→ THE EUROPEAN SPACE AGENCY

ESA CLEANWAVES INITIATIVE:

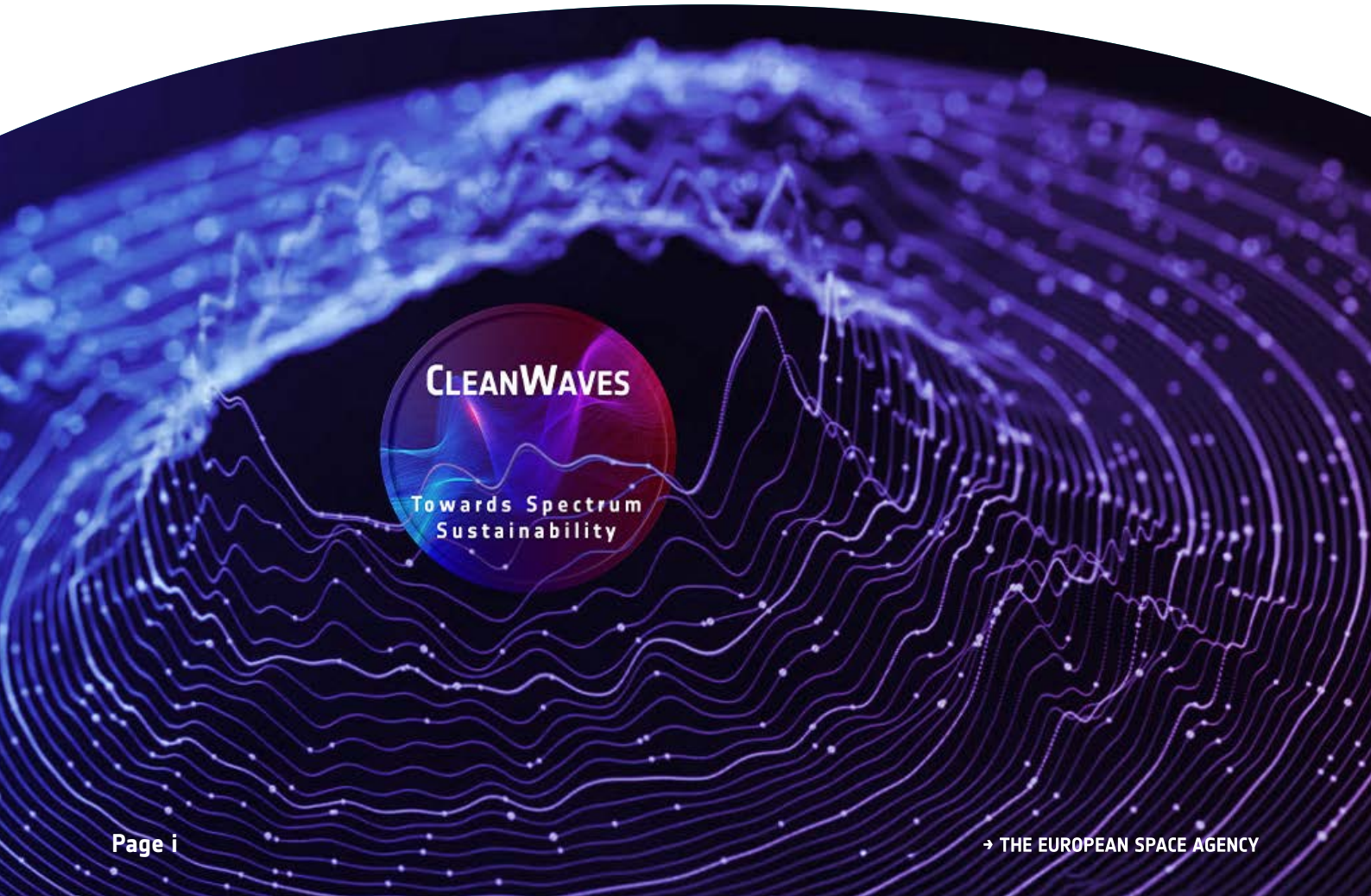
Maturing European industry capabilities to optimise RF spectrum use and preserve it from harmful interference

