# Environmental Report 2023

# Environmental Report 2023

**INFN** - Istituto Nazionale di Fisica Nucleare
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Report by the Direzione Servizio Salute e Ambiente with the involvement of the National Laboratories and CNAF.

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Drafted on 1 October 2024.

# 0. FOREWORD

E' con particolare piacere che pubblichiamo il primo Report Ambientale delle attività dell'INFN.

Sin dalla sua fondazione, l'INFN ha sempre perseguito l'obiettivo di essere non solo un'organizzazione di ricerca teorica e sperimentale, ma anche un Ente impegnato a garantire l'applicazione di alcune delle sue tecnologie nella vita economica e sociale. Per questo l'attenzione alla sostenibilità e al rispetto dell'ambiente sono per noi principi fondamentali a cui ispirarsi.

Con questo spirito pubblichiamo il primo rapporto ambientale dell'INFN che copre gli anni 2021, 2022 e 2023 e fornisce una prima panoramica degli impatti ambientali associati alle attività dell'Ente. Il periodo preso in esame è ancora segnato dalla pandemia di COVID-19 e dall'emergere della guerra in Europa con i conseguenti aumenti dei costi dell'energia. Entrambi i fattori hanno avuto un seppur limitato impatto sui dati che troverete nel rapporto, tuttavia esso rappresenta per noi una base di partenza. Con questo rapporto, infatti, abbiamo imparato molto sulla nostra impronta ambientale: abbiamo iniziato ad implementare misure efficaci per comprenderla e controllarla meglio, a elaborare strategie utili a mitigare l'impronta ambientale delle nostre attività e a promuovere una cultura della sostenibilità al nostro interno. L'obiettivo è bilanciare il perseguimento del progresso scientifico con la responsabilità di proteggere e preservare l'ambiente per le generazioni future. Parallelamente al recente aumento della consapevolezza dell'importanza della sostenibilità ambientale, l'INFN intende contribuire al raggiungimento dell'obiettivo della decarbonizzazione fissato dall'Unione Europea impegnandosi a svolgere le proprie attività scientifiche con un impatto ambientale minimo. Partendo dall'analisi dei dati che potete trovare in questo rapporto, abbiamo ad esempio iniziato a lavorare per ridurre le nostre emissioni di gas serra, a implementare importanti misure di risparmio energetico e a gestire in modo più accurato i consumi idrici.

Sebbene ci sia ancora molta strada da fare, abbiamo iniziato un percorso importante che vuole portarci a far progredire le frontiere della conoscenza riducendo al minimo l'impatto ambientale delle nostre strutture e diventando un contributore positivo di soluzioni. Il cambiamento climatico e la protezione dell'ambiente sono tra le più grandi sfide che l'umanità deve affrontare: spetta a tutti noi fare la nostra parte per mitigare l'impatto dell'attività umana sul pianeta che abitiamo e l'INFN non mancherà di fare la sua.

ISTITUTO NAZIONALE DI FISICA NUCLEARE
IL PRESIDENTE
(Prof. Antonio Zoccoli)

# 1. INTRODUCTION

Sustainability is a multifaceted concept that integrates environmental, social, and economic dimensions, each playing a crucial role in shaping a sustainable future. Understanding the interplay between these dimensions is vital for fostering a comprehensive approach to sustainability.

- **Environmental Sustainability** involves the preservation and protection of natural resources and ecosystems. It focuses on minimizing human impact on the environment, reducing pollution, and promoting the efficient use of resources. This dimension is critical because the health of our planet directly affects the ability of current and future generations to thrive. Key areas include energy use, waste management, water conservation, and the reduction of greenhouse gas emissions.

- **Social Sustainability** emphasizes the importance of maintaining and improving the well-being of individuals and communities. It involves ensuring access to essential services, promoting social equity, and fostering inclusive societies where everyone has the opportunity to contribute to and benefit from economic activities. Social sustainability is crucial for creating resilient communities that can adapt to and recover from environmental and economic challenges.

- **Economic Sustainability** focuses on the long-term viability of economic systems. It involves creating stable and prosperous economies that can support present and future generations. Economic sustainability requires balancing growth with the responsible use of resources, ensuring that economic activities do not deplete the natural and social capital needed for future prosperity. Key aspects include responsible production and consumption, innovation, and the promotion of green technologies.

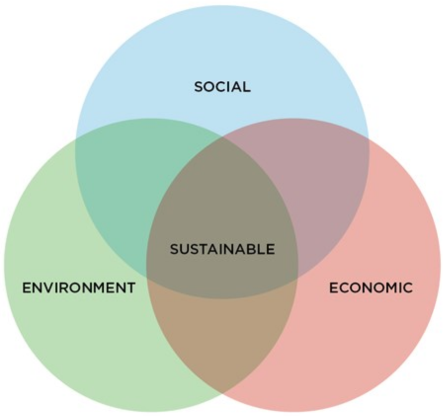


*Figure 1. The three pilar of sustainability.*

While all three dimensions of sustainability are interconnected and equally important, this report focuses specifically on environmental sustainability of Istituto Nazionale di Fisica Nucleare (INFN). The urgency of addressing climate change and environmental degradation necessitates immediate and concentrated efforts. Climate change represents one of the most pressing challenges of our time. The scientific consensus is clear: human activities, particularly the emission of greenhouse gases, are driving significant changes in the Earth's climate system. Given the critical role the research institute plays in scientific advancement, addressing environmental impacts is essential. Laboratories are often energy-intensive and resource-dependent, and their operations can significantly contribute to greenhouse gas emissions and other forms of environmental impact. By focusing on environmental sustainability, research institute can lead by example, demonstrating how scientific progress can be achieved without compromising the health of our planet.

This report aims to provide a comprehensive overview of the environmental impacts associated with the INFN. It seeks to support the development of strategies to mitigate these effects and promote a culture of sustainability within the organization. The goal is to balance the pursuit of scientific progress with the responsibility to protect and preserve the environment for future generations.

To understand the environmental footprint of INFN, some key aspects such as energy consumption, carbon footprint, waste management, and water use were examined.

Through this report, it will then be possible to establish strategies and recommendations for implementing "greener" and more sustainable systems. Investing in energy-efficient equipment and infrastructure upgrades, implementing energy management systems to monitor and optimize energy use, and encouraging energy-saving behaviours among laboratory staff are vital for improving energy efficiency. Conducting regular carbon footprint assessments, implementing emission reduction strategies, and exploring opportunities for carbon offsetting are essential for reducing the carbon footprint. Adopting sustainable procurement practices, implementing comprehensive waste segregation and recycling programs, and ensuring the safe and compliant disposal of hazardous waste are critical for waste reduction and management. Investing in water-efficient technologies and infrastructure, implementing water recycling and reuse practices where feasible, and monitoring and managing water consumption are crucial for water conservation.

Finally, by implementing these actions, research laboratories will be able to reduce their environmental impact while continuing to contribute valuable scientific insights and innovations.

# 2. ABOUT INFN

The National Institute for Nuclear Physics (INFN) is the Italian research agency dedicated to the study of the fundamental constituents of matter and the laws that govern them, under the supervision of the Ministry of Education, Universities and Research (MIUR). It conducts theoretical and experimental research in the fields of subnuclear, nuclear and astroparticle physics. All the INFN's research activities are undertaken within a framework of international competition, in close collaboration with Italian universities on the basis of solid academic partnerships spanning decades. Fundamental research in these areas requires the use of cutting-edge technology and instruments, developed by the INFN at its own laboratories and in collaboration with industries.

Groups from the Universities of Rome, Padua, Turin, and Milan founded the INFN on 8th August 1951 to uphold and develop the scientific tradition established during the 1930s by Enrico Fermi and his school, with their theoretical and experimental research in nuclear physics. In the latter half of the 1950s the INFN designed and built the first Italian accelerator, the electron synchrotron developed in Frascati, where its first national laboratory was set up. During the same period, the INFN began to participate in research into the construction and use of ever-more powerful accelerators being conducted by CERN, the European Organisation for Nuclear Research, in Geneva.

Today the INFN employs some 5 000 scientists whose work is recognised internationally not only for their contribution to various European laboratories, but also to numerous research centres worldwide.

The INFN is organized into four main structures: Division and associated groups; National Laboratories and consortia; National Centres and Schools, and Central Administration (see Figure 2).

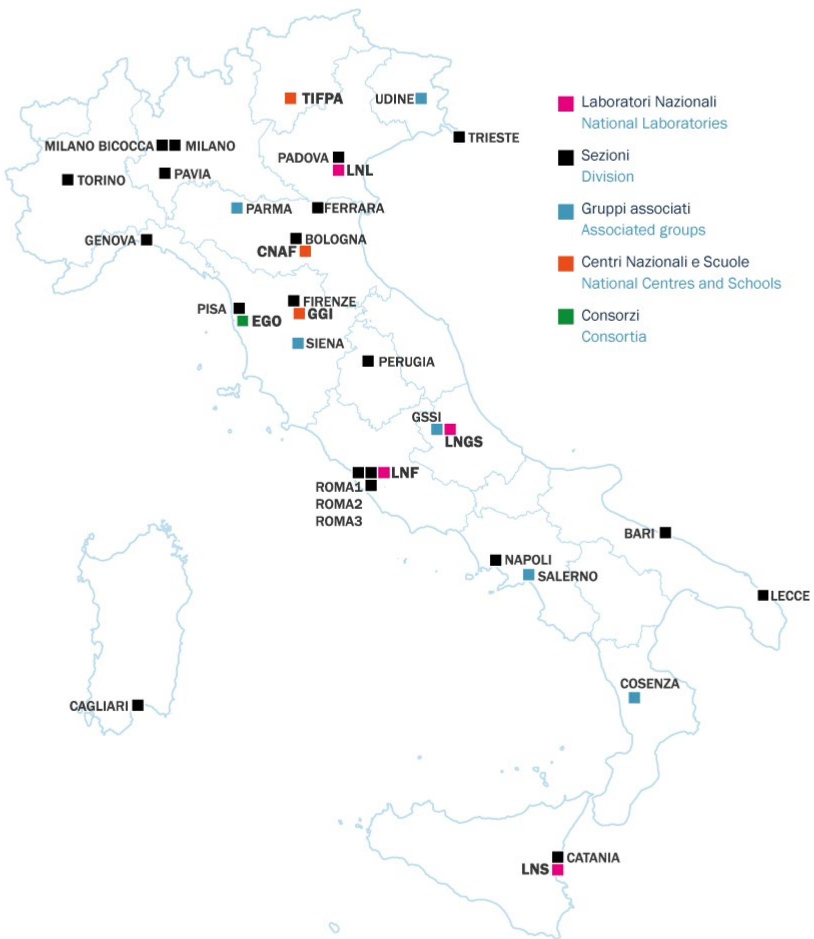


*Figure 2. Organization of the INFN in the Italian territory.*

In detail:

a) Division: scientific structures whose purpose is to carry out research and higher education activities within the framework of the Institute's programmatic objectives; they are normally based in the physics departments of universities on the basis of special agreements.
b) National Laboratories: scientific institution whose purpose is to develop, build and manage large instrumental facilities for the Institute's research activities by making them available to a broad national and international community, including interdisciplinary ones, as well as to carry out research activities within the framework of the Institute's programmatic objectives.
c) National Centres and Schools: scientific-technological centres with the purpose of developing, constructing and/or operating instrumental equipment for the Institute's activities, as well as carrying out technological research and development; and scientific- educational centres, with the purpose of promoting the advancement of scientific knowledge and the preparation of young Italians and foreigners for highly qualified scientific research through the management of training activities at the doctoral level.
d) Central Administration: coordinated by the Director General, manages centralized administrative functions, carries out policy, coordination and verification functions of administrative activities, and provides technical, professional and monitoring services.

Within such organization, National Laboratories represent a fundamental framework for all initiatives of the INFN. Alongside National Centres, they host large equipment and infrastructure made available to the national and international scientific community. The other Divisions, associated groups, National Centres or Schools are located inside the Italian Universities and it is impossible to evaluate the INFN footprint. The following facilities have been considered in the present study.

**Laboratori Nazionali di Frascati (LNF)**

Built in 1955, the Frascati National Laboratories (LNF) were the first Italian research facility for the study of nuclear and subnuclear physics with accelerators and are the largest laboratory of the National Institute for Nuclear Physics (INFN), the public body whose mission is theoretical, experimental and technological research in subnuclear, nuclear and astroparticle physics.

The main characteristic of LNF consists in knowing how to build particle accelerators.

This activity started in 1957 with the 1.1 GeV electron synchrotron, the most powerful machine at the time, continued with AdA (1961), the first electron-positron collider ever built, and its successor ADONE (1969) and culminated in 2000 with the construction of DAφNE, the collider still in operation that holds the world record of low energy instantaneous luminosity.

In addition, LNF hosts the SPARC free-electron laser, built in collaboration with ENEA and CNR, and the extremely high-power FLAME laser for the study of innovative particle acceleration techniques.

The fourteen hectares of laboratories include all the necessary research infrastructures: equipment for the design and construction of high-technology accelerators and detectors, the computer centre with connection to GARR (the communication network dedicated to research institutions), the library and the scientific documentation service. In addition, the laboratory also hosts the Health Physics and Occupational Medicine Service and the Occupational Safety Departments, responsible for all safety measures including risks from pollution and radiation sources.

LNF also houses the Administrative HQ of the INFN. It carries out tasks related to policymaking, coordinating, and overseeing decentralized administrative activities. Additionally, it ensures the provision of central technical, professional, and surveillance services. Furthermore, it is responsible for the preparation and execution of deliberative acts within its competence, based on the directives of the Executive Committee.

Below are the main data of the laboratory.

*Table 1. Data of LNF.*

| | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| Machine time (DAφNE) | hours | 3 063 | 1 475 | 4 176 |
| Annual expenditure | € | 19 528 881 | 19 764 849 | 19 498 495 |
| Employees (LNF+AC) | n° | 477 | 479 | 519 |
| Average daily attendance (workplace canteen) | n° | 235 | 289 | 316 |
| Built area | mq | 28 512 | 28 512 | 28 512 |

**Laboratori Nazionali del Gran Sasso (LNGS)**

LNGS is the largest underground laboratory in the world devoted to neutrino and astroparticle physics, a worldwide research facility for scientists working in this field of research, where particle physics, cosmology and astrophysics meet. It is unequalled anywhere else, as it offers the most advanced underground infrastructures in terms of dimensions, complexity and completeness.

Located between L'Aquila and Teramo, at about 120 kilometres from Rome, the underground structures are on one side of the 10-kilometre long highway tunnel which crosses the Gran Sasso massif (towards Rome); the underground complex consists of three huge experimental halls (each 100-metre long, 20-metre large and 18-metre high) and bypass tunnels, for a total volume of about 180 000 m3. Halls are equipped with all technical and safety equipment and plants necessary for the experimental activities and to ensure proper working conditions for people involved.

The 1400 metre-rock thickness above the Laboratory represents a natural coverage that provides a cosmic ray flux reduction by one million times; moreover, the flux of neutrons in the underground halls is about thousand times less than on the surface due to the very small amount of uranium and thorium of the Dolomite calcareous rock of the mountain. The permeability of cosmic radiation provided by the rock coverage together with the huge dimensions and the impressive basic infrastructure, make the Laboratory unmatched in the detection of weak or rare signals, which are relevant for astroparticle, sub nuclear and nuclear physics. LNGS research activities range from neutrino physics to dark matter search, to nuclear astrophysics, and also to earth physics, biology and fundamental physics.

Outside, immersed in a National Park of exceptional environmental and naturalistic interest on the slopes of the Gran Sasso Mountain chain, an area of more than 23 acres hosts laboratories and workshops, the Computing Centre, the Directorate and several other Offices. Currently 1100 scientists from 29 different Countries are taking part in the experimental activities of LNGS.

*Table 2. Data of LNGS.*

| | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| Machine time | hours | NA | NA | NA |
| Annual expenditure | € | 10 689 137 | 11 387 793 | 10 305 305 |
| Employees | n° | 131 | 138 | 148 |
| Average daily attendance (Access management system) | n° | 114 | 139 | 146 |
| Built area | mq | 32 800 | 32 800 | 32 800 |

**Note:** NA: not available.

**Laboratori Nazionali di Legnaro (LNL)**

Located about ten kilometres east of Padua, LNL occupies a large area in the outskirts of Legnaro, on the border Ponte San Nicolò. The Laboratories were founded in 1961 and are an international centre for core physics and applications of nuclear technologies. It hosts three major nuclear particle accelerators: Tandem (XTU), Cyclotron (B70), and Linac (PIAVE-Alpi). Additionally, smaller accelerators (CN, AN2000) are operational for studies on material properties, radiobiology, environmental physics, and health physics.

The experiments conducted at the Tandem-Alpi-Piave (TAP) complex primarily focus on studying the structure of exotic nuclei (such as those formed in stars) generated through appropriate nuclear collisions, and the various mechanisms involved in nuclear reactions. Currently, these experiments utilize the GALILEO gamma-ray spectrometer (a system of hyperpure germanium detectors cooled with liquid nitrogen) coupled with various complementary detectors. Investigating the dynamics of reactions requires different instruments specialized in detecting and identifying specific fragments produced: the PRISMA magnetic spectrometer, the GARFIELD multi-detector, the electrostatic deflector, the PISOLO time-of-flight spectrometer, and the EXOTIC infrastructure for in-flight production of exotic light ions. Conversely, numerous interdisciplinary physics activities are conducted at the AN2000 and CN accelerators, based on the use of ion beams, with experiments dedicated to elemental analysis of samples of various natures, characterization of targets for the development of innovative radioisotopes, studies in radiobiology and microdosimetry, and irradiation of detectors and electronic devices.

In the coming years, the completion and operation of SPES will enable the production of unstable ion beams for fundamental nuclear physics and innovative and experimental radionuclides for medical diagnostics, therapy, or other applications.

