eu/eli/dir/2011/92/oj/eng>

¹⁴ An overview, including targets and indicators concerning SDG8, is available at the following URL: <https://sdgs.un.org/goals/goal8>

is important to note that EU development funds, such as the Just Transition Fund¹⁵, pay particular attention to territories affected by the transition towards a climate-neutral economy, by supporting research and innovation, job-search assistance, up-and reskilling of workers. However, financial contributions to the future RIs must be provided under stable budget lines and multiannual planning, devising funding mechanisms that can facilitate this transition by allowing, at the same time, to focus on science and high-quality access to the services offered, instead of looking for funding. In this respect, it is vital to establish a precise legal framework for ET funding, in line with its long-term nature. This issue is linked to the legal nature of the future RI, as the main difference in terms of funding instruments is between intergovernmental organizations (budget by law) and research consortiums (usually, with annual dedicated funding schemes) (ESFRI, 2024).

2.7. Promotion of a safe and secure working environment

Large-scale research infrastructures have a societal value, which goes beyond their role in innovation and science (OECD, 2019). They create networks and communities, which produce cultural, educational, economic and social impacts; and also, jobs. Some of the staffing profiles required by RIs are difficult to find, due to the fact that, especially very large-scale research infrastructure require highly trained staff, not easy to find on the traditional job market (OECD, 2023). Promoting a safe and secure working environment for all workers, by taking duly into account diversity and gender equality, can boost the RI's attractiveness and the mobility of skilled professionals and operators. The Einstein Telescope will guarantee competitive working conditions, based on stable and secure career paths for staff moving from other facilities, universities and research centers; safe working conditions and regular trainings; equal pay for work of equal value; and equal opportunities for leadership. Being located within the European Research Area, the future RI will follow the regulatory framework established by the EU across the European labour market, including the directives adopted to overcome the persisting gender gaps and inequalities. Competitive human resources schemes are also one of the essentials characteristics of the future ET governance (see Deliverable 2.1 – Viable options for ET legal entity).

¹⁵ The Just Transition Fund (JTF) supports EU territories expected to be the most negatively impacted by the transition towards climate-neutrality (i.e. the regions that are most dependent on fossil fuel and carbon intensive industries) and it is implemented under the overall framework of Cohesion Policy 2021-2027.

3. Sustainability aspects relevant for ET different phases: methods and tools

Given the complexities of the ET project, the environmental, social, and economic aspects necessary to ensure the sustainability of the infrastructure will be considered separately for each different phase, and namely for:

- the preparation and design phase,
- the construction phase,
- the operation phase (including upgrades),
- the dismantling phase (in the very long term).

3.1. Preparation and design phase

Starting from the preparatory and preliminary design phase, the main sources of emissions contributing to the carbon footprint of the infrastructure will be considered and estimated. In this phase, significant contributions are expected from business trips to visit candidate sites, participation in workshops and conferences, conducting measurement campaigns, and computing activities (simulations, data storage, videoconferencing, etc.). The final sustainability plan of ET-PP (scheduled for M36) will include a calculation of the environmental footprint produced by the ET collaboration during the preparatory phase and an estimation of future environmental impacts. The methods used for modelling, calculating and reporting ET environmental impact are those currently available at the international level, including established practices and standards (e.g. ISO 14000/44).

During the preparatory design phase, sustainability consideration will impact the studies of optical couplings for ET mirrors. The scientific community is examining advanced coatings and materials, which often rely on Tantalum and Hafnium. The extraction and processing of Tantalum present significant ecological challenges. Addressing these issues requires responsible mining practices, enhanced processing technologies, increased recycling efforts, and strong regulatory framework.

3.2. Construction phase

The construction phase will lead to significant carbon (-equivalent) emissions. In this phase we will focus on resources optimization and minimization of carbon footprint and waste. A number of areas

have been identified and will lead to quantitative estimates of their impact: (1) mass production of the various detector components; (2) the infrastructures (roads, power plans, etc.) to be developed to serve the ET site; (3) the civil engineering work (both in surface and underground: including power, heating, cooling and all the services annexed); (4) the preservation of the landscape and biodiversity.