November 2025

By ESA Connectivity and Secure Communications Directorate
4S Space for Safety and Security Strategic Programme Line

CleanWaves Team

TABLE OF CONTENTS



LIST OF ACRONYMS

Acronym	Definition
CEPT	Conference of Postal and Telecommunications Administrations
COPERNICUS programme	Earth Observation component of the European Union's Space
D/CSC	Directorate of Connectivity and Secure Communications
D/EOP	Directorate of Earth Observation Programmes
D/NAV	Directorate of Navigation
D/OPS	Directorate of Operations
D2D	Direct-to-Device
EC	European Commission
ECC	Electronic Communications Committee
ERS	European Resilience from Space
ESA	European Space Agency
EU	European Union
EUSPA	European Union Agency for the Space Programme
GNSS	Global Navigation Satellite System
IRIS2	Infrastructure for Resilience, Interconnectivity and Security by Satellite
ITTs	Invitations to Tender
ITU	International Telecommunication Union
RF	Radio Frequency
RFI	RF Interference
RR	Radio Regulations

1. RADIO-FREQUENCY SPECTRUM:

A Strategic Domain

1.1 RF SPECTRUM, A GLOBALLY CONTESTED STRATEGIC ASSET

Radio frequency (RF) spectrum plays a pivotal role in the delivery of all wireless services, including those offered by satellite. The rapid proliferation of new spectrum-dependent services has driven a surge in demand for clean spectrum, intensified competition, and increased the odds of spectrum interference.

Whether due to congestion or deliberate jamming and spoofing, RF interference disrupts not only consumer connectivity services but also critical infrastructures such as aviation, maritime, emergency response systems, and broader satellite communication services.

In parallel, several nations and many corporations are pioneering regulations and positions in national and international fora that align with their economic and strategic interests, reflecting the latest technological developments.

In a rapidly evolving regulatory landscape, frequency regulators and decision-makers must strike a balance between competing imperatives: on one hand, maintaining a stable regulatory framework to protect current licensees and guarantee the reliable delivery of critical services; on the other, fostering innovation and enabling emerging services that depend on timely access to scarce spectrum resources. The timing of regulatory and enforcement actions is particularly sensitive—premature decisions may compromise stability, while delayed action risks stifling innovation and private-sector investment.

In this evolving context, better knowledge of spectrum usage and improved management will provide frequency regulators with the insights needed to make well-informed, balanced decisions that serve the long-term interests of governments, industry, and citizens across Europe.

Indeed, Europe faces significant challenges arising from its fragmented and complex regulatory and market environment. This fragmentation inevitably slows Europe's ability to keep pace with technological developments and limits its capacity to foster a more efficient, flexible, and coordinated use of interference-free radio frequencies. To safeguard the economic interests and strategic autonomy of its Member States and of Europe as a whole, it is essential to secure access to spectrum and ensure efficient use.

1.2 NATIONAL REGULATORS AND INDUSTRIAL USERS INTERESTED IN RF CAPABILITIES

A rapidly expanding ecosystem is emerging around RF monitoring and spectrum surveillance. However, much of this innovation is currently dominated by non-European actors. As a result, European institutional and corporate users (e.g., critical service providers, satcom operators, telecom operators, etc.) often find themselves reliant on foreign technologies, services, and infrastructures.

This dependency limits Europe's ability to independently respond to RF threats. It also raises fundamental concerns about sovereignty, security, and the long-term autonomy of Europe.

1.2.1 INCREASED FOCUS OF RF STAKEHOLDERS ON DEVELOPING CAPABILITIES

In its role to anticipate technology evolutions serving European interests, ESA has undertaken a large consultation cycle over 2024, which culminated in a conference bringing together key stakeholders, such as National Regulatory Authorities, International Telecommunication Union (ITU), satellite operators, commercial ground-based solution providers, space-based solutions providers, mobile network operators and other relevant communities. ESA D/OPS, D/CSC, D/NAV and D/EOP were also represented.