*Table 3. Data of LNL.*

| | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| Machine time | hours | 3 797 | 5 637 | 7 690.5 |
| Annual expenditure | € | 8 091 559 | 10 440 073 | 11 320 688 |
| Employees | n° | 206 | 210 | 206 |
| Average daily attendance (workplace canteen) | n° | 155 | 165 | 185 |
| Built area | mq | 29 600 | 29 600 | 29 600 |

**Laboratori Nazionali del Sud (LNS)**

Founded in 1976, the research activities are mainly oriented towards Nuclear Physics and Nuclear and Particle Astrophysics. The LNS are also an advanced technological pole for development of different types of instrumentation.

The LNS have two additional separate branches: one, located at the port of Catania, mostly used for assembling and temporary location of systems and apparata of the infrastructure KM3, the other one, located in Portopalo di Capopassero, is the station for acquisition of data traveling from undersea detectors through an electro-optical cable.

At the LNS two accelerators are operating, a Tandem Van de Graaff with maximum terminal voltage of 15 MV, and a K800 Superconducting Cyclotron, a very compact machine with superconductive coils working in Liquid Helium bath at a temperature of 4.2 K, able to generate a magnetic field up to 4.8 Tesla. Ion beams to be injected into the Cyclotron are produced by two ECR sources, named SERSE and CAESAR. The two accelerators allow to produce and accelerate heavy ion beams in a very wide range of mass (from hydrogen to lead) and energy (1-80 MeV per a.m.u.), providing the possibility of investigating on different properties of nuclear matter with several types of reaction. Beams produced by the two accelerators can be transported to the LNS experimental halls, which are provided with complex detection systems, scattering chambers, vacuum systems and all the devices necessary to the study of nuclear collisions.

Nucleus-nucleus collisions at low (below the Coulomb barrier) and higher (the Fermi value) energy are an effective tool of experimental investigation of nuclear structure and reaction mechanisms. Consequently, each experimental detection system is different from the other ones depending upon the type of reaction to be studied, upon the type of reaction products, upon the number of emitted fragments.

*Table 4. Data of LNS.*

| | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| Machine time | hours | 0 | 0 | 0 |
| Annual expenditure | € | 8 374 207 | 8 269 875 | 8 009 356 |
| Employees | n° | 169 | 172 | 186 |
| Average daily attendance | n° | 108 | 103 | 114 |
| Built area | mq | 22 163 | 22 163 | 22 163 |

## CNAF

The acronym CNAF stands for "Centro Nazionale Analisi Fotogrammi" (National Center for Frame Analysis) and takes us backward through time to 1962, when CNAF was founded as a new INFN Technological Centre dedicated to the analysis and high precision measurement of bubble chamber photographic films. At that time, bubble chambers were used in many nuclear physics labs – and in many INFN sites – to detect elementary particles and create images of their interactions.

CNAF is the national centre of INFN dedicated to Research and Development on Information and Communication Technologies. Being the central computing facility of INFN, CNAF is historically involved in the management and evolution of the most important information and data transmission services in Italy, in support of INFN activities at national and international level. Moreover, since the creation of the distributed computing system on geographical scale known as "Grid", CNAF has been deeply involved in the development of Grid middleware and in the management of the Grid infrastructure in an international framework, in particular in the context of the World-wide LHC Computing Grid (Worldwide LHC Computing Grid).

Since 2003, CNAF has hosted the Italian Tier-1 data centre for the high-energy physics experiments at the Large Hadron Collider in Geneva, providing the resources, support and services needed for data storage and distribution, data processing and analysis, and Monte Carlo production.

CNAF also represents a key computing facility for many astro-particle and neutrino-physics experiments, making it one of the most important centres for distributed computing in Italy.

*Table 5. Data of CNAF.*

| | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| Power Usage Effectiveness (PUE) | hours | NA | NA | NA |
| Annual expenditure | € | 5 656 196 | 5 557 383 | 8 725 969 |
| Employees | n° | 60 | 55 | 62 |
| Average daily attendance (Access management system) | n° | 19 | 26 | 33 |
| Built area | mq | 2 600 | 2 600 | 2 600 |

**Note:** NA: not available.

# 3. ENVIRONMENTAL RESPONSABILITY

Environmental responsibility and protection are important issues for INFN. The institute has always been aware of environmental themes and in 2023 signed the resolution that proclaim 2024-2033 International Decade of Science for Sustainable Development. The resolution was proposed during the 96$^{th}$ plenary meeting of 77$^{th}$ session of the United Nations General Assembly, which was held on August 25, 2023. The goal of this initiative is to offer a unique opportunity for humanity to take advantage of the essential role that science plays in pursuing sustainable development, as one of the main means for implementing and responding to the complex challenges of our time, and thus ensuring the conditions for a safe and prosperous future for everyone. In addition, INFN endorses the European Strategy for Particle Physics, revised in 2020, which outlines a cohesive and globally synchronized approach to advancing the field in Europe. This Strategy underscores the paramount importance of environmental conservation, affirming the perpetual need to meticulously examine and mitigate the environmental repercussions of particle physics endeavours.

The Health, Safety and Environmental Service (Servizio Salute, Sicurezza e Ambiente - SSA) operates as a centre of expertise and coordination among the Institute's different facilities regarding environmental issues and provides impulse to the Organization's safety policy. This policy encompasses all aspects of health, safety and environmental protection, with the specific goal of reducing the Organization's environmental footprint. INFN adheres to the precautionary principle across all dimensions of environmental management, taking proactive measures to pre-empt potential significant environmental harm. This principle remains steadfast even in situations where scientific data may not facilitate a comprehensive risk assessment, ensuring precautionary measures are enacted under all circumstances.

## 3.1. MANAGEMENT APPROACH

In addition to the commitment to environmental issues, some INFN facilities have implemented environmental management systems.

As defined in UNI EN ISO 14001, an environmental management system is *"the part of an organization's system used to develop and implement its environmental policy and manage its environmental aspects"*. The management system includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources. Therefore, the environmental management system is a powerful tool for identifying, monitoring, managing and improving environmental problems related to the Institute's activities, as well as preventing and knowing how to deal with environmental emergencies. Such systems also enable the Institute to maintain a high level of attention to environmental issues through verification of legislative compliance, continuous improvement with the aim of increasing environmental performance and preventing pollution.

At the moment, the laboratories that have a management system that complies with the requirements of ISO 14001 are the Legnaro and Gran Sasso laboratories. This certification enhances the facilities' constant efforts to environmental themes: all research activities are carried out in strict compliance with environmental protection regulations. The main actions concern the prevention of all types of pollution, as well as constant improvement of performance in the environmental field.

## 3.2. ENVIRONMENTAL KPIs

In the analysis of environmental impacts, identifying and understanding material themes is crucial for effective and sustainable resource management and KPIs definition. Material themes represent the most significant aspects that affect the environment and need to be carefully monitored and managed. This section explores the material themes identified for the research institute, highlighting their importance and strategies for addressing them.

**Energy consumption** is one of the most relevant material issues for the research institute. Research laboratories are often among the most energy-intensive facilities due to the specialized equipment and controlled environments required for scientific research. High-performance computers, particle accelerators, analytical instruments, and climate-controlled spaces consume large amounts of electricity. Reducing energy consumption in laboratories is crucial for minimizing their environmental impact. Implementing energy-efficient technologies and practices, optimizing the use of equipment and infrastructure, and transitioning to renewable energy sources are vital steps in this direction.

Another relevant material issue for the research institute are **greenhouse gas emissions**. The carbon footprint of a research laboratory measures the total greenhouse gas emissions generated by its operations, including direct emissions from on-site activities, that are relevant in laboratories where electrostatics accelerators operate, and indirect emissions from energy consumption and supply chains. Understanding and reducing the carbon footprint is essential for mitigating the impact of research laboratories on climate change. Conducting comprehensive carbon footprint assessments, identifying and implementing emission reduction strategies, and offsetting unavoidable emissions through credible carbon offset projects are key areas of focus.

The use of **water resources** is another crucial material theme. Water is a critical resource in research laboratories, used in processes or cooling systems. Efficient water use and management are important for reducing the environmental impact of laboratory operations and conserving this vital resource. Implementing water-saving technologies and practices, recycling and reusing water where possible, and monitoring and reducing water consumption are essential measures.

**Waste management** is another crucial material theme. Research laboratories generate various types of waste, including hazardous waste, electronic waste, and general solid waste. Proper management of these waste streams is vital to minimize environmental harm and ensure compliance with regulatory requirements. Reducing waste generation through sustainable procurement and usage practices, implementing effective waste segregation and recycling programs, and ensuring the safe and compliant disposal of hazardous waste are crucial strategies.

Finally, given the institute's research, the theme of **ionising radiation** was also considered as material. Research laboratories use particle accelerators, radiogenic machines, and radioactive sources that generate ionizing radiation. The use of such ionizing radiation sources takes place within buildings equipped with the necessary prevention, protection, and alarm systems.

# 4. ENERGY

This chapter analyses the energy consumption used to power buildings, laboratories, and scientific equipment, since they significantly impact the environmental footprint of the INFN. One of the primary reasons why energy consumption influences environmental impact is the emission of greenhouse gases. A substantial portion of the energy used originates from fossil fuels such as coal, oil, and natural gas. Additionally, energy consumption affects the depletion of natural resources because it necessitates an increased demand for non-renewable resources like fossil fuels. The extraction, processing, and transportation of these resources cause significant environmental impacts, including habitat destruction, biodiversity loss, and air and water pollution. Reducing energy consumption helps alleviate the pressure on natural resources, preserving them for future generations.

## 4.1. METHODOLOGY

For the assessment of energy consumption, a single indicator was used, which expresses energy consumption in tonnes of oil equivalent (toe) (total values were also reported in gigawatt hours - GWh). The calculation of energy consumption in toe is based on the collection of data regarding the various types of energy used within the laboratories, such as electricity consumption, natural gas, liquid fuels, and fuel consumption for vehicles (data inventory described in section 4.2).

Once these data were collected, they were converted using the conversion factors defined by the Italian Federation for Energy Efficiency (FIRE). These conversion factors allow the transformation of energy consumption from their original units (kWh, m, litres) into toe, thus facilitating the comparison and aggregation of various energy consumptions. The commonly used conversion factors are provided below (Table 6).

*Table 6. Primary energy conversion factors in toe.*

| | UM | Conversion Factor |
|---|---|---|
| Electricity | toe/kWh | $0.187 \times 10^{-3}$ |
| Natural gas | toe/Smc | $0.836 \times 10^{-3}$ |
| Diesel oil | toe/l | $0.860 \times 10^{-3}$ |
| Gasoline | toe/l | $0.765 \times 10^{-3}$ |
| LPG | toe/l | $0.616 \times 10^{-3}$ |

## 4.2. DATA INVENTORY

The following data were collected for the evaluation of energy consumption, categorized by type and usage. The data were extracted from the analysis of monthly energy bills, meters installed in the laboratories, and the organization's management systems.

### 4.2.1. Fuel

Table 7 and Table 8 respectively present the consumption of methane and diesel in fixed equipment within the analysed INFN facilities.

*Table 7. Methane consumption.*

| Fuel | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| LNF | smc | 85 883 | 40 635 | 38 329 |
| LNGS | smc | 199 482 | 207 685 | 237 578 |
| LNL | smc | 334 709 | 264 606 | 213 999 |
| LNS | smc | 56 670 | 53 517 | 46 076 |
| CNAF | smc | 0 | 0 | 0 |
| **TOTAL** | smc | **676 744** | **566 443** | **535 982** |

*Table 8. Diesel oil consumption.*

| Fuel | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| LNF | lt | 0 | 0 | 0 |
| LNGS | lt | 0 | 0 | 0 |
| LNL | lt | 0 | 564 | 1 430 |
| LNS | lt | 500 | 500 | 500 |
| CNAF | lt | 9 545 | 1 210 | 2.437 |
| **TOTAL** | lt | **10 045** | **2 274** | **4 367** |

Table 9 shows the fuel consumption of owned vehicles with an indication of the anti-pollution class and the type of fuel used.

*Table 9. Fuel consumption for laboratories-owned cars.*

| Lab | Type | EURO | Fuel | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| LNF | FIAT TIPO | 6 | Diesel oil | lt | 560 | 430 | 525 |
| | FIAT DUCATO | 6 | Diesel oil | lt | 507 | 994 | 1.046 |
| | OPEL MERIVA | 6 | LPG | lt | 11 105 | 11.205 | - |
| | | | Gasoline | lt | 26 | 69 | - |
| | KIA SPORTAGE | 6 | Diesel oil | lt | 8 846 | 17 488 | 1 386 |
| | JEEP COMPASS | 6 | Gasoline / Electric | lt | - | - | 26 015 |
| LNGS | FIAT PANDA | 6 | Gasoline | lt | 700 | 700 | 700 |
| | FIAT PANDA | 6 | Gasoline | lt | 700 | 700 | 700 |
| | FIAT PANDA | 6 | Gasoline | lt | 700 | 700 | 700 |
| LNL | PSA BOXER | 4 | Diesel oil | lt | 609 | 438 | 221 |
| | FIAT FIORINO | 6D | Diesel oil | lt | 300 | 392 | 359 |
| | FIAT 500L | 6D | Diesel oil | lt | 67 | 442 | 463 |
| | OPEL COMBO | 6D | Diesel oil | lt | - | | 50 |
| LNS | FURGONE | 6D | Diesel oil | lt | 359 | 359 | 359 |
| CNAF | FIAT DUCATO | 6D | Diesel oil | lt | - | - | 143 |
| | FORD TRANSIT | 6 | Diesel oil | lt | - | - | 184 |
| | PSA BOXER | 6 | Diesel oil | lt | 372 | 778 | - |

### 4.2.2. Electricity

Below are tables of electricity consumption in the analysed INFN facilities.

*Table 10. Electricity consumption of LNF.*

| Electricity | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| High voltage electricity | kWh | 21 742 976 | 15 238 950 | 20 857 711 |
| Medium voltage electricity | kWh | 0 | 0 | 0 |
| Low voltage electricity | kWh | 0 | 0 | 0 |
| Renewable electricity | kWh | 0 | 0 | 0 |
| **TOTAL** | kWh | **21 742 976** | **15 238 950** | **20 857 711** |

*Table 11. Electricity consumption of LNGS.*

| Electricity | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| High voltage electricity | kWh | 0 | 0 | 0 |
| Medium voltage electricity | kWh | 9 647 969 | 9 409 311 | 9 710 585 |
| Low voltage electricity | kWh | 0 | 0 | 326 |
| Renewable electricity | kWh | 0 | 0 | 0 |
| **TOTAL** | kWh | **9 647 969** | **9 409 311** | **9 710 911** |

*Table 12. Electricity consumption of LNL.*

| Electricity | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| High voltage electricity | kWh | 10 041 315 | 13 681 611 | 16 553 430 |
| Medium voltage electricity | kWh | 381 276 | 5 097 | 125 331 |
| Low voltage electricity | kWh | 0 | 0 | 0 |
| Renewable electricity | kWh | 0 | 0 | 0 |
| **TOTAL** | kWh | **10 422 591** | **13 686 708** | **16 678 761** |

*Table 13. Electricity consumption of LNS.*

| Electricity | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| High voltage electricity | kWh | 0 | 0 | 0 |
| Medium voltage electricity | kWh | 5 679 211 | 3 617 761 | 3 851 501 |
| Low voltage electricity | kWh | 32 625 | 36 531 | 74 924 |
| Renewable electricity | kWh | 0 | 0 | 0 |
| **TOTAL** | kWh | **5 711 836** | **3 654 292** | **3 926 425** |

*Table 14. Electricity consumption of CNAF.*

| Electricity | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| High voltage electricity | kWh | 0 | 0 | 0 |
| Medium voltage electricity | kWh | 7 593 555 | 8 012 994 | 8 219 869 |
| Low voltage electricity | kWh | 0 | 0 | 0 |
| Renewable electricity | kWh | 0 | 0 | 0 |
| **TOTAL** | kWh | **7 593 555** | **8 012 994** | **8 219 869** |

## 4.3. RESULTS

The main results of the quantification of energy consumption are given below: first in aggregate form, as the sum of the four laboratories and the national centre, and then in detail for each site.

Total consumption is shown in the table below in both absolute and relative terms.

*Table 15. Total energy consumption of INFN.*

| | um | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|---|
| Electrical energy (EE) | toe | 10 307 | 94.6% | 9 350 | 94.9% | 11 107 | 95.9% |
| Thermal energy (TE) | toe | 574 | 5.3% | 476 | 4.8% | 452 | 3.9% |
| Fuel (Transportation) | toe | 18 | 0.2% | 27 | 0.3% | 28 | 0.2% |
| **TOTAL** | toe | **10 900** | | **9 853** | | **11 587** | |
| | GWh | 62.01 | | 55.85 | | 64.98 | |

In general, INFN's energy consumption averages around 10 800 toe for the three-year period under consideration. In detail, there was a 10% reduction in consumption in 2022 compared to the previous year while in 2023 energy consumption increased by 6% compared to 2021 (Figure 4).

