23rd International Conference on Renewable Energies and Power Quality (ICREPQ'25)
Tenerife (Spain), 25th to 27th June 2025
ISBN-13: 978-84-09-66511-2

Accelerators and Sustainable Development: the case of IFMIF-DONES

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Abstract. Particle accelerators are behind multiple milestones of Mankind. From old TVs to the most advanced radiotherapy machines. From our daily life to the cutting-edge research on the very limits of both the macroscopic and the microscopic world. The interest of the scientific community has been focused on two main aspects: their improvement in technical terms and the minimization of potential hazards associated to these devices. However, little attention has been paid to their contribution to Sustainable Development from a global perspective. This work is focused on the "International Fusion Materials Irradiation Facility - DEMO Oriented Neutron Source", known as IFMIF-DONES, a unique experimental facility based on a deuterium accelerator whose final target is the production of fusion-like neutrons to test materials for the constructions of future vessels in fusion reactors. The multiple and sometimes non-trivial relationships with the Sustainable Development Goals as well as a detailed analysis to maximize the sustainability of this experiment will be presented and discussed.

Key words. Accelerator, IFMIF-DONES, Sustainable Development Goals, Fusion, Energy.

1. Introduction

1.1 The "International Fusion Materials Irradiation Facility-Demo Oriented Neutron Source" IFMIF-DONES.

Fission and fusion were understood and described in the 1930s of the past century through the pioneer works of scientists like Meitner, Hahn, Strassmann, Edington, Oliphant, Bethe and Fermi among other. Although the theoretical advances in both processes were simultaneous, their implementation has followed completely different paths. Thus, the first reliable reactor of fission started to work in 1942 under the direction of Enrico Fermi. However, there is little hope to have a fusion reactor ready to commercial exploitation before 20 years. This gap of 100 years illustrates the huge difficulty and titanic challenges of the use of nuclear fusion.

The long way to its use, needs to complete several milestones, and IFMIF-DONES is a major one.

The primary objective of the international DONES program is to gather and complete information on materials that could potentially be used in the fusion program, with the aim of incorporating them into future fusion reactors designed to produce energy on a commercial scale and in a continuous manner.

IFMIF-DONES (International Fusion Materials Irradiation Facility – Demo Oriented Neutron Source) is the main infrastructure of the DONES program [1]. It is a neutron source designed to replicate the extreme conditions that will occur inside future fusion reactors. It consists of the following components: a Deuteron Source, a Linear Particle Accelerator capable of accelerating deuterium ions to 40 MeV, a Liquid Lithium Target that requires a Lithium Management System to continuously purify and recycle the liquid lithium, control its temperature, and regulate its flow. A Test Cell will house the materials to be irradiated, exposing them to a neutron flux equivalent to what they will endure on the first wall of a fusion reactor, the Test Cell will also include Irradiation Modules needed to collect data, Cooling Systems to dissipate the heat generated during the processes, ensuring that temperatures remain within stable and safe limits, as well as Facilities for the proper handling of materials and radioactive waste, as irradiated materials will become activated and therefore require safe handling and storage.

This scientific-technical infrastructure is included in the ESFRI roadmap (European Strategy Forum on Research Infrastructures), highlighting its significance and key role in the fusion program, which began development in the 1990s. Its mission, the qualification of materials to test their durability and resistance under the conditions they will face inside a fusion reactor, is of critical strategic importance for the development of the fusion program and is considered an indispensable link in the program.

Its construction is a vital pillar in achieving the goal of commissioning a Demonstration Fusion Power Plant (DEMO).

The implementation plan consists of several phases as shown in Figure 1:

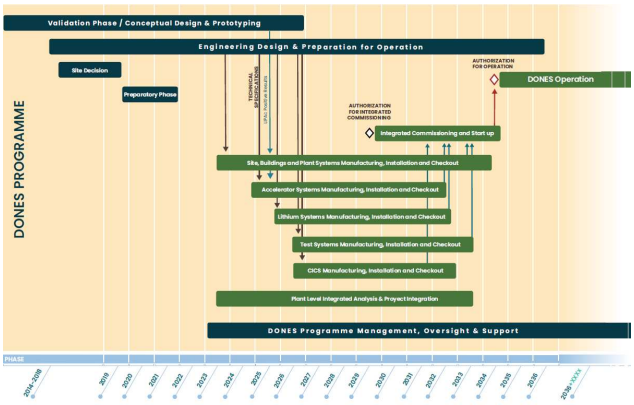

Figure 1. Phases of IFMIF-DONES project.