As part of these consultations, stakeholders have emphasised the need for proactivity in positioning European stakeholders on this topic and the importance of ESA's role as a neutral and expert enabler in the RF spectrum domain. In particular, ESA's engagement with both commercial and institutional user communities is seen as essential to fostering collaboration, aligning interests, and supporting early-stage development[1].

1.2.2 CEPT INVESTIGATING RF MONITORING FROM SPACE AND EFFICIENT USE OF SPECTRUM

The European Conference of Postal and Telecommunications Administrations (CEPT) is investigating the topic of harmful interference, RF monitoring from space, and spectrum sharing. In its published ECC Strategic Plan 2025-2030, the CEPT recognises that: *"Spectrum sharing, where technically feasible, can facilitate effective and efficient use of spectrum in both licensed and unlicensed bands. It can promote innovation by enabling easier and more rapid access to spectrum than some traditional models of making spectrum available (such as clearance). Moreover, the emergence of new technologies may enable the implementation of frameworks that facilitate more efficient use of spectrum. The increasing demand for mid-bands and higher frequency bands, taking into account propagation characteristics, may also promote interest in spectrum sharing. The ECC will consider opportunities to promote spectrum sharing through its technical and regulatory work, including when undertaking compatibility analyses and defining coexistence conditions."* [2]

In recent meetings, CEPT FM22 (the group dealing with monitoring and enforcement) has published new statistics on harmful interference. These statistics can be found on FM22(25)04Annex4Rev1[3], and indicate interferences in satellite broadcasting and FSS/MSS services.

In addition, in April 2025 the CEPT FM22 group, on the initiative of the German regulator, launched a questionnaire on the interest of its Members to explore the added value of space complementing ground RF monitoring. The Group welcomed and supported the introduction of this questionnaire (see FM22 document FM22(25)18Rev1[4]).

25 CEPT Members replied, the large majority of which (96%) answered positively to the question "Does your Administration see possible benefits in satellite-based monitoring on its own territory?". 86% of respondents expressed interest to engage in test and demonstration activities, including by making available their own ground infrastructure.

Furthermore, 40 regulators participated in the follow-up workshop organised by ESA in its ESTEC facilities in Nordwijk, the Netherlands in November 2025.

1 Refer to CleanWaves Workshop report in https://connectivity.esa.int/workshop-spectrum-access
2 Strategic Plan of the Electronic Communications Committee (ECC) for the period 2025-2030, p. 2
3 https://cept.org/documents/fm-22/88017/fm22-25-04annex4_sources-interferers-statistics-2024
4 https://cept.org/documents/fm-22/88297/fm22-25-18rev1-_fm22-63-budapest-meeting-note

1.2.3 THE EUROPEAN COMMISSION SIGNALS NEW RF INITIATIVES

Furthermore, the European Commission (EC) increasingly recognises the importance of developing capabilities that help Europe detect and respond to interference, secure long-term access of spectrum resources, and maintain control over its strategic assets.

The growing interest of the European Union (EU) in space-based RF monitoring is reflected in its inclusion as a supporting element of the "EU Action Plan on Cable Security".[5] In addition, requests for information have been published, for example, by the European Union Agency for the Space Programme (EUSPA) on RF Interference (RFI) payloads and technology for future satellites.[6] Also, COPERNICUS (the Earth Observation component of the European Union's Space programme) aims to define and design concepts for a potential future EU GNSS (Global Navigation Satellite System) RFI Monitoring service from Space.[7]

A Joint White Paper for European Defence Readiness 2030 (JOIN (2025), published 19 March 2025)[8] specifically addresses "The growing hybrid threats [...] electronic interference in global navigation and satellite systems" and calls for "EU-wide advanced electronic systems designed to [...] protect and ensure the unhindered use of the electromagnetic spectrum for land, air, space and naval forces and operations."In addition, an *Opinion* published in February 2025 by the Radio Spectrum Policy Group[9] on request by the EC, recognises that "mechanisms to address and solve interference, technical studies to address sharing and compatibility may be necessary [...] as well as a basis for [...] a legal instrument to enhance compliance of electronic communications satellites with the radio regulations." The same *Opinion* further quotes that "Some Member States are engaged in a common satellite monitoring tool enabling collection of data on satellite spectrum usage. This concept might be extended to provide a basis for mutual assessment or confirmation of an interference or noncompliance situation."