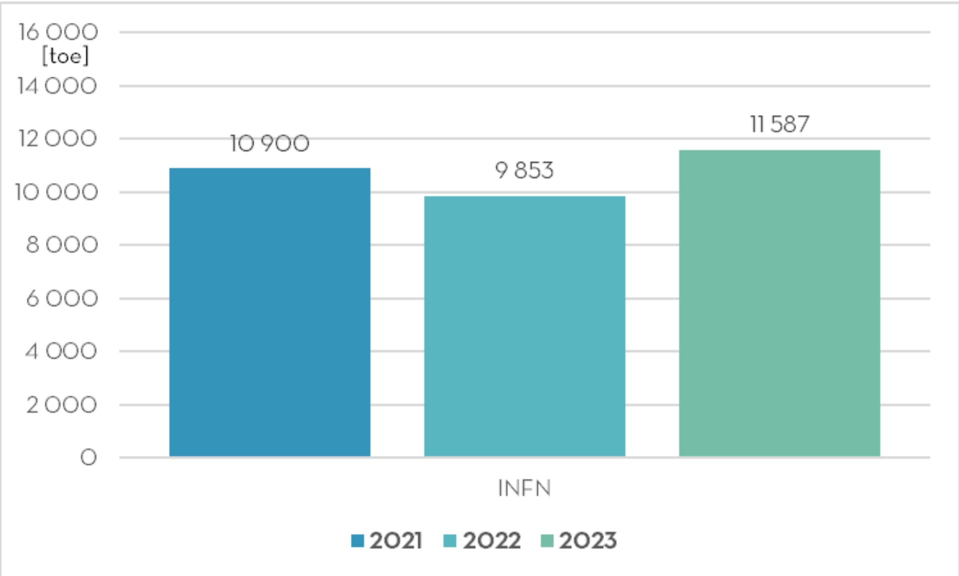


*Figure 3. Trend of total energy consumption of INFN over the three-year period [toe].*

The analysis of energy sources (Figure 4) shows how most of the contribution is due to electricity consumption, which on average accounts for about 95 percent of all energy consumption. The other sources, namely "thermal energy" and transportation fuel, have a negligible impact. Moreover, while electricity has been fluctuating (first a decrease and then an increase), thermal energy has decreased in both years: -17% in 2022 compared to the previous year and -5% in 2023 compared to the previous year.

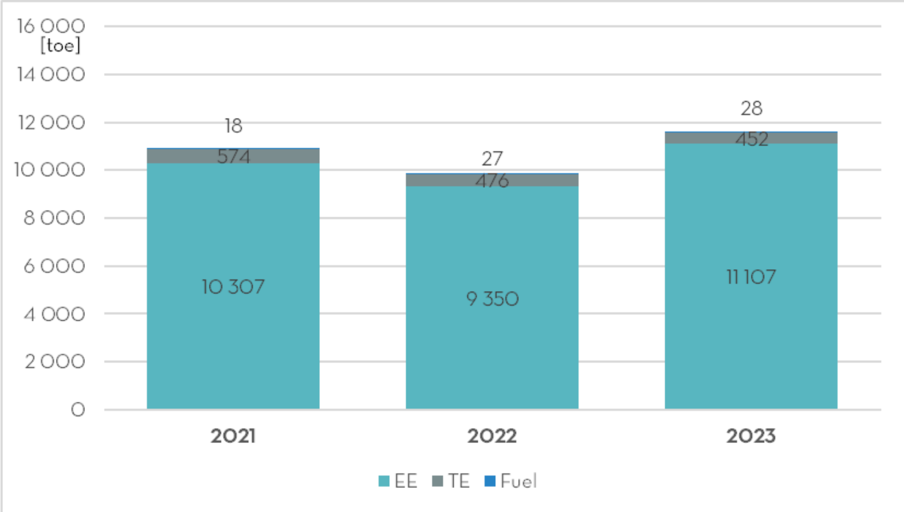


*Figure 4. Trend of total energy consumption of INFN over the three-year period by energy source [toe].*

Analysing the contribution of the different facilities to the total, it is evident that some represent a significant portion, while others contribute less. The LNF accounts for the highest contribution (30-38%), followed by the LNL (20-28%) and then by the LNGS (17-20%).

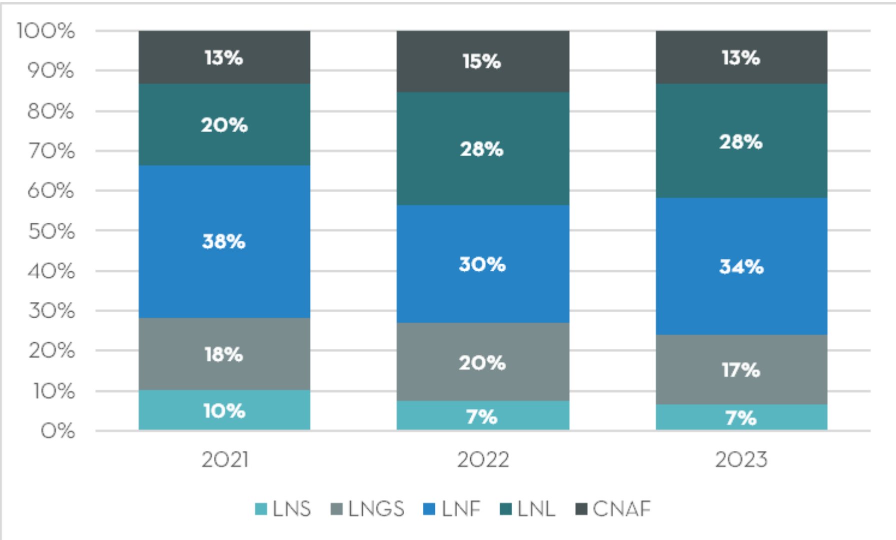


*Figure 5. Breakdown of energy consumption compared to the total of facilities in the three-year period.*

### 4.3.1. Insights by site

**• LNF**

The table below shows energy consumption over the three-year period, broken down by energy source in both absolute and relative terms. Most of the consumption is attributable to electricity, which on average accounts for 98% of the total.

*Table 16. Total energy consumption of LNF [toe].*

| | um | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|---|
| Electrical energy (EE) | toe | 4 066 | 97.90% | 2 850 | 98.03% | 3 900 | 98.55% |
| Thermal energy (TE) | toe | 72 | 1.73% | 34 | 1.17% | 32 | 0.81% |
| Fuel (Transportation) | toe | 15 | 0.37% | 23 | 0.80% | 25 | 0.64% |
| **TOTAL** | toe | **4 153** | | **2 907** | | **3 958** | |
| | GWh | 22.76 | | 15.90 | | 21 52 | |

Analysing the trend, there was a 30% reduction in energy consumption in 2022 compared to 2021. However, in 2023, due to the increase of DAφNE 's operation and machine time, consumption increased by 36% compared to the previous year, although still lower than in 2021.

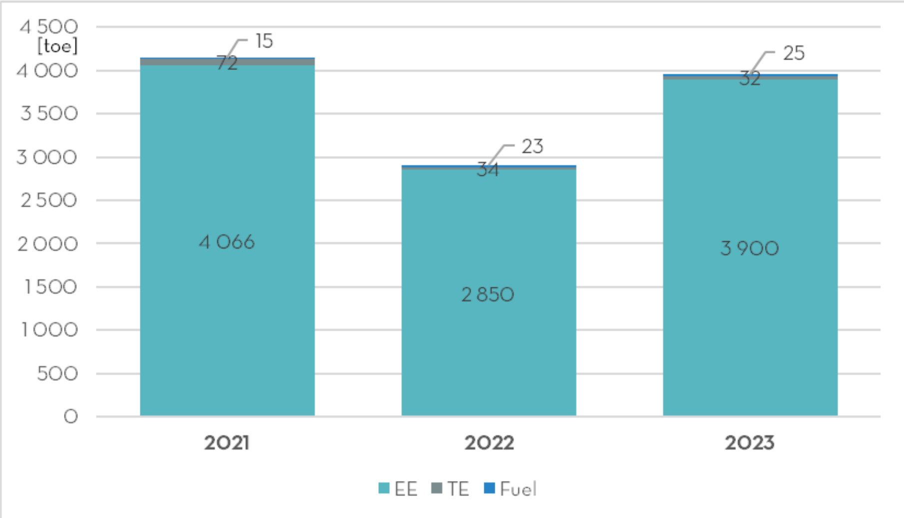


*Figure 6. Trend of total energy consumption of LNF over the three-year period by energy source [toe].*

**• LNGS**

Energy consumption over the three-year period is broken down by energy source in both absolute and relative terms. In all three years considered, the majority of the consumption is attributable to electricity, which on average accounts for about 90% of the total.

*Table 17. Total energy consumption of LNGS [toe].*

| | um | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|---|
| Electrical energy (EE) | toe | 1 804 | 91.46% | 1 760 | 90.94% | 1 816 | 90.07% |
| Thermal energy (TE) | toe | 167 | 8.45% | 174 | 8.97% | 199 | 9.85% |
| Fuel (Transportation) | toe | 2 | 0.08% | 2 | 0.08% | 2 | 0.08% |
| **TOTAL** | toe | **1 973** | | **1 935** | | **2 016** | |
| | GWh | 11.61 | | 11.45 | | 12.04 | |

Over the three-year period, energy consumption remained relatively stable: there was a 2% reduction in 2022, followed by a 4% increase due to the full resumption of scientific activities and the launch of new experiments.

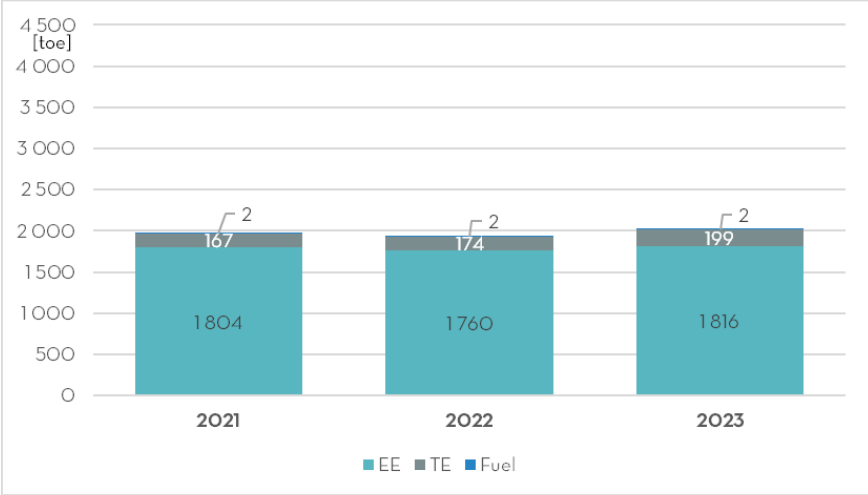


*Figure 7. Trend of total energy consumption of LNGS over the three-year period by energy source [toe].*

• **LNL**

The table below shows energy consumption over the three-year period, broken down by energy source in both absolute and relative terms. The majority of the consumption is attributable to electricity, which on average accounts for about 91% of the total.

*Table 18. Total energy consumption of LNL [toe].*

| | um | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|---|
| Electrical energy (EE) | toe | 1 949 | 87.41% | 2 559 | 91.99% | 3 119 | 94.51% |
| Thermal energy (TE) | toe | 280 | 12.55% | 222 | 7.97% | 180 | 5.46% |
| Fuel (Transportation) | toe | 1 | 0.04% | 1 | 0.04% | 1 | 0.03% |
| **TOTAL** | toe | **2 230** | | **2 782** | | **3 300** | |
| | GWh | 13.69 | | 16.28 | | 18.78 | |

In the period considered, energy consumption in 2022 and 2023 increased by 25% and 19%, respectively, compared to the previous year. These increases were due to the increase in working hours within the laboratory for research activities.

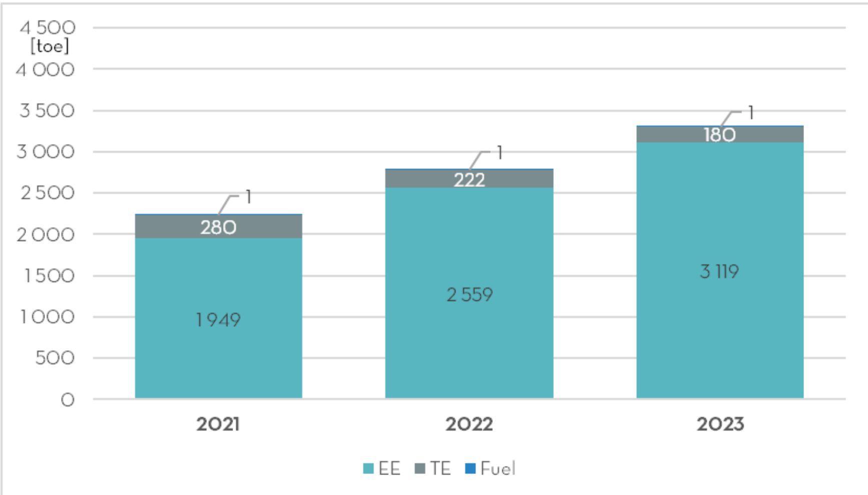


*Figure 8. Trend of total energy consumption of LNL over the three-year period by energy source [toe].*

• **LNS**

Energy consumption broken down by energy source is shown in the table below. The data shows that most of the consumption is attributable to electricity, which on average accounts for about 95% of the total.

*Table 19. Total energy consumption of LNS [toe].*

| | um | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|---|
| Electrical energy (EE) | toe | 1 068 | 95.69% | 683 | 93.76% | 734 | 94.92% |
| Thermal energy (TE) | toe | 48 | 4.28% | 45 | 6.20% | 39 | 5.04% |
| Fuel (Transportation) | toe | 0 | 0.03% | 0 | 0.04% | 0 | 0.04% |
| **TOTAL** | toe | **1 116** | | **728** | | **773** | |
| | GWh | 6.27 | | 4.18 | | 4.38 | |

In 2022, there was a 35% reduction in energy consumption compared to the previous year due to the shutdown of the particle accelerator. However, in 2023, consumption increased by 6% as a result of the start of testing and preparation for new experiments.

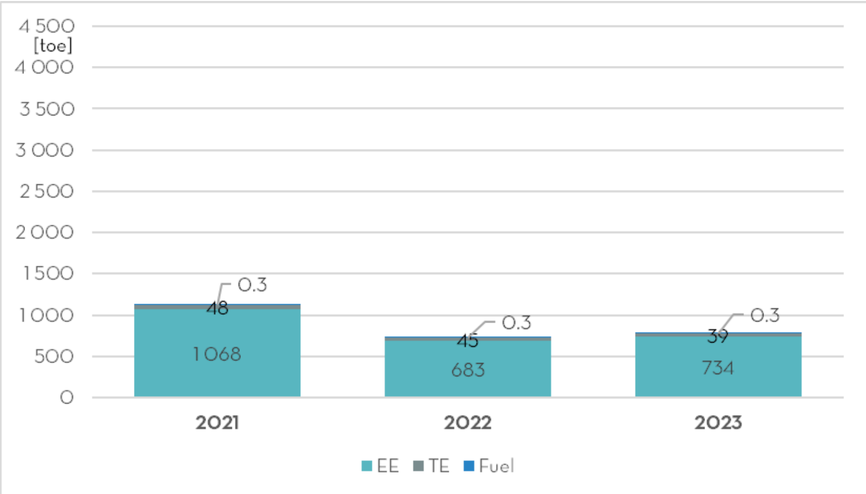


*Figure 9. Trend of total energy consumption of LNS over the three-year period by energy source [toe].*

• **CNAF**

Energy consumption at CNAF is almost exclusively associated with electricity consumption, and the data for the three-year period, broken down by energy source, is shown below.

*Table 20. Total energy consumption of CNAF [toe].*

| | um | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|---|
| Electrical energy (EE) | toe | 1 420 | 99.40% | 1 498 | 99.89% | 1 537 | 99.85% |
| Thermal energy (TE) | toe | 8 | 0.57% | 1 | 0.07% | 2 | 0.14% |
| Fuel (Transportation) | toe | 0.3 | 0.02% | 0.7 | 0.04% | 0.3 | 0.02% |
| **TOTAL** | toe | **1 429** | | **1 500** | | **1 539** | |
| | GWh | 7.69 | | 8.03 | | 8.25 | |

During the period considered, there was a slight increase in consumption: in 2022, there was a 5% increase compared to the previous year, while in 2023, there was a 2% increase compared to 2022.

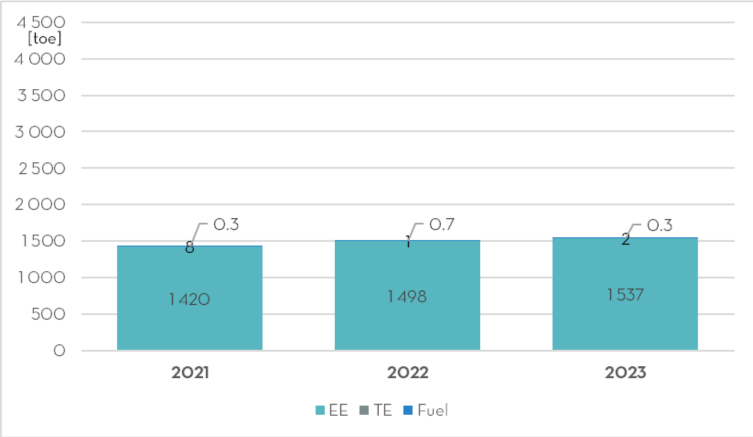


*Figure 10. Trend of total energy consumption of CNAF over the three-year period by energy source [toe].*

### 4.3.1. Performance indicator

For those laboratories where machine time data were available, the energy intensity per operating hour of the particle accelerator was calculated. Table 21 reports the values over the three-year period for LNF and LNL.

*Table 21. Performance indicator of LNF and LNL.*

| Energy intensity per operating hour of the particle accelerator | um | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| LNF | toe / hours | 1.36 | 1.97 | 0.95 |
| LNL | toe / hours | 0.59 | 0.49 | 0.43 |

LNF's energy intensity per operating hour of the particle accelerator showed a peak in 2022 followed by a sharp reduction in 2023 (Figure 11). In detail, in 2021-2022, the indicator increased from 1.36 to 1.97 toe/h, indicating a growth of about 45% while in 2022-2023, it dropped from 1.97 to 0.95 toe/h, showing a significant decrease of about 52%.

LNL follows a different pattern, with a consistent downward trend in values across the three years, indicating a continuous decrease in the energy intensity per operating hour of the particle accelerator (Figure 12). In 2021-2022, the indicator decreased from 0.59 to 0.49 toe/h, representing a decline of approximately 17%, while in 2022-2023, it further decreased from 0.49 to 0.43 toe/h, showing another reduction of about 12%.