In addition to the already completed site selection phase, and Preparatory Phase, the implementation plan of IFMIF-DONES includes several key stages necessary for the project to progress towards full operational capacity. These are the main phases that follow:

1. Construction Phase
Detailed design phase: A thorough and precise design of the facility to ensure that the infrastructure can generate the necessary neutron flux with the required energy.
Manufacture phase: This phase has already begun, with the first auxiliary buildings being constructed at the chosen site, in the town of Escúzar in Granada.
Commissioning phase: In this phase, the systems must be adjusted and tested to ensure their proper functioning in a integrated design.
Operation phase: This phase will extend over several years during which material irradiation tests will be conducted, as well as any other experiments of interest to the scientific community. These may include the use of neutrons in industrial applications, astrophysics, nuclear physics, advanced materials research and other fusion related experiments
Integration with DEMO: In this final phase, the results obtained will be applied to the design and construction of the future DEMO fusion reactor.

IFMIF-DONES will be built in Escúzar (Granada, Spain). It is expected to become the most important scientific installation ever in Spain and its economic, environmental [2-4], and social impacts [5-6].

1.2 The Sustainable Development Goals (SDG)

The SDGs [7] consist of a package of 17 global objectives that were agreed upon at the United Nations Sustainable Development Summit held in New York on September 25, 2015, and they are one of the pillars of the 2030 Agenda for Sustainable Development, which was adopted on the same date.

Figure 2. Sustainable Development Goals

SDG 1: No Poverty
End poverty in all forms everywhere, ensuring access to resources and basic services.
SDG 2: Zero Hunger
End hunger, improve food security, nutrition, and promote sustainable agriculture.
SDG 3: Good Health and Well-being
Ensure healthy lives and promote well-being for all ages.
SDG 4: Quality Education
Ensure inclusive, equitable, and quality education for all.
SDG 5: Gender Equality
Achieve gender equality and empower women and girls.
SDG 6: Clean Water and Sanitation
Ensure sustainable water management and sanitation for all.
SDG 7: Affordable and Clean Energy
Ensure access to reliable, sustainable, and modern energy.
SDG 8: Decent Work and Economic Growth
Promote inclusive economic growth and decent jobs for all.
SDG 9: Industry, Innovation, and Infrastructure
Develop sustainable infrastructure and foster innovation.
SDG 10: Reduced Inequality
Reduce inequality within and among countries.
SDG 11: Sustainable Cities and Communities
Make cities inclusive, safe, and sustainable.
SDG 12: Responsible Consumption and Production
Promote sustainable consumption and production patterns.
SDG 13: Climate Action
Take urgent action to combat climate change and its impacts.
SDG 14: Life Below Water
Conserve oceans and marine resources.
SDG 15: Life on Land
Protect terrestrial ecosystems and biodiversity.
SDG 16: Peace, Justice, and Strong Institutions
Promote peaceful societies and provide access to justice.
SDG 17: Partnerships for the Goals
Strengthen global partnerships to achieve sustainable development.

2. Compliance of IFMIF-DONES and Fusion Energy with each SDG.

SDG 1: No Poverty
IFMIF-DONES is currently a driving force for new industrial opportunities, which implies the creation of both direct and indirect new jobs. Furthermore, the infrastructure will be built in the geographical area of La Malahá, which is classified as an ERDF area due to its low economic development, high unemployment rate and lack of significant infrastructures.
Therefore IFMIF-DONES is going to be a revulsive at local level for the economy of the area helping the economic development of the area.

SDG 2: Zero Hunger
IFMIF-DONES will be one of the main keys in the development of cheap, safe and stable energy sources implies a decrease in food production costs from production through processing to transport.

SDG 3: Good Health and Well-being
IFMIF-DONES will contribute to the generation of fusion energy which will be significantly cleaner energy, with very low radioactive waste generation in terms of both quantity and half-life, and the rate of emissions will be very low compared to the emissions generated by current energy sources. It will not produce CO2 or other greenhouse gases as it does not involve the use of fossil fuels.
Tritium emissions are expected as it is used as a fuel, but these will be extremely low and therefore will not have a significant environmental impact.
The production of energy by fusion will imply a drastic reduction in dependence on coal or oil, which will undoubtedly be associated with a mitigation of the effects of climate change.