Certainly, the greatest challenge during the construction phase is represented by the excavation activities, which will generate a significant amount of excavation material. Proper management of this material, including its on-site reuse or repurposing as a byproduct, is crucial for minimizing the environmental impact associated with excavation operations. Since the potential for reusing this material is directly related to its level of contamination, which varies depending on the excavation method used, the choice of the most suitable excavation method plays a significant role in ensuring sustainability.

In particular, the tunneling methods are selected on the basis of the prevailing geology as well as the tunnel geometry and have great influence not only on anthropogenic contamination but also on the grain size of the excavated material. A fundamental distinction can be made between drill-and-blast (NATM – New Austrian Tunnelling Method) and a tunnel boring machine (TBM).

In NATM, contaminants include cement-bound materials, explosives, and hydrocarbons from mineral oils used in vehicles (Berger et al., 2015). Explosives contribute nitrite (NO_2^-), nitrate (NO_3^-), and ammonia (NH_4^+), which enter the debris from blasting vapor (Poscher, Mammel, Sedlacek, & Fisch, 2002). For instance, the Gotthard Base Tunnel showed 6.0 to 15.0 g nitrate, 1.0 to 2.4 g nitrite, and 0.2 to 3.3 g ammonium per ton of excavated material, with these values halving in three months due to natural denitrification (Sachs, 2016).

Contamination also comes from concrete, shotcrete, and grouts, which can exceed 5 vol-% in the material, disqualifying it for landfill or subsoil backfill and raising the pH to 11-12.5, potentially mobilizing metals like hexavalent chromium (Cr^{6+}) and aluminum (Berger et al., 2015). Hydrocarbon contamination from vehicles can reach 50 to 500 mg/kg (Berger et al., 2015). A benefit of NATM is the diverse grain size of the debris, which ranges from μm to dm , allowing for better downstream processing (Berger et al., 2015).

In TBM tunneling, there are gripper TBMs for unfractured rock, shielded TBMs for fractured rock, and earth pressure balance (EPB) or slurry machines for loose material (Maidl, Schmid, Ritz, & Herrenknecht, 2008). Gripper TBMs and shielded TBMs machines do not use additives, whereas EPBs

and slurry machines employ surfactants and polymers to create an earth slurry, supporting the face and preventing clayey material from sticking to the drill bits. These additives are processed on-site and recirculated (Oliveira, Thewes, & Diederichs, 2019).

If additives are used, their effects on excavated material and groundwater must be tested. Regardless, complex processing of the excavated material is required (Berger et al., 2015). A drawback of TBM tunneling in hard rock is the production of small chip-like fragments. About 30% of the material is crushed to fines of a few μm , which requires separate landfilling to prevent environmental issues (DepVo, 2008).

To ensure the sustainability of the construction phase, it is recommended to prioritize tunneling methods that minimize contamination and maximize the potential for reuse of excavated materials, supported by thorough environmental assessments and adaptive management strategies.

3.3. Operation phase

During the operation phase, the energy systems which will power the facility will play a major role, as some green energy sources may be incompatible with the requirements for Einstein Telescope, such as the windmill farms whose vibrations can produce noise signals for ET if close to the experimental site, or may produce a large impact on the surface, such as photovoltaic plants. In order to evaluate an optimal energy strategy, all the ET working groups committed to the design of the technological and scientific devices will have to consider and properly address sustainability issues associated with the systems they are developing.