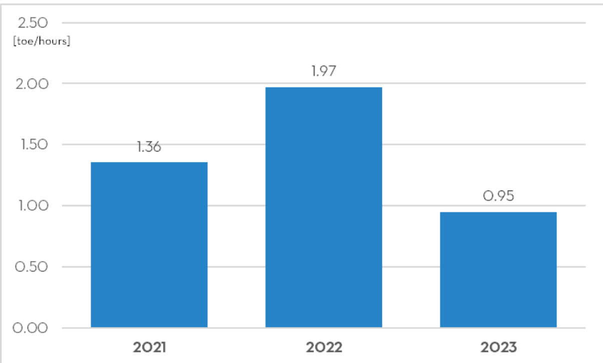


*Figure 11. Trend of Energy intensity per operating hour of the LNF's particle accelerator [toe/hours].*

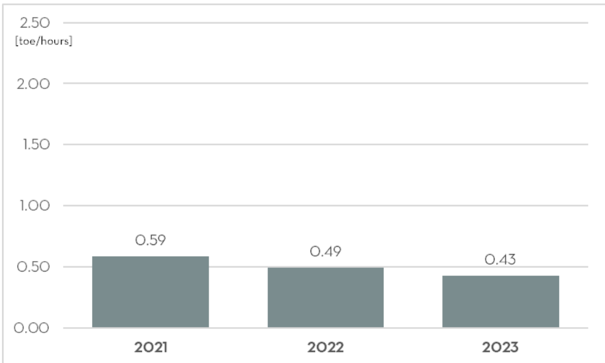


*Figure 12. Trend of Energy intensity per operating hour of the LNL's particle accelerator [toe/hours].*

# 5. CARBON FOOTPRINT

This chapter outlines the methodological approach and results of the greenhouse gas emissions quantification activity conducted for the four National Laboratories and CNAF of INFN.

The calculation of carbon footprint is paramount in contemporary environmental discourse, underpinning efforts to mitigate climate change and foster sustainability. By quantifying the GHG emissions associated with various processes and operations, a comprehensive understanding of carbon footprint can be obtained, enabling informed decisions and targeted intervention strategies.

Moreover, by setting clear targets and benchmarks for emission reductions, the effectiveness of mitigation efforts can be evaluated, and strategies adjusted accordingly. This evaluative process not only fosters continuous improvement but also underscores a commitment to environmental responsibility, positioning organization as leader in the global transition towards a low-carbon future.

## 5.1. Methodology

The quantification and reporting of INFN's greenhouse gas emissions (i.e., Carbon Footprint) have been developed with general reference to the GHG Protocol and ISO 14064-1 standard.

As defined by the standard and the Intergovernmental Panel on Climate Change (IPCC), the greenhouse gases (GHG) considered include Carbon Dioxide ($CO_2$), Methane ($CH_4$), Nitrous Oxide ($N_2O$), Hydrofluorocarbons (HFCs), Sulphur Hexafluoride ($SF_6$), Nitrogen Trifluoride ($NF_3$), and Perfluorocarbons (PFCs). By measuring the different impacts of these greenhouse gases, it was possible to express the total greenhouse gas production by referring to only one parameter, namely $CO_2$ equivalent.

In accordance with the GHG Protocol and UNI EN ISO 14064-1, the following principles have been adopted in this reporting of greenhouse gas emissions:

- Relevance: selected the GHG source, GHG sink, GHG reservoirs, data and methodologies appropriate to the needs of intended user.
- Completeness: included all relevant GHG emission and removals.
- Consistency; enabled meaningful comparison in GHG-related information.
- Accuracy: reduced bias and uncertainties as far as is practical.
- Transparency: disclosed sufficient and appropriate GHG-related information to allow intended users to make decisions with reasonable confidence.

Below are the boundaries and consolidation methodologies, the emission categories that are considered, and the description of methodologies and the emission factors.

### 5.1.1. Organizational boundaries

In conducting a carbon footprint, defining organizational boundaries of analysis is essential for accurately assessing emissions and understanding environmental impact.

One crucial aspect of this is establishing the reference period, typically spanning multiple years to capture emissions trends and variations over time. For this analysis, the reference period encompasses the years 2021, 2022, and 2023, providing a comprehensive view of emissions patterns and allowing for meaningful comparisons and trend analysis.

Moreover, in this report, the focus is on evaluating emissions from four National Laboratories (i.e., LNF, LNGS, LNL and LNS) and the National Centre CNAF. These facilities represent important hubs of scientific research and innovation, with various activities and operations that contribute considerably to the carbon footprint.

Finally, organizational boundaries have been defined through the operational approach. Under this approach, an organization accounts for 100 percent of GHG emissions from operations over which it has control, that is, it has full authority to introduce and implement its own operational policies in the operation. It does not account for GHG emissions from operations in which it owns an interest but does not have operational control.

### 5.1.2. Reporting boundaries

Reporting boundaries in a carbon footprint analysis delineate the extent to which emissions are accounted for in environmental reporting. These boundaries are crucial for ensuring transparency and accuracy in assessing an organization's environmental impact.

In this analysis, reporting boundaries include Scope 1 and Scope 2 emissions while excluding Scope 3 emissions.

Scope 1 emissions encompass direct greenhouse gas emissions from sources that are owned or controlled by the organization. This includes emissions from combustion of fuels in facilities, vehicle fleets, and industrial processes. Scope 2 emissions comprise indirect emissions from the generation of purchased electricity, heat, or steam consumed by the organization. These emissions occur off-site but are associated with the organization's activities.

While Scope 1 and Scope 2 emissions are under the control of the organization, Scope 3 emissions, cover all other indirect emissions such as supply chains, capital goods, waste generated, employee commuting and business travel. The exclusion of Scope 3 is due to the challenges associated with data collection and attribution for these emissions, as they extend beyond the organization's immediate control. The quantification of Scope 3 emissions will be conducted from next year on 2024 data.

### 5.1.3. Emission factors

The calculation of the carbon footprint is based on the formula below, which is the product of the Activity Data (AD), Emission Factor per unit of activity (EF), and Global Warming Potential (GWP).

*CARBON FOOTPRINT = DA x EF x GWP*

This method, adopted by the GHG Protocol and other standards, is the most widely used for carbon footprint calculation and greenhouse gas inventories, as well as for reporting within the European Union Emissions Trading System (EU-ETS).

The emission factors and global warming potentials utilized in the analysis are provided herein, whereas the activity data is detailed in Section 5.2.

#### *5.1.3.1. GWP*

Global Warming Potential (GWP) is a measure used to evaluate the potency of greenhouse gases (GHGs) in contributing to global warming over a specified timeframe relative to carbon dioxide ($CO_2$). It quantifies the amount of heat trapped in the Earth's atmosphere by a particular greenhouse gas compared to the same mass of $CO_2$. GWP values are expressed as multiples of $CO_2$'s warming potential, with higher values indicating greater warming potential. GWP serves as a standardized metric for comparing the climate impact of different GHGs, aiding in the development of policies and strategies to mitigate climate change.

Each GWP value is calculated for a specific time interval (20, 100, or 500 years), and the climate-warming potentials of various gases have been calculated by the Intergovernmental Panel on Climate Change (IPCC) and are periodically updated.

In this report, the updated Global Warming Potentials from the IPCC's 2021 Sixth Assessment Report, calculated with reference to a 100-year time frame, have been used. The main GWP values are listed below.

*Table 22. GWP factors*

| GAS | GWP (AR6 IPCC - 100y) |
|---|---|
| $CO_2$ | 1.0 |
| $CH_4$ - fossil | 29.8 |
| $CH_4$ - non fossil | 27.0 |
| $N_2O$ | 273.0 |
| R134a | 1 530 |
| R-227ea | 3 600 |
| R407c | 1 908 |
| R410a | 2 256 |
| R-448a | 1 494 |
| $SF_6$ | 24 300 |
| $CF_4$ | 7 380 |

#### *5.1.3.2. EF*

Emission factors (EF) refer to numerical values used to quantify the amount of greenhouse gases (GHGs) emitted per unit of activity, process, or product. These factors represent the average emission rate of GHGs associated with specific activities or sources, such as energy consumption, transportation, or industrial processes. Emission factors are typically expressed in units of mass (e.g., kilograms or metric tons) of GHGs emitted per unit of activity (e.g., kilowatt-hour of electricity generated, kilometer travelled by vehicle).

The main emission factors utilized in the analysis are presented below, categorized by emission type.

**EF for combustion in stationary sources.** Regarding emission factors for combustion in stationary sources, the values from the "Table of national standard parameters for monitoring and reporting greenhouse gases", defined annually by the Ministry of the Environment and Energy Security (MASE), have been used. The table defines the reference values according to the coefficients used for $CO_2$ emissions inventory in the UNFCCC National Inventory under Legislative Decree 47/2020.

**EF for combustion in mobile sources.** Emission factors for proprietary mobile sources have been derived from the ISPRA database concerning road transport. These values are based on estimates made for the preparation of the national emissions inventory, conducted annually by ISPRA as a tool for verifying international environmental protection commitments.

**EF for electricity consumption.** Regarding electricity consumption, both approaches currently employed in GHG reporting were used: location-based method and market-based method.

The location-based method relies on the organization's location and analyses emissions from the local power grid. The method reflects the emissions footprint of local utility services. For the emission factors calculation, the national estimate, prepared by ISPRA based on the national energy mix, was used. Despite containing inaccuracies because it is estimated solely based on Italian production and not on the actual consumed energy (which includes, for example, imported electricity with its emissions occurring outside national borders) and because it also considers renewable energy in its calculation, it was chosen because it allows:

- Transparency, as it is a national coefficient provided by ISPRA and not the result of third-party reworkings.
- Comparability, as it is immediately usable.

- Compliance with international standards, as it is a coefficient directly derived from a national official source and used for reporting to an international organization.

Table 23 shows the calculated emission factors for the three-year period under consideration.

*Table 23. Electricity emission factor (location-based approach).*

| | 2021 | 2022 | 2023 |
|---|---|---|---|
| Emission factors | HT: 267.90 $gCO_2/kWh$<br>MT: 278.08 $gCO_2/kWh$ | HT: 303.40 $gCO_2/kWh$<br>MT: 314.93 $gCO_2/kWh$ | HT: 257.20 $gCO_2/kWh$<br>MT: 266.97 $gCO_2/kWh$ |

The market-based method, on the other hand, measures the specific emission footprint of the electricity providers and is therefore linked to the institute's decisions on energy procurement. For the emission factor calculation, the electricity providers' declarations regarding the energy mix were used. Using data provided by ISPRA, the specific emission factors of the suppliers were calculated considering gross electricity production by fuel and the associated emissions. Table 30 shows the electricity suppliers and their respective emission factor.

## 5.2. DATA INVENTORY

Below are the activity data (DA), which characterize the operations that generate greenhouse gas emissions, used for the carbon footprint analysis.

### 5.2.1. Scope 1 – Direct GHG emissions

Regarding direct emissions from stationary sources, the activity data pertains to the annual consumption of methane and diesel oil for heating and laboratory activities. For the data, refer to Table 7 and Table 8.

Regarding direct emissions from mobile sources, the activity data has been extracted from the fuel consumption of the different vehicles that are under the control of the different laboratories. For the data, refer to Table 9. Table 24 shows the distances driven by owned cars.

*Table 24. Distance travelled by owned cars.*

| Lab | Type | EURO | Fuel | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| LNF | FIAT TIPO | 6 | Diesel oil | km | 8 125 | 6 237 | 7 624 |
| | FIAT DUCATO | 6 | Diesel oil | km | 5 330 | 10 440 | 10 989 |
| | OPEL MERIVA | 6 | LPG | km | 920 | 930 | - |
| | | | Gasoline | km | 323 | 859 | - |
| | KIA SPORTAGE | 6 | Diesel oil | km | 613 | 787 | 100 |
| | JEEP COMPASS | 6 | Gasoline / Electric | km | - | - | 1 368 |
| LNGS | FIAT PANDA | 6 | Gasoline | km | 10 000 | 10 000 | 10 000 |
| | FIAT PANDA | 6 | Gasoline | km | 10 000 | 10 000 | 10 000 |
| | FIAT PANDA | 6 | Gasoline | km | 10 000 | 10 000 | 10 000 |
| LNL | PSA BOXER | 4 | Diesel oil | km | 6 091 | 4 384 | 2 206 |
| | FIAT FIORINO | 6D | Diesel oil | km | 5 003 | 6 530 | 5 977 |
| | FIAT 500L | 6D | Diesel oil | km | 1 119 | 7 369 | 7 722 |
| | OPEL COMBO | 6D | Diesel oil | km | - | - | 762 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LNS | FURGONE | 6D | Diesel oil | km | 3 589 | 3 589 | 3 589 |
| CNAF | FIAT DUCATO | - | Diesel oil | km | - | - | 1 429 |
| | FORD TRANSIT | - | Diesel oil | km | - | - | 2 039 |
| | PSA BOXER | 6 | Diesel oil | km | 3 716 | 3 716 | - |

Finally, the data related to fugitive emissions have been derived from both the annual gas purchases for experiments and the maintenance and refilling operations of refrigerant gas within the cooling systems. Below is a detailed breakdown of the activity data for each laboratory.

*Table 25. Activity data related to the LNF's fugitive emissions*

| System | Gas | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| Firefighting system | R-227ea | kg | 0.00 | 0.00 | 0.00 |
| CDZ _ DAφNE RC | R407 | kg | 83.00 | 0.00 | 0.00 |
| Chiller Emicon | R407 | kg | 6.00 | 0.00 | 0.00 |
| Gas mixtures used for experiments | | | | | |
| Exp. CYGNO | $CF_4$ | kg | 38.00 | 38.00 | 38.00 |
| Exp. CMS | $CF_4$ | kg | 7.00 | 7.00 | 7.00 |
| Lab. DDG ed.8 | $CF_4$ | kg | 13.50 | 13.50 | 13.50 |
| Lab. DDG ed.8 | $C_2H_2F_4$ | kg | 33.00 | 33.00 | 33.00 |
| Exp. CMS | $SF_6$ | kg | 13.00 | 13.00 | 13.00 |

*Table 26. Activity data related to the LNGS's fugitive emissions*

| System | Gas | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| EMERSON LIEBERT | R-407C | kg | 12.00 | 0.00 | 0.00 |
| HIROSS | R-448A | kg | 18.00 | 0.00 | 0.00 |
| MCQUAY | R-448A | kg | 15.00 | 0.00 | 0.00 |
| RC GROUP | R-407C | kg | 13.00 | 0.00 | 0.00 |
| CLIVET | R-407C | kg | 10.40 | 0.00 | 0.00 |
| Gas mixtures used for experiments | | | | | |
| - | $SF_6$ | kg | 0.00 | 0.00 | 0.00 |
| - | $CF_4$ | kg | 0.00 | 0.00 | 0.00 |

*Table 27. Activity data related to the LNL's fugitive emissions*

| System | Gas | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| Cooling systems _a | R134a | kg | 0.00 | 35.00 | 0.00 |
| Cooling systems _b | R407c | kg | 3.00 | 3.00 | 4.00 |
| Cooling systems _c | R410a | kg | 31.00 | 12.00 | 0.00 |
| Gas mixtures used for experiments | | | | | |
| Electrostatic particle accelerator restoration | $SF_6$ | kg | 520.00 | 2 080.00 | 2 360.00 |
| Tetrafluoromethane | $CF_4$ | lt | 0.00 | 40.00 | 0.00 |
| Hydrostar (gas mixture) | 95% Ar + 3% $CF_4$ + 2% $C_4H_{10}$ | lt | 200.00 | 400.00 | 0.00 |
| Gas mixture | 90% Ar + 10% $C_4H_{10}$ | lt | 0.00 | 0.00 | 80.00 |

| | | | | | |
|---|---|---|---|---|---|
| Gas mixture | 95% Ar + 5% $C_4H_{10}$ | lt | 0.00 | 160.00 | 0.00 |
| Carbon dioxide-nitrogen mixture (for CN and AN2000) | 70% N2 + 30% $CO_2$ | lt | 1 000.00 | 1 280.00 | 0.00 |
| Gas mixture | 90% Ar + 10% $CO_2$ | lt | 14.00 | 0.00 | 0.00 |
| Carbon dioxide | $CO_2$ | lt | 0.00 | 56.00 | 28.00 |
| Methane | $CH_4$ | lt | 0.00 | 20.00 | 0.00 |

*Table 28. Activity data related to the LNS's fugitive emissions*

| System | Gas | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| Firefighting system | IG-541 (40% Ar + 52% N + 8% $CO_2$) | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 110 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 38 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 38 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 110 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 110 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 110 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| CLINT- Capacity tot kg 19 | R-410A | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 312 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| DAIKIN- Capacity tot kg 312 | R-134a | kg | 0.00 | 0.00 | 0.00 |
| YORK- Capacity tot kg 11,4 | R-407C | kg | 0.00 | 11.40 | 0.00 |
| CLIMAVENETA- Capacity tot kg 13.2 | R-410A | kg | 0.00 | 13.20 | 0.00 |
| CLINT- Capacity tot kg 19 | R-425B | kg | 0.00 | 0.00 | 0.00 |
| CLIMAVENETA- Capacity tot kg 74 | R-410A | kg | 0.00 | 0.00 | 0.00 |
| RHOSS- Capacity tot kg 48 | R-410A | kg | 0.00 | 0.00 | 0.00 |
| Gas mixtures used for experiments | | | | | |
| Electrostatic particle accelerator restoration | $SF_6$ | mc | 27.0 | 50.0 | 45 |
| Lab. Numen | Isobutane | kg | 11.00 | 11.00 | 11.00 |
| Lab. Radiobiologia | CO2 | kg | 120.00 | 120.00 | 120.00 |

*Table 29. Activity data related to the CNAF's fugitive emissions*

| System | Capacity | Gas | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|
| CDZ Uffici - FUJITSU | 14 | R410a | kg | 0.00 | 0.00 | 0.00 |
| CDZ Stanza 45 -EMERSON HPSE06 | 7,7 | R407c | kg | 0.00 | 0.00 | 0.00 |
| CDZ sala trafo -LIEBERT M47OA | 60 | R407c | kg | 0.00 | 0.00 | 0.00 |
| Chiller - EMERSON SRH032 | 432 | R407c | kg | 0.00 | 0.00 | 0.00 |
| Firefighting system | 1393,6 | R-227ea | kg | 696.80 | 0.00 | 0.00 |

### 5.2.2. Scope 2 – Electricity indirect GHG emissions

The activity data related to indirect emissions from imported energy refer to the electricity consumption in the five laboratories. The consumption data were extracted from management systems and corporate accounts and are based on the quantities billed by the supplier. For the data refer to Table 10 and following, while below is the information on the main electricity supplier for each laboratory. For each supplier, the energy mix published on its website was taken as the reference[1].