SDG 4: Quality Education
IFMIF DONES as a world-class scientific infrastructure will be a driving force for education both through its scientific dissemination activities and the need it will generate for highly qualified manpower.

SDG 5: Gender Equality
It is also called upon to foster gender equality by promoting and encouraging women's participation in fields in which women's participation has so far been lower than men's, such as engineering, mathematics, physics, etc.

SDG 6: Clean Water and Sanitation
IFMIF-DONES is one of the necessary steps for the generation of cleaner energy that will drastically reduce the pollution of water resources, thus facilitating a supply of quality water for a larger portion of the population.

SDG 7: Affordable and Clean Energy
This is the most impactable SDG.
IFMIF-DONES it´s a main step on the road to develop fusion technologies. Fusion is expected to be a limitless source of energy with a minimum environmental impact, as mentioned on SDG 3 with no significant greenhouse gas emissions, this SDG it's the sourdough starter that impact on the rest of the SDGs.

SDG 8: Decent Work and Economic Growth
IFMIF-DONES as a main step of the development of fusion energy will undoubtedly stimulate economic growth and create high-quality jobs. It will also serve as a driving force for indirect employment (in fields such as maintenance, supply chains, transport etc) in the regions where future fusion reactors are built.

SDG 9: Industry, Innovation, and Infrastructure
The technological challenge involved in the construction of an infrastructure of these characteristics will require an additional effort from industry in terms of R&D&I (Research, Development, and Innovation), as well as improvements in the infrastructure of many companies that wish to supply components for the project. This will apply on an even larger scale once the first fusion reactors begin to be built.

SDG 10: Reduced Inequality
The DNA of IFMIF-DONES is that of an international project, which inherently involves knowledge sharing not only in the field of fusion but also in other applications that are expected to emerge from the facility. These applications could span across diverse fields such as astrophysics and industrial sectors.
This global and multidisciplinary collaboration will undoubtedly lead to innovations and improvements in areas such as those mentioned, as well as many others. These advancements can be applied worldwide, improving processes and optimizing resources on a global scale.

SDG 11: Sustainable Cities and Communities
IFMIF-DONES will facilitate the integration of fusion energy into city Infraestructures will make urban areas significantly more energy efficient. Cities will also benefit, apart from a cleaner energy supply, but also of the opportunity to increase the number and quality of the services offered to population due to the reduction of cost of the energy that such services will demand.

SDG 12: Responsible Consumption and Production
The path to the construction of future fusion reactors will be paved by, among others, the IFMIF-DONES project Those fusion reactors will require elements that are abundant, such as deuterium and lithium, which will contribute to a more sustainable and reliable consumption of natural resources due to their availability. As we've noted, the abundance of these materials ensures that fusion energy will not face the same resource scarcity challenges as fossil fuels or other energy sources.

The reduction in energy costs enabled by fusion will empower companies to adopt more sustainable consumption and production policies. Lower energy expenses will allow businesses to allocate more resources toward making their processes cleaner and environmentally safer.

SDG 13: Climate Action
IFMIF-DONES will facilitate the reduction of the impact of using fossil fuels making possible the availability of fusion energy.

SDG 14/15: Life Below Water/Life on Land
This reduction in the use of fossil fuels such as natural gas, oil, and coal will inevitably lead to a decrease in activities related to their extraction, and consequently, a reduction in the environmental degradation (habitats and ecosystems degradation, and sometimes, irreparable destruction, contamination, air pollution…) that this extraction inevitably causes in both marine and terrestrial environments.

SDG 16: Peace, Justice, and Strong Institutions
In most of biggest modern armed conflicts, there is an underlying struggle for natural resources control that ends in a armed conflict.

- I and II World War (1914-1918/1939-1945)

Aside from the well-known geopolitical tensions, both World Wars shared a common denominator: the need for oil. This resource was crucial for both factions and became a driving force behind the conflict, as securing access and control over oil fields became essential for sustaining military operations. As a result, many battles and fronts were motivated by the strategic goal of gaining or defending access to oil.

- The Gulf War (1990-1991) [8]

Had its primary, and almost exclusive, origin in the control of Kuwait's oil resources. The regime of Saddam Hussein invaded the neighbouring country with the goal of seizing control of its vast oil fields, which would have significantly increased Iraq's power in the global oil market.