Other sustainability issues to be addressed in the operation phase include the promotion of a safe and secure working environment for all workers; the adoption of suitable procurement processes, flexible, but in line with the environmental and social aspects relevant for the future RI. All these aspects pertain to the long-term sustainability of the ET and affect the socio-economic impact of the infrastructure and its societal role, including its capacity to contribute to the achievement of the UN SDGs (e.g., SDG4- Quality Education¹⁶, SDG5- Gender Equality¹⁷, SDG8- Decent Work and Economic Growth¹⁸;

¹⁶ Further details about SDG4 available here: <https://sdgs.un.org/goals/goal4>

¹⁷ More info on SDG5, here: <https://sdgs.un.org/goals/goal5>

¹⁸ See above, footnote n. 13.

SDG12- Sustainable consumption and production¹⁹). How this can be done? For example, by supporting quality education, both formal (e.g., training and activities in schools and universities) and informal (e.g., educational video); by promoting decent work; by adopting a Gender Equality Plan, which ensures gender balance in top-management positions, committee and research teams, and a clear legal framework for green and socially responsive procurement.

3.4. Dismantling

The long-term objective of the Einstein Telescope is to maintain its operation for ~ fifty years. However, the emergence of new technologies and competitors may lead to restructuring the RI for other uses or dismantle it. This is something very sensitive, as it could imply the need for additional resources. For example, data will have to be preserved; physical components of the RI reused or disposed; and RI staff managed appropriately. When a RI can no longer provide its services, it could be used for other purposes (e.g. education). Bearing this in mind since the design phase could help to ensure the long-term sustainability and value of the RI.

4. ET Sustainability: objectives, responsibilities and timeline

Long-term sustainability is not only a mission, but also an opportunity for the Einstein Telescope Community. While becoming a world leading scientific RI, ET can assume social responsibility toward society and the future generations, e.g., by promoting sustainable consumption practices (e.g. saving energy during construction and operation phases); adopting responsible waste disposal; creating a gender-equal work environment.

The organizational chart of sustainability relationships, presented in Fig. 6 below is based on current knowledge of the ET governance structure and will be updated in the final Sustainability Plan, in accordance with the possible evolution of the ET governance/structure.

¹⁹ An overview on SDG12 is available at the following URL: <https://sdgs.un.org/goals/goal12>

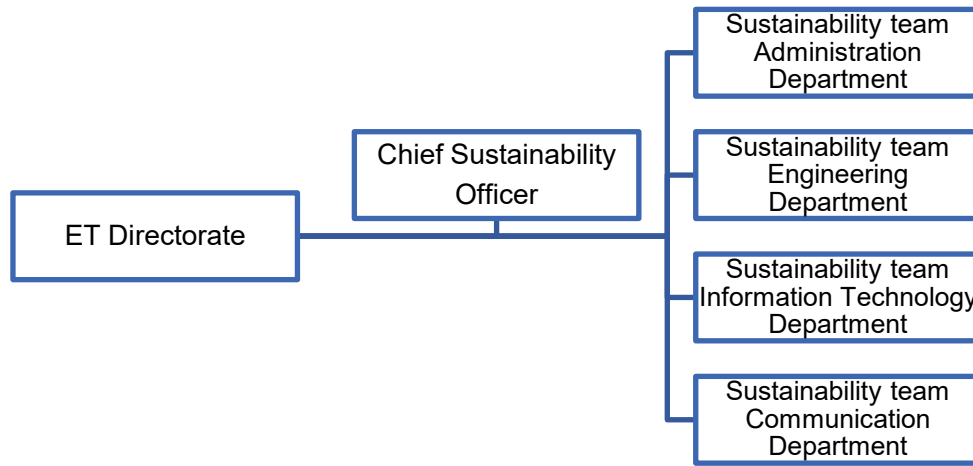


Figure 6- “Organizational chart of sustainability relationships”

The ET Directorate (the Director or Board of Directors, depending on ET future governance system) will demonstrate commitment to sustainability by promoting awareness of the impacts that the future RI will produce on the environment and society. A Chief Sustainability Officer, reporting to the ET Directorate, will be set up to engage the leadership, within each department (e.g., Administration; Engineering; Information Technology, Communication, etc.). A Sustainability Team will be set up at Departments level to integrate sustainability across the ET Departments.