*Table 30. Electricity supplier for each laboratory and its emission factor.*

| Laboratory | 2021 | 2022 | 2023 |
|---|---|---|---|
| LNF | HERA<br>HT: 244.23 $gCO_2$/kWh | HERA<br>HT: 296.71 $gCO_2$/kWh | HERA<br>HT: 296.71 $gCO_2$/kWh |
| LNGS | AGSM<br>MT: 285.97 $gCO_2$/kWh | A2A<br>MT: 336.61 $gCO_2$/kWh | A2A<br>MT: 336.61 $gCO_2$/kWh |
| LNL | Enel<br>HT: 227.09 $gCO_2$/kWh | Enel<br>HT: 247.34 $gCO_2$/kWh | Enel<br>HT: 247.34 $gCO_2$/kWh |
| LNS | HERA<br>MT: 253.88 $gCO_2$/kWh | HERA<br>MT: 308.43 $gCO_2$/kWh | HERA<br>MT: 308.43 $gCO_2$/kWh |
| CNAF | A2A<br>MT: 249.47 $gCO_2$/kWh | A2A<br>MT: 248.29 $gCO_2$/kWh | Enel<br>MT: 257.11 $gCO_2$/kWh |

## 5.3. RESULTS

This paragraph presents the main results of the quantification of greenhouse gas emissions. The results are first presented in aggregate form as the sum of the four laboratories and the national centre, and then in detail for each site. The emissions inventory does not include biogenic emissions, nor does it account for absorption or storage.

Total emissions are reported in both absolute and relative terms in the table below.

*Table 31. Total emissions [ton $CO_2e$].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Direct GHG emissions (SCOPE 1) | 21 874 | 61% | 60 419 | 82% | 66 264 | 80% |
| Electricity indirect GHG emissions (SCOPE 2)[2] | 13 888 | 39% | 13 468 | 18% | 16 171 | 20% |
| **TOTAL** | **35 762** | | **73 888** | | **82 435** | |

There is a clear upward trend in total GHG emissions over the three years, with the total almost doubling from 2021 to 2022 and continuing to rise in 2023 (Figure 13). The direct GHG emissions (Scope 1) have seen a significant rise each year, growing from 21 874 tons in 2021 to 66 265 tons in 2023. The electricity indirect GHG emissions (Scope 2) initially decreased slightly in 2022 compared to 2021, but then increased in 2023.

[1] Due to the lack of publication of suppliers' energy mix related to 2023, energy mixes from the previous year were used.

[2] For the calculation of electricity indirect GHG emissions, the market-based methodology was used as a reference.

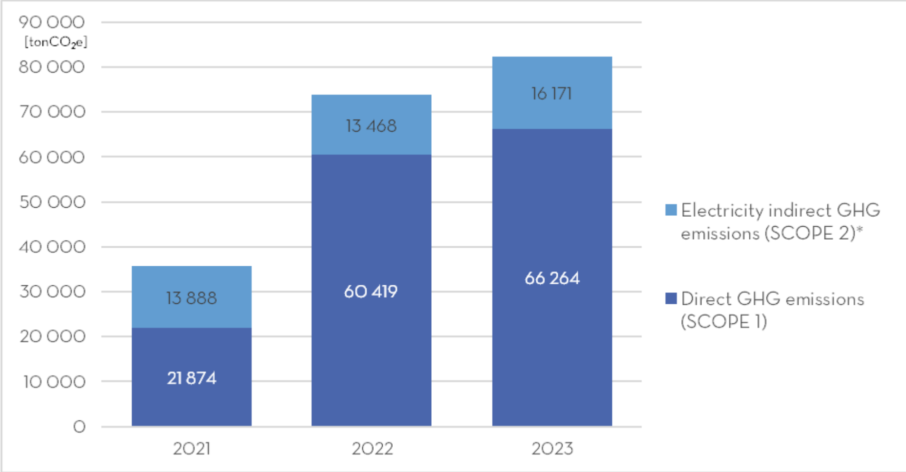


*Figure 13. Trend of total GHG emissions in absolute value over the three-year period [ton $CO_2e$].*

Analysing the distribution among the emission categories, it appears that the main category is direct emissions (or Scope 1). In addition, despite the annual fluctuations, the percentage share of Scope 2 emissions decreased significantly from 39% in 2021 to 18% in 2022 and then slightly increased to 20% in 2023.

The details and impact of the different emission categories are shown below.

**Direct GHG emissions (Scope 1)**

Table 32 shows that 'Direct fugitive emissions' are the predominant source of direct GHG emissions, consistently making up 94-98% of the total direct emissions over the three years. Emissions from stationary combustion show a declining trend from 1 371 tons in 2021 to 1 136 tons in 2022, and further to 1 088 tons in 2023. Emissions from mobile combustion are minimal and relatively stable, fluctuating slightly from 12 tons in 2021 to 14 tons in 2022 and then to 13 tons in 2023, representing on average 0.03% of total direct emissions.

*Table 32. Total direct GHG emissions (Scope 1) [ton $CO_2e$].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Direct emissions from stationary combustion | 1 371 | 6% | 1 136 | 2% | 1 088 | 2% |
| Direct emissions from mobile combustion | 12 | 0% | 13 | 0% | 13 | 0% |
| Direct process emissions and removals arise from industrial process | - | - | - | - | - | - |
| Direct fugitive emissions arise from the release of GHG in anthropogenic systems | 20 491 | 94% | 59 270 | 98% | 65 163 | 98% |
| Direct emissions and removals from Land Use, Land Use Change and Forestry | - | - | - | - | - | - |
| **TOTAL** | **21 874** | | **60 419** | | **66 264** | |

Overall, the increase in total direct emissions is driven primarily by the significant rise in fugitive emissions (Figure 14). Fugitive emissions constitute the largest share of direct emissions, increasing significantly from 20 491 tons in 2021 to 59 270 tons in 2022, and further to 65 163 tons in 2023.

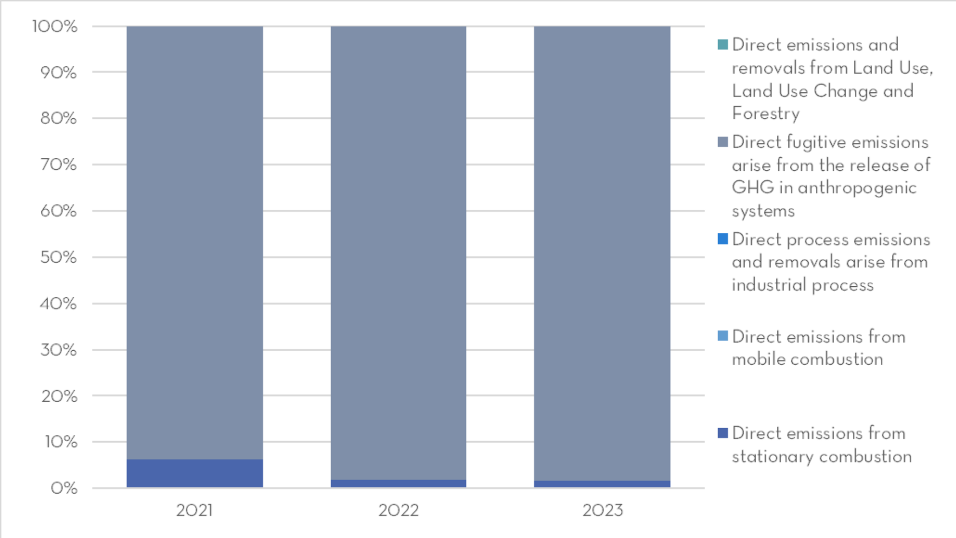


*Figure 14. Breakdown of indirect GHG emissions in relation to total emissions over the three-year period.*

Table 33 shows direct fugitive emissions arise from the release of GHG broken down by different gases in the years 2021 to 2023.

*Table 33. Direct fugitive emissions arise from the release of GHG in anthropogenic systems [ton $CO_2e$].*

| | 2021 | 2022 | 2023 |
|---|---|---|---|
| $C_4H_{10}$ | 6.60E-05 | 6.60E-05 | 6.60E-05 |
| $CF_4$ | 4.32E+02 | 4.33E+02 | 4.32E+02 |
| $CH_4$ | 0.00E+00 | 4.27E-04 | 0.00E+00 |
| $CO_2$ | 1.20E-01 | 1.76E-01 | 1.48E-01 |
| Experimental gas mixtures | 2.42E-01 | 3.07E-01 | 6.72E-05 |
| Hydrostar gas | 7.44E-03 | 1.49E-02 | 0.00E+00 |
| R-134a | 5.05E+01 | 1.04E+02 | 5.05E+01 |
| R-227ea | 2.51E+03 | 0.00E+00 | 0.00E+00 |
| R-407C | 2.23E+02 | 2.75E+01 | 7.63E+00 |
| R-410A | 6.99E+01 | 5.68E+01 | 0.00E+00 |
| R-448A | 4.93E+01 | 0.00E+00 | 0.00E+00 |
| $SF_6$ | 1.72E+04 | 5.86E+04 | 6.47E+04 |
| **TOTAL** | **2.25E+04** | **6.13E+04** | **6.72E+04** |

Notably, SF6 emissions have increased dramatically over the three years, accounting for an average of 90 percent of the total impacts, while emissions of CF4 and R134a show stability with minor fluctuations. Emissions of R-227ea, R-407C, R410A, and R-448A have decreased, while several gases registered a very low carbon footprint over the three years.

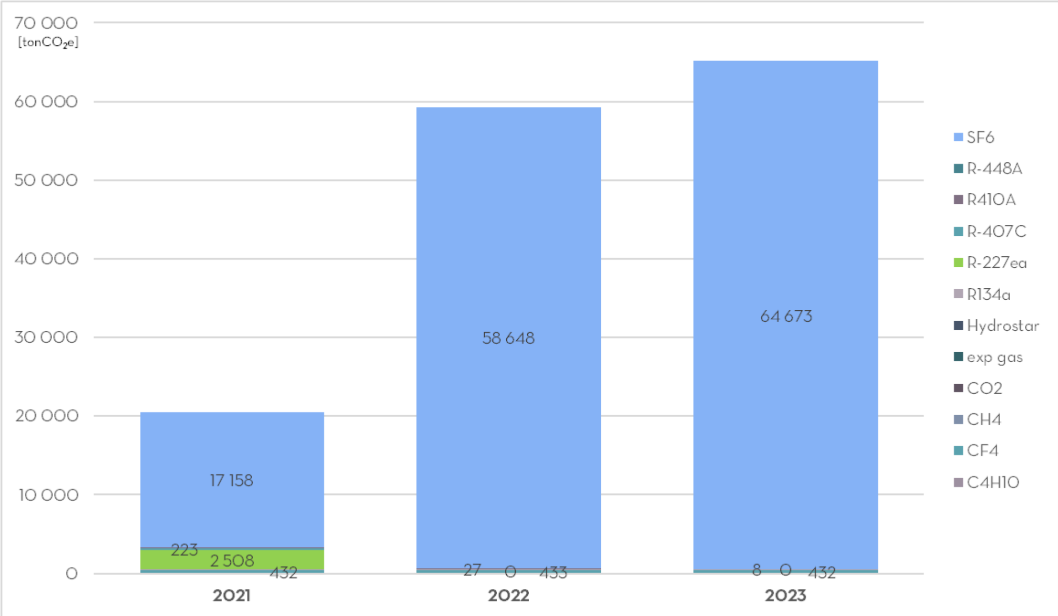


*Figure 15. Trend of the direct fugitive emissions arise from the release of GHG over the three-year period [ton $CO_2e$].*

### Electricity indirect GHG emissions (Scope 2)

For the indirect emissions related to electricity consumption, the results of the calculations are provided according to both the market-based and location-based methodologies, in addition to the category related to energy imports, which is zero for all sites.

Concerning the market-based approach, there is a slight decline in emissions from 2021 to 2022, followed by an increase in 2023. In contrast, location-based emissions show a consistent slight increase each year from 2021 to 2023 of about 2%.

*Table 34. Total electricity indirect GHG emissions (Scope 2) [ton $CO_2e$].*

| | 2021 | 2022 | 2023 |
|---|---|---|---|
| Indirect emissions from imported electricity (market-based approach) | 13 888 | 13 468 | 16 171 |
| Indirect emissions from imported electricity (location-based approach) | 15 107 | 15 511 | 15 761 |
| Indirect emissions from imported energy | 0 | 0 | 0 |

These differences in emission trends are related to the variability of emission factors associated with the electricity sources chosen in the market. The market-based approach often leads to more greenhouse gas emissions than the location-based approach. This is because the energy mixes of suppliers often have a lower renewable energy component and a higher fossil source generation component than the national energy mix.

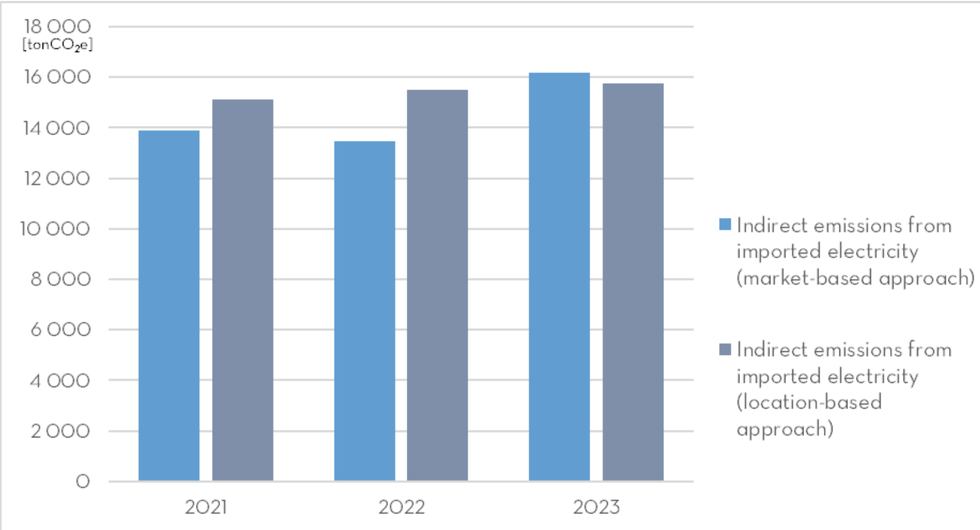


*Figure 16. Trend of electricity indirect GHG emissions (Scope 2) over the three-year period [ton $CO_2e$].*

### 5.3.1. Insights by site

Table 35 shows the contribution of each facility to total GHG emissions in both absolute and relative terms. Overall, LNL stands out with a dramatic increase in emissions, becoming the primary contributor to the overall rise in total emissions. This trend is largely due to the contribution of SF6 gas emissions. While these emissions are not directly linked to the operation of the electrostatic accelerators, they become significant during maintenance procedures. Indeed, maintenance activities often involve processes that can result in the inadvertent release of SF6, leading to a noticeable increase in emissions. The other laboratories show varying trends, with some increases and decreases, but none as pronounced as LNL.

*Table 35. Total emissions by facilities [ton $CO_2e$].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| LNF | 6 493 | 18% | 5 434 | 7% | 7 106 | 9% |
| LNGS | 3 275 | 9% | 2 784 | 4% | 2 922 | 4% |
| LNL | 15 769 | 44% | 54 576 | 74% | 61 949 | 75% |
| LNS | 5 782 | 16% | 9 084 | 12% | 8 324 | 10% |
| CNAF | 4 443 | 12% | 2 009 | 3% | 2 135 | 3% |
| **TOTAL** | **35 762** | | **73 888** | | **82 435** | |

Figure 17 highlights LNL's increasing dominance in total emissions, while the other laboratories, particularly LNF, LNGS, LNS, and CNAF, have seen a decrease in their relative contributions over the same period. In detail:

- the percentage of total emissions from LNL increased dramatically from 44% in 2021 to 74% in 2022 and then slightly to 75% in 2023.
- the percentage of total emissions from LNS decreased from 16% in 2021 to 12% in 2022, and further to 10% in 2023.
- the percentage of total emissions from LNF decreased significantly from 18% in 2021 to 7% in 2022, then slightly increased to 9% in 2023.
- the percentage of total emissions from LNGS consistently decreased from 9% in 2021 to 4% in both 2022 and 2023.
- the percentage of total emissions from CNAF dropped from 12% in 2021 to 3% in both 2022 and 2023.