- The Congo Conflict (1998-Present)

Is one of the longest and most complex conflicts in modern history, and its origins largely lie in the struggle for control of strategic minerals such as coltan (key mineral on production of a large number of electronic devices such as mobile phones), tin, and other natural resources essential for the production of many of today’s technological supplies,

- Russia-Ukraine War (2022-Present) [9]

Gas and Oil: although Russia is the producer of this combustible fossils, a large part of the gas pipelines with destination to Europe run through Ukrainian soil.
Minerals: Ukraine is a rich region in minerals and rare earth elements as in Congo those minerals are strategic resources in the production of technologic devices.
Nuclear Energy: Ukraine has in its territory the biggest fission nuclear power plant, located in Zaporizhzhia among several others distributed all over the country.

SDG 17: Partnerships for the Goals
IFMIF-DONES is a paradigm of scientific and economic collaboration between regional and national Spanish administrations of different political sign, between international technologic institutions, universities and between countries.
The organizational project´s architecture perfectly reflects the achievements that can be accomplished with both collaborative attitude and spirit.

3. Discussion and Conclusions

IFMIF-DONES as a scientific infrastructure aimed to clear the path to fusion presents clear positive aspect in the development of the SDGs.

At this stage of the project, its largest impact is expected to fall upon SDGs 7,8,9,12,13,14 and 15, with a significant repercussion also on the consecution of the rest.

However, remarkable challenges also arise, especially regarding technological development. Likewise, the fusion program will require a large investment and will take a considerable amount of time to be successfully completed, meaning that some of the expected benefits will take time to materialize which means in terms of impact and time that:

It is already having impact on SDGs 4,5,8,9 and 17.

The demand for specialized and high skilled workforce is currently driving an expansion in education related to scientific careers, incorporating a gender perspective, supported by various statal initiatives aimed to achieving full equality in these fields. Additionally, collaboration and knowledge exchange are being promoted, strengthening international partnerships and alliances to improve and reinforce this transfer of know-how.

The impact on the rest of the SDGs will occur in the middle and long term.

The most significant contributions to the rest of the SDGs will not materialize in the short term; their results and impact will gradually become visible over the coming decades. Fusion energy is set to change the paradigm of global energy production by providing a cheap, safe, and nearly inexhaustible energy source, thereby reducing dependence on fossil fuels. This profound shift in energy generation will mitigate habitat destruction and air pollution while enabling much more efficient industrial processes.

Challenges:

Technology.

The success of the project depends on overcoming numerous challenges in the scientific and engineering fields, particularly in replicating the neutron flux. A constant and sustained investment in R&D&I is essential, both in this area and in various secondary fields such as Nuclear Physics, Plasma Physics, Particle Acelerator Technology, Computational Fluid Dynamics for Neutron Behaviour, Target Systems Engineering (especially Liquid Lithium Targets)

Financial Investment.

IFMIF-DONES is one of the essential links in achieving fusion energy and requires long-term financial commitments, not only for its construction but also for its operational phase, which is estimated to cost 50 million euros per year. Therefore, the commitment of institutions and industry must be unwavering and sustained over time, overcoming any uncertainties that may arise during the decades in which the project remains in operation.

Public Perception.

The goal to achieve commercial fusion reactors is expected as mentioned before to take decades.
Managing public expectations over such a long period is going to be critical due to this public perception is going to help strengthen institutional commitments if it is positive, but can, also overcome a significant weakness if the sense of necessity to achieve the objective as a key factor for global improvement is lost.

Public engagement, educational policies and clear external communication will be essential to maintain the trust generated in the project so far.

Environmental and Safety Regulations.

Regulatory framework will have to be adapted due to the unique and innovative characteristics of fusion technology, safety, environmental, and waste management protocols, among others, will need to be established. These protocols are not yet fully developed and will be crucial for the proper integration and utilization of fusion technology.

Final Conclusion:

IFMIF-DONES embodies scientific advancement and sustainability although there are big challenges remain, its potential benefits will play a pivotal role in the future generation of cleaner and safer energy.

The data achieved from this unique and innovative project will be the key to develop DEMO and therefore the future commercial fusion reactors contributing without any doubt to the consecution of more a sustainable, equitable and secure world

Acknowledgement

We would like to express our deepest gratitude to the IFMIF-DONES España Consortium, for their generous financial support and commitment to advancing research in the field of fusion energy. This study would not have been possible without their invaluable resources and infrastructure, which facilitated our research efforts.

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