Moreover, in his keynote speech at the European Defence and Security Summit on 10 June 2025, Commissioner Kubilius emphasised the critical role of RF monitoring from space, stating that defence readiness in space demands that we "work towards RFI monitoring" as part of the EU's strategic capabilities in orbit. In this context, Commissioner Kubilius also emphasised that "ESA has valuable engineering expertise and is the trusted partner of the European Commission" in delivering the objectives presented.[10]

5 https://digital-strategy.ec.europa.eu/en/factpages/joint-communication-strengthen-security-and-resilience-submarine-cables
6 https://www.euspa.europa.eu/opportunities/procurement-grants/procurements/request-information-space-based-gnss-radio-frequency
7 https://esastar-publication.sso.esa.int/ESATenderActions/details/155622
8 https://www.eeas.europa.eu/eeas/white-paper-for-european-defence-readiness-2030_en
9 https://radio-spectrum-policy-group.ec.europa.eu/document/download/7c6039f4-0e01-402c-9b78-638d800ce965_en?filename=RSPG25-008final-Draft_Opinion_on_D2D_and_Access_to_EU_Market-for_PC.pdf
10 https://ec.europa.eu/commission/presscorner/detail/en/speech_25_1477

2. CLEANWAVES:

ESA's Initiative to Address Emerging RF Spectrum Challenges

2.1 *CLEANWAVES* OBJECTIVES: ADDRESSING THE NEEDS OF RF STAKEHOLDERS BY PROMOTING EUROPEAN INDUSTRIAL CAPABILITIES

The European Space Agency (ESA) is mandated by its Member States, as per its Convention, to anticipate the evolution of technology and prepare the European industry, "improving its world-wide competitiveness [...] by maintaining and developing space technology and by encouraging the rationalisation and development of an industrial structure appropriate to market requirements."[11]

By virtue of this mandate, ESA's Connectivity and Secure Communications Directorate (CSC) has launched *CleanWaves* initiative, to support European stakeholders (users on the one hand, industry on the other hand) in advancing the capabilities to effectively address emerging RF challenges, as driven by strategic and market considerations.

To achieve this, the objectives of the *CleanWaves* initiative in the areas of RF monitoring, interference detection, location and mitigation, and spectrum use optimisation are to:

- identify and anticipate needs, requirements, boundaries, and constraints of users of RF information
- progress European industrial capabilities through ESA technology development and validation, including in-orbit demonstration activities
- support technology developments on their path to the markets, including integration with existing ground-based RF services

This aims at positioning ESA Member States to be:

- better equipped to protect European critical infrastructures from rising sources of interference
- better prepared to use spectrum resources more efficiently
- less dependent on non-European technologies and infrastructures
- better positioned to negotiate and enforce spectrum regulation