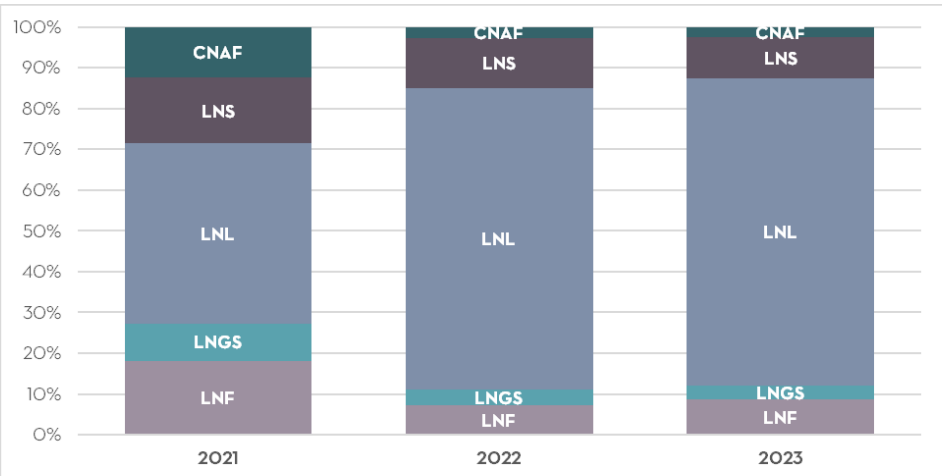


*Figure 17. Breakdown of total greenhouse gas emissions for facilities over the three-year period.*

• **LNF**

In LNF, indirect emissions from electricity consumption account for the main fraction, averaging 85% of total laboratory GHG emissions. The rest of the emissions are associated with fugitive emissions and a negligible quota is associated to emissions from stationary sources. As regard indirect emissions from imported electricity (Market-Based Approach), emissions decreased from 2021 to 2022 but increased again in 2023, surpassing the levels of the previous two years. In the same period, the fugitive emissions saw a notable decrease from 2021 to 2022, and remained stable in 2023, while emissions from stationary combustion have decreased significantly from 2021 to 2022, with a slight further reduction in 2023.

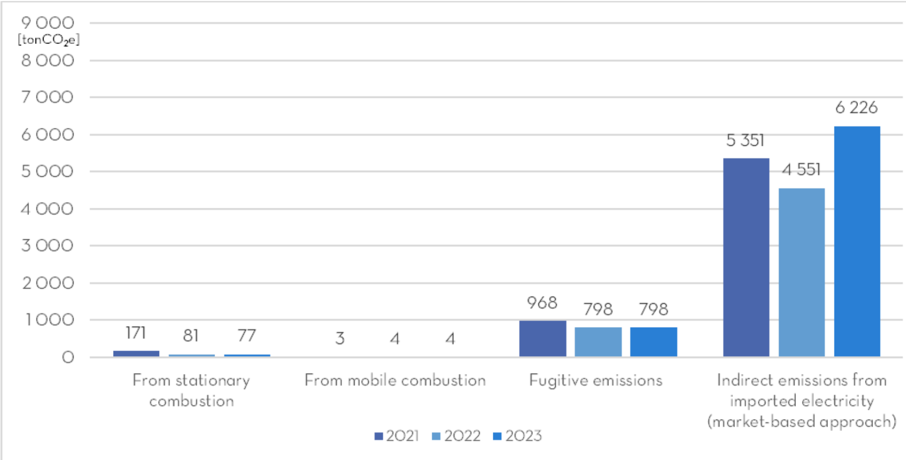


*Figure 18. Trend of emission categories over the three-year period of LNF [ton $CO_2$e].*

• **LNGS**

In LNGS, a similar pattern to LNF is found. Indirect emissions from imported electricity account for the majority of the laboratory's total emissions while direct emissions from stationary combustion a much smaller share.

Analysing the trends, there is a general decrease in indirect emissions from imported electricity from 2 777 in 2021 to 2 366 in 2022, followed by a slight increase to 2 440 ton$CO_2$e in 2023. As regard direct emissions from stationary combustion, there was a reduction from 2021 to 2022, but a slight rise in 2023. The emissions from stationary combustion are increasing year over year. The data shows a steady rise from 396 in 2021 to 477 ton$CO_2$e in 2023.

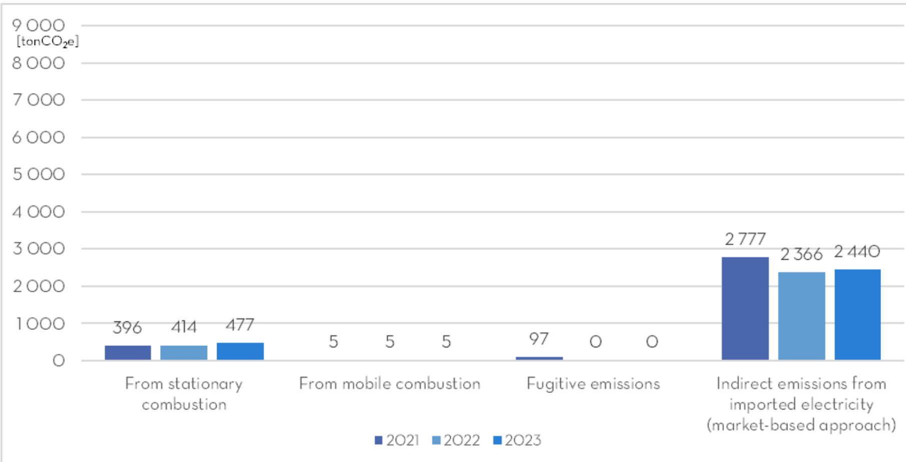


*Figure 19. Trend of emission categories over the three-year period of LNGS [ton $CO_2$e].*

**• LNL**

The category with the largest impacts in LNL is the fugitive emissions category due to the large amounts of $SF_6$ leaked from laboratory equipment. The other categories account for a smaller fraction of the total, although in absolute value they are comparable with emissions of the other laboratories.

Analysing the progress over the 3-year period shows that fugitive emissions show a substantial increase over the years. Starting from 12 712 in 2021, they rose sharply to 50 632 in 2022 and further increased to 57 356 ton$CO_2$e in 2023. However, leakage represent on average 4.3% during the three-year period under consideration, which is lower than the average value from the literature (5÷7%) of leakage due to electrostatic particle accelerator restoration (IPCC 2006).

Indirect emissions from imported electricity have also been increasing steadily. The emissions grew from 2 390 in 2021 to 4 157 ton$CO_2$e in 2023. Finally, there is a noticeable decrease in emissions from stationary combustion over the three years. Emissions dropped from 665 in 2021 to 434 ton$CO_2$e in 2023, indicating a significant reduction in this category.

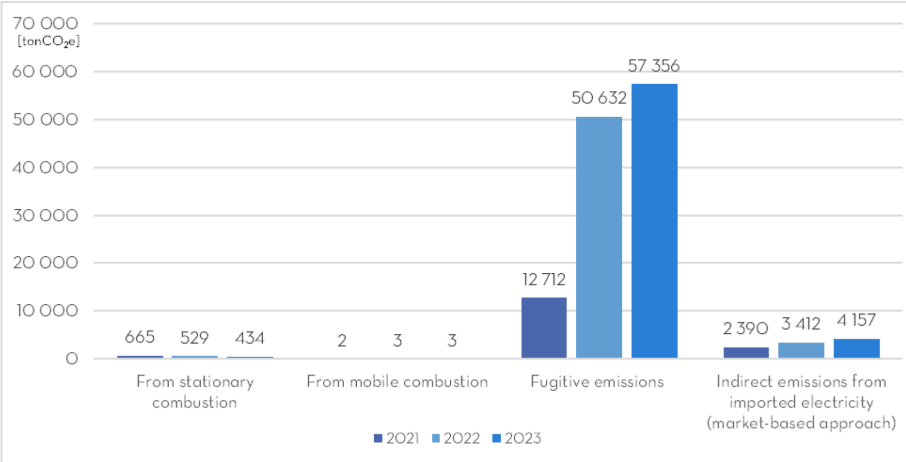


*Figure 20. Trend of emission categories over the three-year period of LNL [ton $CO_2$e].*

**• LNS**

Even in LNS the main category is fugitive emissions due to the release of $SF_6$ following the shutdown of some experimental activities. In the three-year period, fugitive emissions increased significantly from 4 206 in 2021 to 7 840 in 2022, then decreased slightly to 7 009 ton$CO_2$e in 2023. Indirect emissions from imported electricity decreased from 1 461 in 2021 to 1 135 in 2022 but then increased slightly to 1 220 ton$CO_2$e in 2023; and there is a steady decrease in emissions from stationary combustion over the three years.

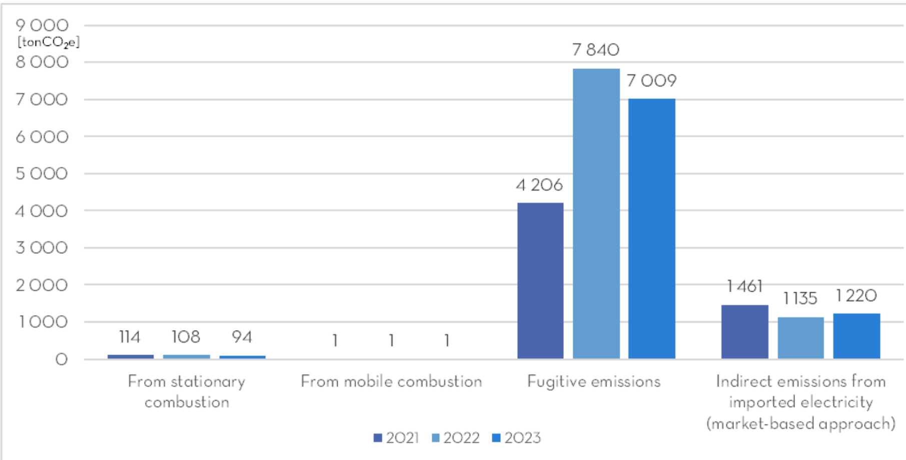


*Figure 21. Trend of emission categories over the three-year period of LNS [ton $CO_2$e].*

**• CNAF**

At CNAF, the main emission category is due to electricity consumption. Indirect emissions from imported electricity have been steadily increasing over the three years (average +5.6 % per year), rising from 1 909 in 2021 to 2 128 ton$CO_2$e in 2023.

Except for the peak in fugitive emissions in 2021 due to an outbreak of fire caused by a short circuit that ignited the firefighting system, the other categories have a negligible impact. In addition, emissions from stationary combustion show a dramatic decrease from 25 in 2021 to 3 in 2022, followed by a slight increase to 6 ton$CO_2$e in 2023.

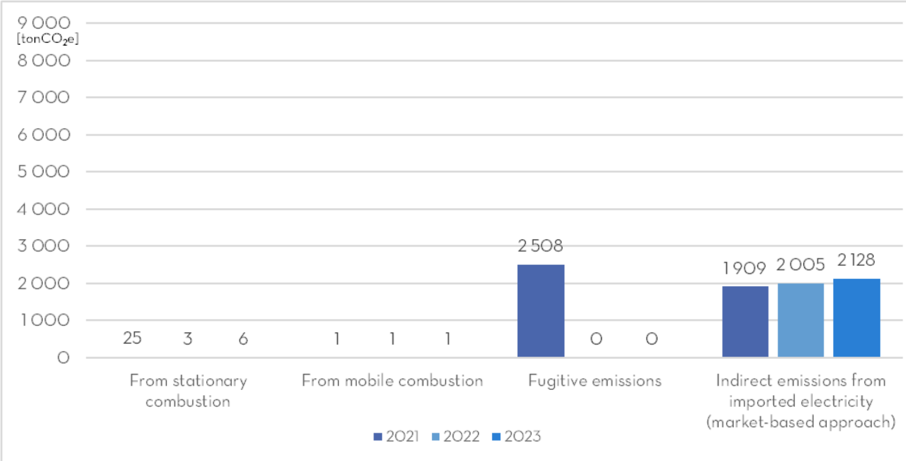


*Figure 22. Trend of emission categories over the three-year period of CNAF [ton $CO_2$e].*

## 5.4. INTERPRETATION

### 5.4.1. Uncertainty assessment

In accordance with the GHG protocol and as stipulated by ISO 14064-1, an assessment of uncertainty for GHG emissions and removals, including the uncertainty associated with emission and removal factors, has been conducted.

Specifically, the overall uncertainty associated with each emission category included within the GHG inventory has been evaluated using qualitative criteria, to which a corresponding numerical score has been assigned. Given that uncertainties of individual parameters are largely unknown, the Pedigree Matrix approach has been employed. This approach relies on a matrix composed of five data quality indicators:

- Precision
- Completeness
- Temporal representativeness
- Geographical representativeness
- Technological representativeness

In the assessment, an uncertainty factor is assigned to each of the five data quality indicators using four data quality criteria (very good, good, fair, poor). These uncertainty factors are then used to calculate the square of the geometric standard deviation.

With this approach, the results of the qualitative data assessment are utilized to relate the data quality indicators to the uncertainty intervals of individual parameters. The results of the data quality assessment for activity data and emission factors are then separately translated and ultimately analysed together to assess the propagation of parameter uncertainty.

Below is the detail of the assessment of the various indicators for each emission category, divided by activity data and emission factors.

| | Activity Data | | | | |
|---|---|---|---|---|---|
| | Reliability / Precision | Completeness | Temporal Representativeness | Geographic Representativeness | Technological Representativeness |
| Direct emissions from stationary combustion | Very Good | Very Good | Very Good | Very Good | Very Good |
| Direct emissions from mobile combustion | Very Good | Very Good | Very Good | Very Good | Very Good |
| Direct process emissions and removals arise from industrial process | Fair | Fair | Fair | Fair | Fair |
| Direct fugitive emissions arise from the release of GHG in anthropogenic | Very Good | Very Good | Very Good | Very Good | Very Good |
| Direct emissions and removals from Land Use, Land Use Change and Forestry | Fair | Fair | Fair | Fair | Fair |
| Indirect emissions from imported electricity (market-based approach) | Very Good | Very Good | Very Good | Very Good | Very Good |
| Indirect emissions from imported energy | Fair | Fair | Fair | Fair | Fair |

| | Emission Factor | | | | |
|---|---|---|---|---|---|
| | Reliability / Precision | Completeness | Temporal Representativeness | Geographic Representativeness | Technological Representativeness |
| Direct emissions from stationary combustion | Very Good | Very Good | Very Good | Very Good | Very Good |
| Direct emissions from mobile combustion | Very Good | Very Good | Very Good | Very Good | Very Good |
| Direct process emissions and removals arise from industrial process | Fair | Fair | Fair | Fair | Fair |
| Direct fugitive emissions arise from the release of GHG in anthropogenic | Very Good | Very Good | Very Good | Very Good | Very Good |
| Direct emissions and removals from Land Use, Land Use Change and Forestry | Fair | Fair | Fair | Fair | Fair |
| Indirect emissions from imported electricity (market-based approach) | Good | Very Good | Very Good | Very Good | Very Good |
| Indirect emissions from imported energy | Fair | Fair | Fair | Fair | Fair |

The result of the analysis of the total uncertainty of the carbon footprint, expressed as a 95% confidence interval, using the square of the geometric standard deviation, is shown in the Figure below. The blue column represents the carbon footprint result for the year 2023, while the uncertainty is represented by the error bar. The combination of these values gives rise to a range of carbon footprint values ranging from 77 694 to 87 466 tons $CO_2$e.

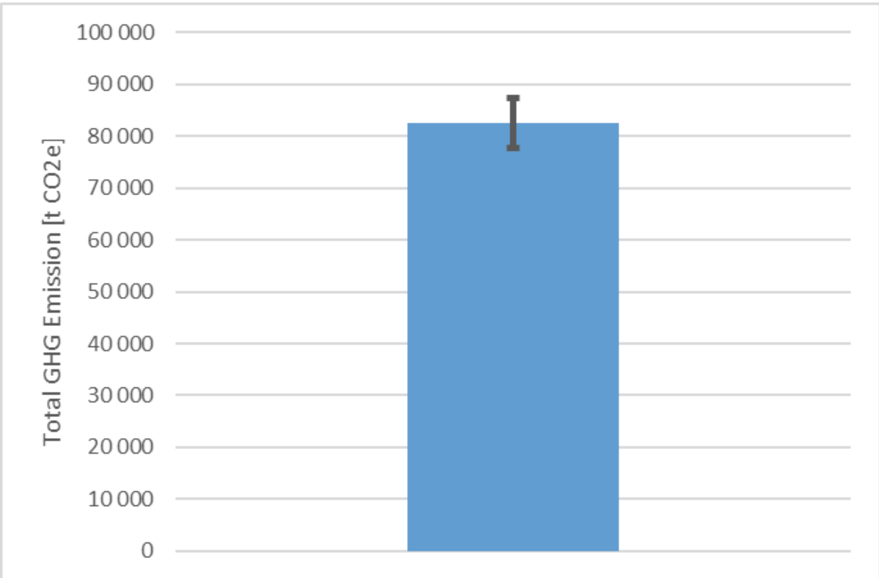


*Figure 23. Carbon footprint and uncertainty analysis of INFN (2023) [ton $CO_2$e].*

# 6. WATER FOOTPRINT

The water footprint is a measure of the total volume of freshwater used to support the operations of an organization, including both direct and indirect consumption. For the purpose of this analysis, we will focus on the direct water footprint, which pertains to the actual volume of freshwater directly consumed by the facilities for various activities, such as cooling, laboratory processes, and domestic uses.

## 6.1. METHODOLOGY

To measure the direct water footprint, a few main parameters describing the INFN's use of water resources were chosen. The indicators concern to the total volume of water consumed and the sources of supply. Specifically, the percentage of water sourced from sustainable supplies and the percentage of water extracted from local sources provide valuable insights into the impact of various facilities on water resources and their capacity to adapt to potential changes in water availability. Finally, to monitor the environmental impact of water discharge and ensure compliance with current regulations, wastewater management was also monitored. In detail:

- **Total annual water consumption:** measured in cubic meters, this indicator provides a direct measure of the amount of water used by the facilities over a specific period, allowing for the assessment of any changes in consumption over time.
- **Sources of supply:** this indicator analyses the proportion of water used that comes from renewable or sustainably managed sources, such as collected rainwater or greywater recycling systems, or from local sources, such as wells or municipal water systems.
- **Total annual water discharge:** this indicator provides a direct measure of the amount of water released into the environment or wastewater treatment systems.
- **Wastewater quality:** assessed through the treatments that wastewater undergoes before being discharged into the receiving body. This indicator helps evaluate the environmental impact of water discharge and compliance with environmental regulations. The treatments are divided into the following categories: no treatment; public sewer and internal wastewater treatment which removes and eliminates contaminants.