A synopsis of the ET preliminary sustainability plan’s objectives and targets, along with the attached responsibility and timing (i.e. the relevant phases of ET lifecycle when the objectives will be reached), is provided in Table 1, below:

Objectives	Sustainability Target	Responsibility	Timing
Implement sustainable practices in excavation	Reduce contamination and enhance material reuse	Engineering Department	»» By the end of the design phase
Enhance sustainable construction techniques	Prioritize sustainable site design and sustainable practices (e.g. reduce energy usage; minimize waste, etc.)	Project Office and Engineering Department	»» Preparatory phase (end of 2026)
Obtain ISO 50001 certification	Reduce energy consumption at the ET site.	Engineering Department>	»» 1 year after ET reaches full

Adopt effective environmental management systems (in line with guidelines provided by the ISO 14000 series or similar)	Increase the share of renewable energy in the energy mix. Improve energy efficiency.	Technical Systems Service > Energy Manager	operativity (operation phase)
	Achieve efficient use of natural resources at the ET site.	ET Management	>>> When ET starts operating and until the dismantling phase (operation and termination phases)
	Reduce waste Soundly manage chemicals and all wastes in accordance with existing guidelines	Engineering Department	>>> Since the construction phase and until the dismantling phase (implementation, operation and termination phases)
Adopt sustainable practices for data management	Develop stable and robust repositories while ensuring that data are stored in an environmentally friendly manner	Engineering Department	>>> Since preparatory Phase 2
	Adopt digital technologies that offer green solutions (e.g. green cloud)	Information Technology Department> Computing Facilities and Data Storage Division	>>> When ET starts operating and until the dismantling phase

Adopt a Gender Equality Plan	Ensure a gender-equal working environment	Direction > Gender Equality Plan Manager	»»»	6 months after ET reaches full operativity
Conduct annual audits to assess and monitor the implementation of the gender equality plan	Ensure a gender-equal working environment	Direction > Gender Equality Plan Manager	»»»	Annually
Adopt smart working agreements	Ensure a better work-life balance and improve the well-being of the employees	Administration > Human Resources Office	»»»	When ET starts operating
Promote safe and secure working environment in accordance with relevant national and international standards (including ISO 45001)	Ensure productive employment and decent work for all, including people with disabilities	Health, Safety and Security Office/Department > Safety Manager	»»»	When ET starts operating and for all phases of the RI lifecycle
Implement company carpooling and shuttle service from the nearest public transport facility to/from the ET site	Reduce emissions and promote sustainable mobility	Administration Department	»»»	When ET starts operating, and for all phases of the RI lifecycle

Adopt internal rules to ban or limit short-haul flights on routes where fast trains are available	Reduce emissions and promote sustainable mobility	Administration Department	»»	Since the construction phase and until the dismantling phase (implementation, operation and termination phases)
Adopt sustainable procurement practices (in accordance with the ISO 20400 standard) and deliver periodic training courses on sustainable procurement to employees who interact directly with suppliers	Reduce waste and carbon emissions and manage efficiently available resources Enables compliance with social legislations (e.g. by buying ethical products and services whenever it is possible)	Project Office/Engineering Department Administration > Procurement Office	»» »»	Since the preparation phase and for all the lifecycle of the RI When ET starts operating and during its lifecycle
Enter into agreements with research centers and universities from all countries of the ET collaboration	Support educational programs for the development of specialized skills Co-design master courses and training programs	Direction	»»	When ET starts operating and during its lifecycle
Engage the ET community	Develop capacity building and monitoring tools	Project Office and Engineering Department	»»	Preparatory phase (end of 2026)

**Commit to
outreach activities**

Promote citizen science and the understanding of science and technology in society at large

Communication office



Since the preparation phase and for all the lifecycle of the RI

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