## 6.2. RESULTS

Below is the overall water footprint of INFN and the four National Laboratories individually, while CNAF is not included since it has no water consumption.

The results show that total water consumption has been on an upward trend from 2021 to 2023 (Table 36). The increase is primarily driven by the steady rise in water supply consumption. The consumption increased by approximately 6.4% from 2021 to 2022, and by 12.6% from 2022 to 2023. The data on the usage of groundwater or well water shows a steady upward trend in water intake from groundwater or wells over the three years. From 2021 to 2022, the increase was moderate, with an 8% rise. However, between 2022 and 2023, the intake grew at a faster rate (22.9%), showing an acceleration in water usage.

The Figure 24 shows that water consumption from water supply represents the largest fraction, averaging 98% of the institution's annual consumption.

*Table 36. Water consumption [1] [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| From the water supply | 97 211 | 98% | 103 366 | 98% | 116 120 | 98% |
| From groundwater or well | 2 047 | 2% | 2 211 | 2% | 2 718 | 2% |
| **TOTAL** | **99 258** | | **105 577** | | **118 838** | |

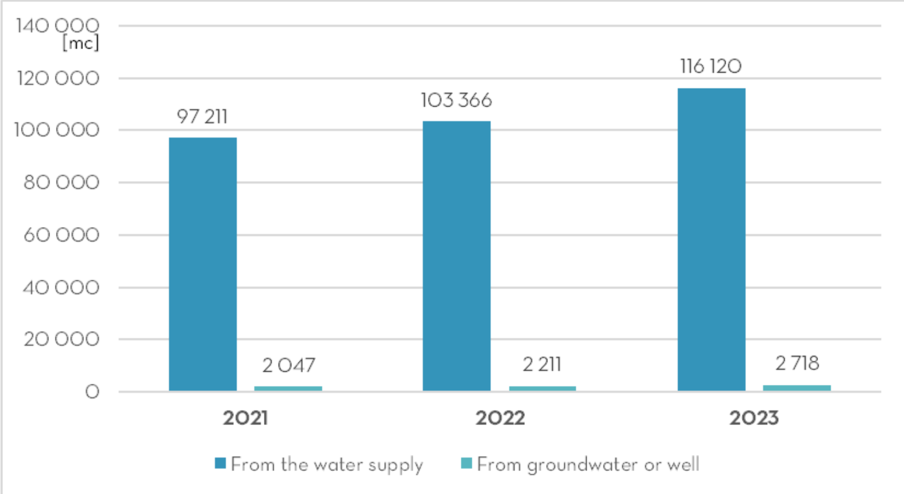


*Figure 24. Total amount of water consumed over the three-year period [mc].*

Regarding wastewater management, the most widely used management is the local wastewater treatment systems (Public sewer), while internal wastewater treatment accounts for an average of 2%. There are no water releases without treatment.

*Table 37. Wastewater management [1] [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| No treatment | 0 | 0% | 0 | 0% | 0 | 0% |
| Public sewer | 97 211 | 98% | 103 366 | 98% | 116 120 | 98% |
| Internal wastewater treatment | 2 047 | 2% | 2 211 | 2% | 2 718 | 2% |
| **TOTAL** | **99 258** | | **105 577** | | **118 838** | |

[1] Provisional data as LNS water consumption is not available.

### 6.2.1. Insights by site

**• LNF**

Table 38 shows the total water supply and the contribution of different sources (water supply and groundwater/well) over three years (2021, 2022, and 2023) in LNF. There is a clear increasing trend in the total water supply: from 2021 to 2022, there was an increase of 7 055 mc (approximately 9% increase) while from 2022 to 2023, the increase was 9 391 mc (approximately 10% increase). Overall, from 2021 to 2023, the total water supply increased by 16 446 mc, which is an overall increase of approximately 20%. The entire water consumption came exclusively from the water supply source, with no contribution from groundwater or wells.

*Table 38. Water consumption by LNF [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| From the water supply | 79 892 | 100% | 86 947 | 100% | 96 338 | 100% |
| From groundwater or well | 0 | 0% | 0 | 0% | 0 | 0% |
| **TOTAL** | **79 892** | | **86 947** | | **96 338** | |

Regarding wastewater management, LNF discharges all wastewater to the local wastewater treatment system (public sewer), which processes it through various processes before releasing it back into receiving bodies of water.

*Table 39. Wastewater management by LNF [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| No treatment | 0 | 0% | 0 | 0% | 0 | 0% |
| Public sewer | 79 892 | 100% | 86 947 | 100% | 96 338 | 100% |
| Internal wastewater treatment | 0 | 0% | 0 | 0% | 0 | 0% |
| **TOTAL** | **79 892** | | **86 947** | | **96 338** | |

**• LNGS**

The water footprint of LNGS is due to the consumption of both water from the water supply and from groundwater or well, and is primarily related to the sanitary services of the facilities. The Table 40 provides data for the last three years.

Overall, the total water consumption at LNGS has shown a steady increase year over year. From 2021 to 2022, there was an increase of 23.7%, and from 2022 to 2023, the increase was 23.6%. The most significant contributor to this increase is the consumption from water supply, which has shown substantial growth each year. The usage increased by 25.7% from 2021 to 2022 and by 24.2% from 2022 to 2023. Water consumption from groundwater or well has remained more stable but also saw an increase in 2023 (15.3% from 2022 to 2023).

*Table 40. Water consumption by LNGS [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| From the water supply | 6 371 | 92% | 8 010 | 94% | 9 948 | 94% |
| From groundwater or well | 528 | 8% | 524 | 6% | 604 | 6% |
| **TOTAL** | **6 899** | | **8 534** | | **10 552** | |

It should be noted that the water consumption from groundwater or well is a small portion of the water that comes from the collection of rock water (approximately 100 liters per second) that percolates through the walls and therefore does not have the appropriate characteristics to be considered potable. The collection does not result in an increase in the extraction from the aquifer but solely utilizes the flow of water that, due to the excavations for the construction of the tunnel, would have been destined for removal, treatment, and discharge into a suitable receiving water body. Most of this water is used within the laboratories for cooling experimental equipment, taking advantage of its naturally low temperature (approximately 6 °C), making them more energy efficient.

*Table 41. Process water used by LNGS [mc].*

| | 2021 | 2022 | 2023 |
|---|---|---|---|
| From groundwater or well | 1 260 912 | 1 260 916 | 1 260 836 |

The management of wastewater reflects the water consumption. The water drawn from groundwater or well (in the internal laboratories), after use, is purified in a biological treatment plant with activated sludge and forced oxidation and then discharged into the receiving water body. Conversely, the water drawn from the water supply (in the external laboratories) is disposed of through the local wastewater treatment.

*Table 42. Wastewater management by LNGS [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| No treatment | 0 | 0% | 0 | 0% | 0 | 0% |
| Public sewer | 6 371 | 92% | 8 010 | 94% | 9 948 | 94% |
| Internal wastewater treatment | 528 | 8% | 524 | 6% | 604 | 6% |
| **TOTAL** | **6 899** | | **8 534** | | **10 552** | |

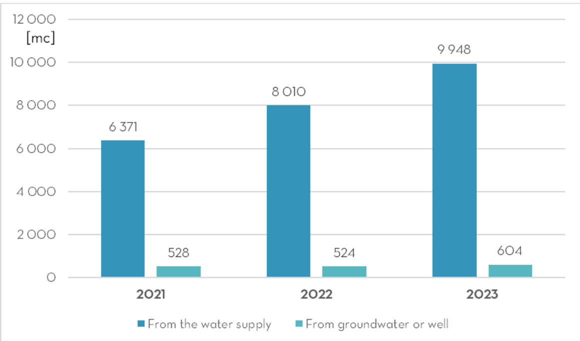


*Figure 25. Total amount of water consumed over the three-year period by LNGS [mc].*

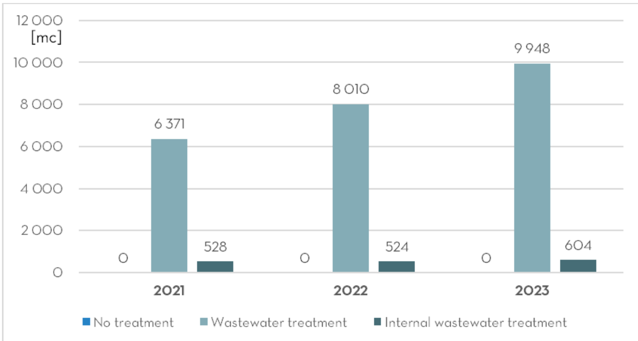


*Figure 26. Total amount of water treatment over the three-year period by LNGS [mc].*

• **LNL**

The tables below show the LNL's water footprint. The consumption of water from the supply has shown some fluctuations over the three years. There is a noticeable decrease from 10 948 in 2021 to 8 409 in 2022, followed by an increase to 9 834 mc in 2023. Despite the rebound in 2023, the overall trend shows a decline from 2021 to 2023. In contrast, the consumption of groundwater or well water has been steadily increasing each year. Starting from 1 519 in 2021, it rose to 1 687 in 2022 and further to 2 114 mc in 2023.

*Table 43. Water consumption by LNL [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| From the water supply | 10 948 | 88% | 8 409 | 83% | 9 834 | 82% |
| From groundwater or well | 1 519 | 12% | 1 687 | 17% | 2 114 | 18% |
| **TOTAL** | **12 467** | | **10 096** | | **11 948** | |

Wastewater management is strictly dependent on the type of water source. Wastewater from water supply is discharged through the local wastewater treatment (public sewer) while wastewater from wells is treated internally through a wastewater treatment system before discharge to the receiving body.

*Table 44. Wastewater management by LNL [mc].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| No treatment | 0 | 0% | 0 | 0% | 0 | 0% |
| Public sewer | 10 948 | 88% | 8 409 | 83% | 9 834 | 82% |
| Internal wastewater treatment | 1 519 | 12% | 1 687 | 17% | 2 114 | 18% |
| **TOTAL** | **12 467** | | **10 096** | | **11 948** | |

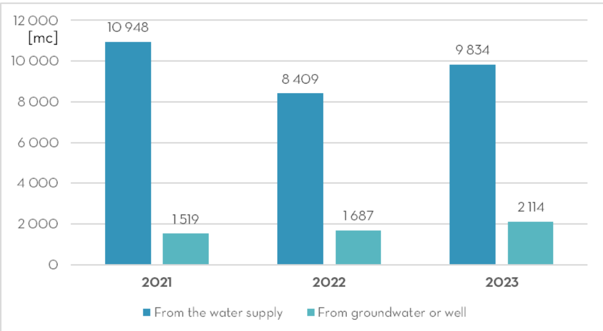


*Figure 27. Total amount of water consumed over the three-year period by LNL [mc].*

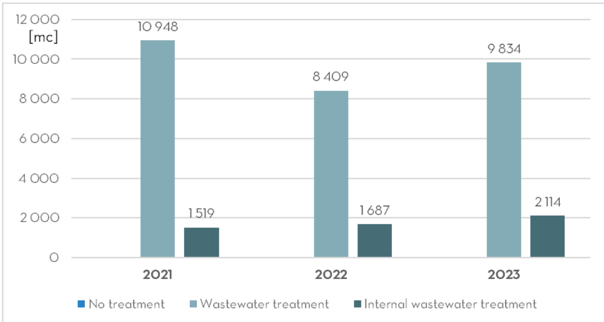


*Figure 28. Total amount of water treatment over the three-year period by LNL [mc].*

• **LNS**

The unavailability of data on the consumption of water from the public water supply system did not allow the evaluation of the LNS's water footprint.

# 7. WASTE

This chapter provides an analysis of the issue of waste and its management within the research laboratories and the national centre in Bologna.

Waste not only represents a disposal problem but also has significant impacts on the environment, including air, water, and soil pollution, as well as the loss of valuable resources. In this context, the concept of a circular economy emerges as a fundamental solution to mitigate the negative impacts of waste and promote sustainable resource management.

## 7.1. METHODOLOGY

To evaluate the effectiveness of environmental policies and to monitor progress towards sustainability in the laboratories and the national centre, appropriate indicators were identified to analyse waste production and management.

Two main indicators have been identified about waste generation:

- **Non-Hazardous Waste**
- **Hazardous Waste**

The first indicator is the annual tonnage of non-hazardous waste produced. Monitoring the total amount of non-hazardous waste is essential for understanding the environmental impact of research activities. Likewise, for hazardous waste, the main indicator is the tons of hazardous waste generated annually. Hazardous waste poses greater risks to the environment and human health; quantifying its production helps ensure it is managed with necessary precautions.

Regarding waste management, two main indicators have been identified:

- **Waste Recovery**
- **Waste Disposal**

In the domain of waste management, recovery is monitored through the total amount of waste recovered and the percentage of waste recovered out of total waste generated. This measure assesses the effectiveness of recovery and recycling processes, which are crucial for reducing landfill waste and promoting the circular economy. On the other hand, waste disposal management is assessed by the percentage of waste disposed of (in landfills, incineration, etc.) out of the total waste produced. Measuring the proportion of waste disposed of helps assess the reduction in landfill dependency and monitor the environmental impact of disposal activities.

The data collection has been based on the annual declaration that organizations must submit to provide detailed information on the waste produced and managed. The waste register data includes the quantity of waste produced, specified by type (hazardous and non-hazardous), waste management methods (recovery, recycling, reuse, and disposal in landfills, incineration, etc.), and the origin of the waste (industrial, domestic, etc.). For the analysis, waste characterized by code R was included in the recovery indicator, while code D was associated with disposal.

## 7.2. RESULTS

The overall values of the waste generation indicators are presented below (Table 45). In the last three years there is an increase in the volume of waste generated reaching 3 479 tons (Figure 29). This increase was mainly due to the production of non-hazardous waste in the Gran Sasso laboratory.

*Table 45. Waste production [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Non-hazardous waste | 677 139 | 79% | 923 750 | 44% | 3 422 889 | 98% |
| Hazardous waste | 179 737 | 21% | 1 195 037 | 56% | 56 407 | 2% |
| **TOTAL** | **856 876** | | **2 118 787** | | **3 479 296** | |

On the other hand, analysing the composition of waste generated shows a fluctuating trend between hazardous and non-hazardous waste generated by the institute. These fluctuations are due to annual changes in experiments and consequent decommissioning of experimental equipment (Figure 30).

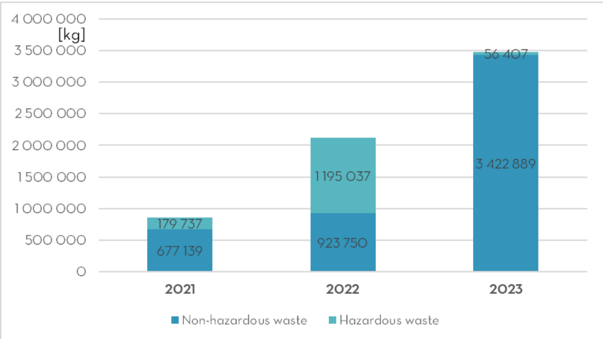


*Figure 29. Total amount of waste generated over the three-year period [kg].*

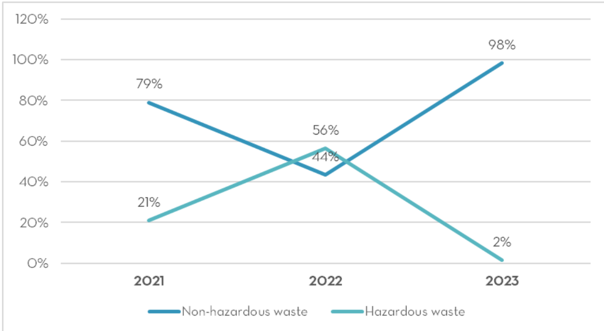


*Figure 30. Percentage of waste produced to total over the three-year period.*

Table 46 shows the annual quantities of waste sent to end-of-life treatment. Again, there is a fluctuating trend between the waste disposed of and waste sent to recycling.

*Table 46. Waste management (end-of-waste) [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Recycling | 240 599 | 28% | 1 375 050 | 65% | 115 203 | 3% |
| Disposal | 616 327 | 72% | 743 977 | 35% | 3 364 092 | 97% |
| **TOTAL** | **856 926** | | **2 119 027** | | **3 479 295** | |

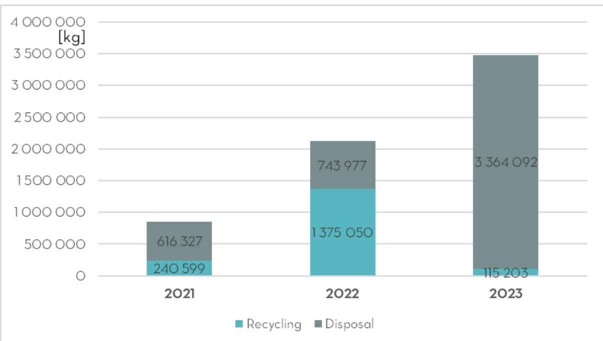


*Figure 31. Total amount of waste treated over the three-year period [kg].*

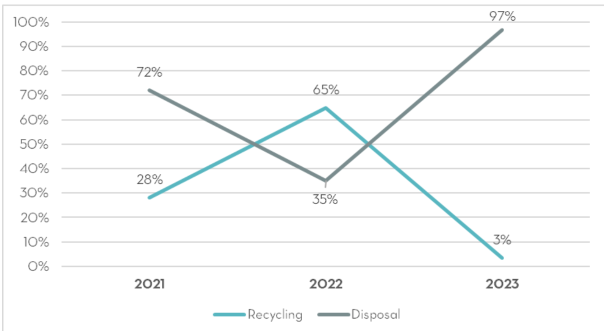


*Figure 32. Percentage of waste treated to total over the three-year period.*

### 7.2.1. Insights by site

**• LNF**

At the Frascati laboratory, there was a reduction in waste generated over the three-year (Table 47). Compared to 2021, total waste decreased by approximately 6% in 2022 and 3% in 2023. Hazardous waste increased slightly but represents a small portion of the total and is attributable to demolition and decontamination works conducted on a site area in 2022 and 2023.

*Table 47. Waste production by LNF [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Non-hazardous waste | 48 290 | 96% | 44 000 | 93% | 44 056 | 90% |
| Hazardous waste | 1 985 | 4% | 3 305 | 7% | 4 880 | 10% |
| **TOTAL** | **50 275** | | **47 305** | | **48 936** | |

*Table 48. Waste management (end-of-waste) by LNF [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Recycling | 49 245 | 98% | 44 440 | 93% | 48 226 | 99% |
| Disposal | 1 080 | 2% | 3 105 | 7% | 710 | 1% |
| **TOTAL** | **50 325** | | **47 545** | | **48 936** | |

An analysis of end-of-life management reveals that most of the waste is sent to treatment centres for subsequent recovery and recycling of materials (Table 48). On average, 97% of all waste produced is recycled, while the remaining portion is sent to landfills.

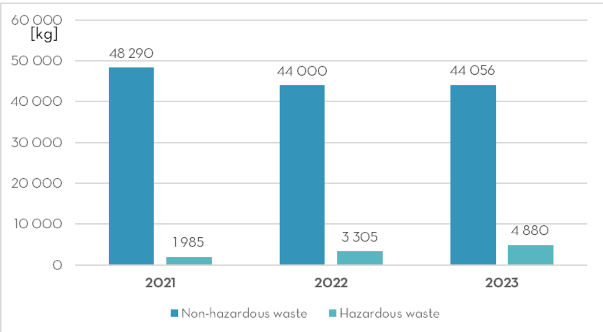


*Figure 33. Total amount of waste generated over the three-year period by LNF [kg].*

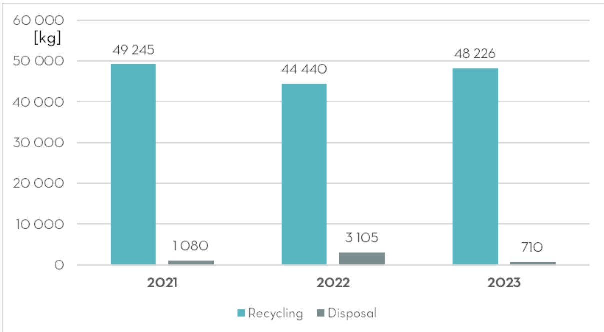


*Figure 34. Total amount of waste treated over the three-year period by LNF [kg].*

**• LNGS**

Analyses indicate a significant increase in waste production at the Gran Sasso laboratory, particularly in the last two years (Table 49). This increase is due to the decommissioning of the Borexino experiment, which began in October 2021 and has contributed to the rise in non-hazardous waste destined for disposal. Specifically, this waste includes the disposal of pseudocumene contained within the experiment, the disposal of the pseudocumene/trimethyl borate mixture with a 95/5 mixing ratio, and the disposal of wastewater from the tanks located in Hall A, which were filled for load test operations for maintenance on the overhead crane located in Hall C and Hall B.

*Table 49. Waste production by LNGS [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Non-hazardous waste | 424 145 | 81% | 607 696 | 35% | 3 237 842 | 100% |
| Hazardous waste | 98 952 | 19% | 1 143 614 | 65% | 14 899 | 0% |
| **TOTAL** | **523 097** | | **1 751 310** | | **3 252 741** | |

*Table 50. Waste management (end-of-waste) by LNGS [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Recycling | 136 125 | 26% | 1 170 016 | 67% | 39 226 | 1% |
| Disposal | 386 972 | 74% | 581 294 | 33% | 3 213 514 | 99% |
| **TOTAL** | **523 097** | | **1 751 310** | | **3 252 740** | |

Regarding end-of-life waste management, it emerges that the majority of waste produced from the decommissioning of the Borexino experiment has been sent for disposal (Table 50).

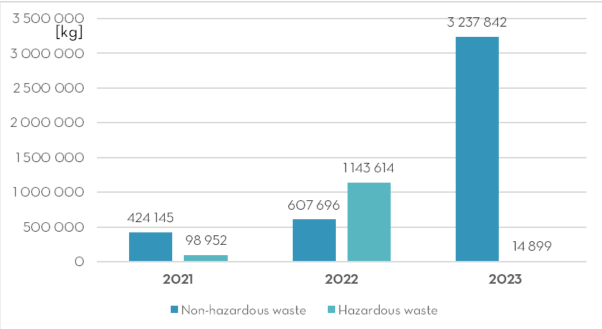


*Figure 35. Total amount of waste generated over the three-year period by LNGS [kg].*

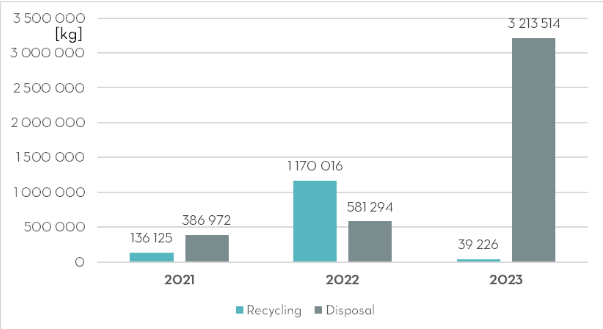


*Figure 36. Total amount of waste treated over the three-year period by LNGS [kg].*

• **LNL**

In the laboratory of Legnaro, the total waste produced saw an initial increase in 2022, followed by a substantial decrease in 2023 (Table 51). The trend shows that while non-hazardous waste initially increased both in quantity and as a percentage of the total waste, it later decreased in quantity but still made up a large portion of the total waste. Hazardous waste has been consistently decreasing in quantity, with its percentage of the total waste fluctuating slightly.

*Table 51. Waste production by LNL [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Non-hazardous waste | 199 334 | 72% | 261 654 | 85% | 140 991 | 79% |
| Hazardous waste | 78 000 | 28% | 47 618 | 15% | 36 628 | 21% |
| **TOTAL** | **277 334** | | **309 272** | | **177 619** | |

*Table 52. Waste management (end-of-waste) by LNL [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Recycling | 49 859 | 18% | 150 194 | 49% | 27 751 | 16% |
| Disposal | 227 475 | 82% | 159 078 | 51% | 149 868 | 84% |
| **TOTAL** | **277 334** | | **309 272** | | **177 619** | |

Analysing waste management (Table 52), disposal waste was predominant in 2021 with 227 475 kg (82% of total waste). In 2022, the quantity of disposal waste decreased to 159 078 kg, making up 51% of the total waste, indicating an improvement in waste management with more waste being recycled. In 2023, disposal waste again became predominant with 149 868 kg, constituting 84% of the total waste, reflecting a reversal of the progress made in 2022.

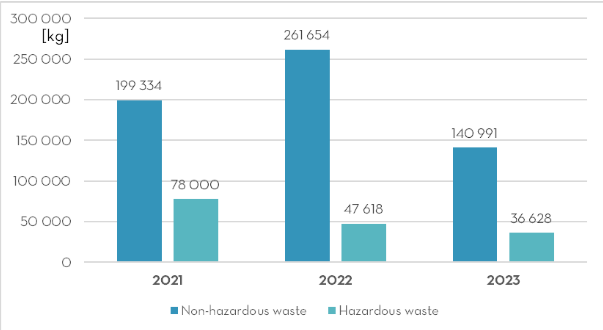


*Figure 37. Total amount of waste generated over the three-year period by LNL [kg].*

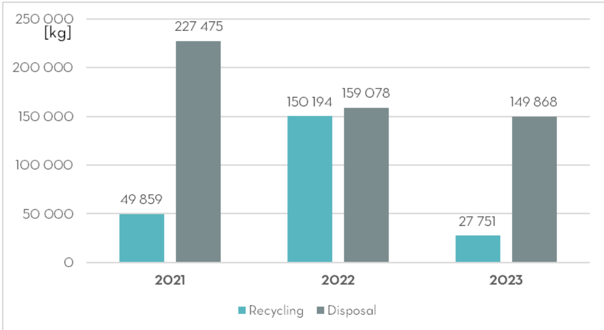


*Figure 38. Total amount of waste treated over the three-year period by LNL [kg].*

**• LNS**

Table 53 shows a reduction in non-hazardous and hazardous waste generation in LNS. In 2022, there was a reduction in both non-hazardous and hazardous waste quantities compared to the previous year, with a notable improvement in the percentage of total waste being recycled. Instead, in 2023, the change in the waste management contract and the transition to the municipal waste management company did not allow the collection of data on waste generated and disposed.

*Table 53. Waste production by LNS [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Non-hazardous waste | 3 500 | 81% | 3 000 | 86% | - | - |
| Hazardous waste | 800 | 19% | 500 | 14% | - | - |
| **TOTAL** | **4 300** | | **3 500** | | **-** | |

*Table 54. Waste management (end-of-waste) by LNS [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Recycling | 3 500 | 81% | 3 000 | 86% | - | - |
| Disposal | 800 | 19% | 500 | 14% | - | - |
| **TOTAL** | **4 300** | | **3 500** | | **-** | |

In terms of end-of-life treatments, most of the waste generated is sent to recycling (84 percent on average) thus promoting raw material recovery and incentivizing circular economy policies (Table 54).

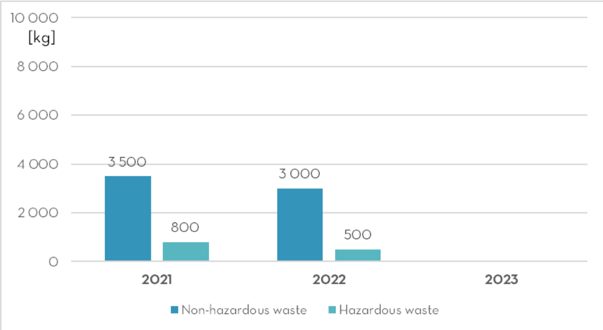


*Figure 39. Total amount of waste generated over the three-year period by LNS [kg].*

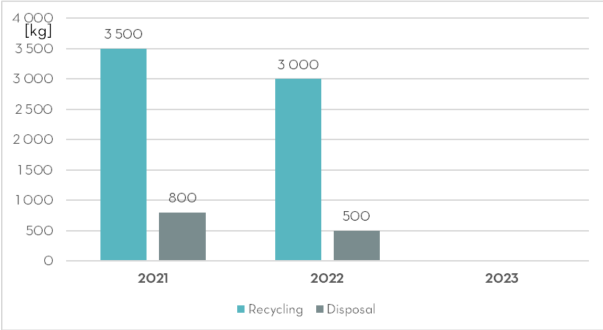


*Figure 40. Total amount of waste treated over the three-year period by LNS [kg].*

• **CNAF**

At CNAF, waste generation involved only non-hazardous waste produced from the decommissioning of electronic equipment such as servers, PCs, and other kind of WEEE.
In 2021, the total waste produced was 1 870 kg, all of which was non-hazardous. This trend continued into 2022, with a significant increase to 7 400 kg of non-hazardous waste. However, by 2023, the production of non-hazardous waste dropped to zero (Table 55).

*Table 55. Waste production by CNAF [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Non-hazardous waste | 1 870 | 100% | 7 400 | 100% | 0 | - |
| Hazardous waste | 0 | 0% | 0 | 0% | 0 | - |
| **TOTAL** | **1 870** | | **7 400** | | **0** | |

The Table 56 reveals that all waste produced was delivered to specialized centres for raw material recovery and recycling, and no waste was sent for disposal.

*Table 56. Waste management (end-of-waste) by CNAF [kg].*

| | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|
| Recycling | 1 870 | 100% | 7 400 | 100% | 0 | - |
| Disposal | 0 | 0% | 0 | 0% | 0 | - |
| **TOTAL** | **1 870** | | **7 400** | | **0** | |

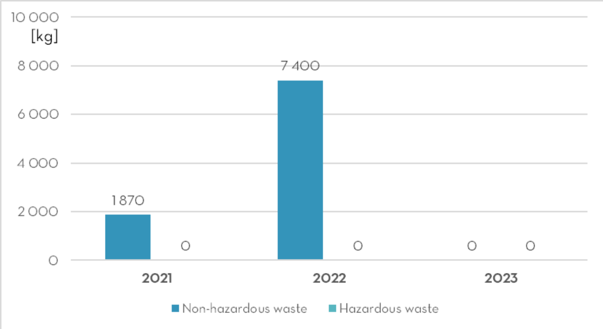


*Figure 41. Total amount of waste generated over the three-year period by CNAF [kg].*

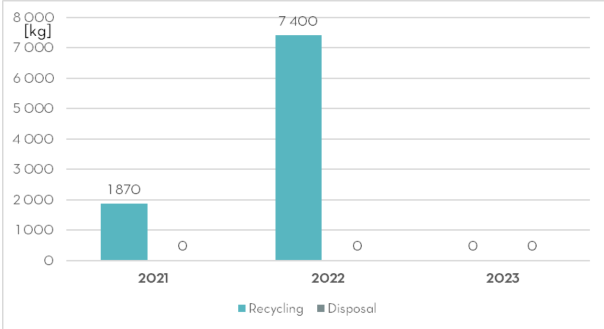


*Figure 42. Total amount of waste treated over the three-year period by CNAF [kg].*

# 8. IONISING RADIATION

The chapter examines the environmental impact of ionizing radiation emissions. Given the INFN research, these data can be particular interested for people living in the near the laboratories an in general for the public.

## 8.1. METHODOLOGY

For the evaluation of environmental impacts related to ionizing radiation emissions, data obtained from the periodic monitoring of laboratories for radioprotection risk assessment were used. Annually, the laboratories undergo dose measurements, expressed in mSv, detected by dosimeters placed along the perimeter.

The evaluation of the emissions involved analysing the difference between the measured value and the exposure from natural background radiation. The natural background radiation consists of terrestrial radiation (produced by primordial nuclides or cosmogenic nuclides in radioactive decay) and cosmic radiation (extraterrestrial). A fundamental component of terrestrial radiation is Radon (Rn-222), a naturally occurring radioactive gas produced during the radioactive decay chain of Uranium-238. It disperses everywhere, and its concentration varies from place to place.

## 8.2. RESULTS

Below are the values of ionizing radiation emissions at the analysed INFN sites (Table 57). During the 2021-2023 period, the data pertains only to laboratories where research activities using particle accelerators were conducted, specifically LNF and LNL. No evaluations of ionizing radiation were carried out at the other sites because it is not applicable at LNGS, the particle accelerators at LNS are not operational, and there are no particle accelerators at CNAF.

*Table 57. Ionising radiation.*

| | UM | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| LNF | mSv | 0.03 | 0.00 | 0.07 |
| LNGS | mSv | - | - | - |
| LNL | mSv | 0.00 | 0.00 | 0.00 |
| LNS | mSv | - | - | - |
| CNAF | mSv | - | - | - |

The highest dose measured in the last three years has been 0.07 mSv at the LNF in 2023, which is about 50 times less than the dose from natural background in Italy. However, the dose received by any member of the public living near the laboratories or visiting the INFN, is estimated to be less than 0.01 mSv per year (it is about 330 times less than the natural background radiation in Italy and 1000 times less than a dose by an abdominal CT).

At the LNF, measurements indicated small traces of ionizing radiation, always below the established limits. In 2021, the value was 0.03 mSv, zero in 2022, and 0.07 mSv in 2023 (Figure 43). These values are an indirect result of various research activities and the increased use of the particle accelerator in 2023. In the Legnaro laboratory area, the indicator was calculated as the sum of 8 perimeter monitors over a ten-year statistical period. The results indicate the absence of ionizing radiation in all three years considered.

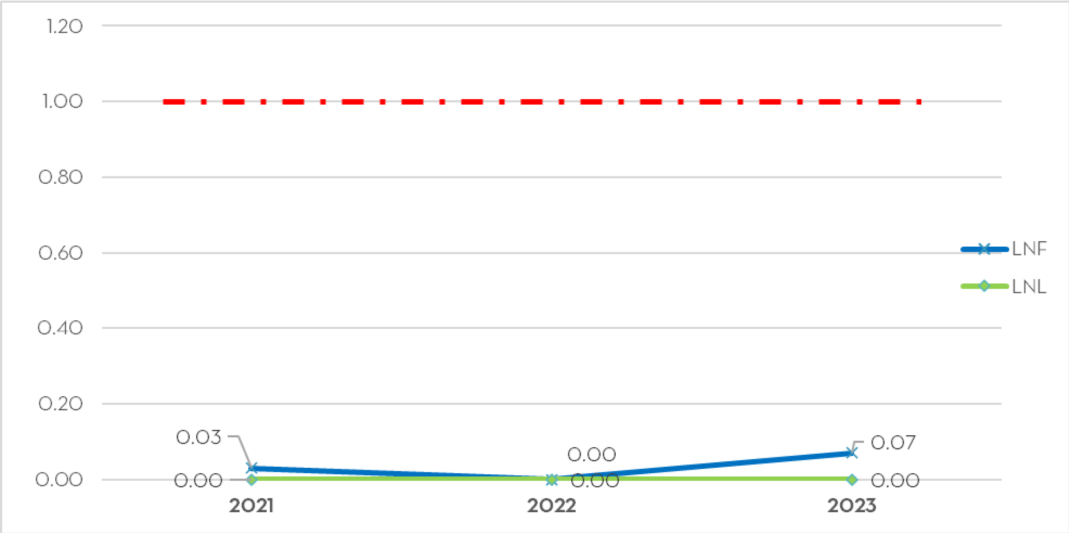


*Figure 43. Emissions of ionising radiation over the three-year period [mSv].*

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