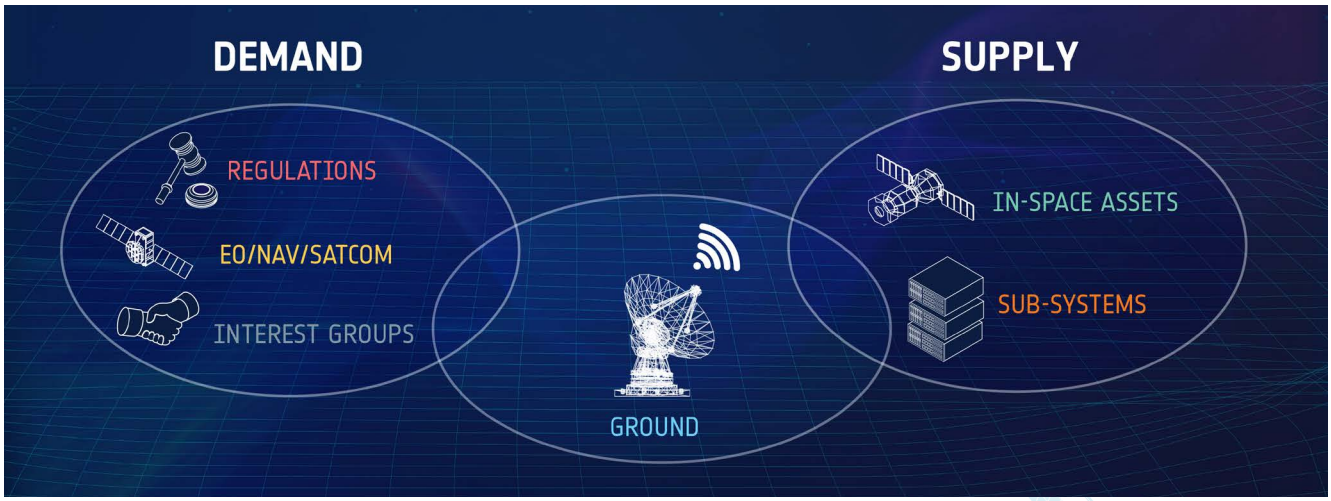


Figure 1: Supporting the bridge between Demand and Supply

11 ESA Convention and Rules of Procedure, art. VII.1.D

2.2 ON-GOING DEVELOPMENTS UNDER THE CLEANWAVES INITIATIVE

2.2.1 ESA AND ITU COLLABORATE TO ADVANCE IN RF SPECTRUM SUSTAINABILITY

ESA CSC Directorate signed a collaboration agreement[12] with the International Telecommunication Union in March 2025. It represents a shared commitment to promote the sustainable and efficient use of RF spectrum for satellite communications. This agreement aims at reinforcing ESA and International Telecommunication Union (ITU) roles as key enablers of an innovative satellite communication ecosystem that can meet growing global demand and respond to increasing spectrum complexity. This effort is supported through an ongoing channel for dialogue and knowledge exchange, towards enhancing space communication systems and advance regulatory frameworks.

2.2.2 ESA SUPPORTS EUROPEAN SPECTRUM DISCUSSIONS THROUGH CEPT

ESA is actively contributing to European-level efforts on spectrum through its engagement with the European Conference of Postal and Telecommunications Administrations (CEPT). In particular, ESA's involvement in CEPT Working Group FM22 (frequency monitoring group) reflects the Agency's role in supporting long-term strategies for RF monitoring and management. In addition, other groups within CEPT/ECC (Electronic Communications Committee), such as FM44, will be kept informed of these efforts.

Among the various subjects under consideration within FM22, the potential role of space-based assets in enhancing RF monitoring capabilities has recently emerged as a topic of particular interest—current RF monitoring frameworks rely almost entirely on ground-based infrastructure, however space-based systems may offer complementary capabilities. In this context, ESA is contributing to FM22 through technical inputs, shared

Figure 2: Promoting the sustainable and efficient use of spectrum

12 https://connectivity.esa.int/news/esa-and-itu-collaborate-advance-radio-spectrum-sustainability

expertise, and funding mechanisms, to support the assessment of the benefits of integrating space-based RF monitoring assets into the current European ground-based RF monitoring network.

In this respect, a questionnaire which was launched in Q2 2025 within FM22 group, has already generated favourable responses from National Regulatory Authorities, indicating an interest to explore the added-value of space-based RF monitoring and geolocation (as introduced above in section 1.2.2).

2.2.3 REGULATORY CONSIDERATIONS AND DATA GOVERNANCE

The monitoring of radio communications—particularly of frequencies not intended for public use—is considered a security-critical issue in several countries. At international level, this is governed by the ITU Radio Regulations[13] (RR), in particular, Articles 17 and 18.4, which establish clear rules on the reception and handling of non-public radiocommunication signals.

All ESA Member States are signatories to the ITU Radio Regulations, and ESA itself is bound by these regulations through its host country, France. Consequently, ESA projects involving RF monitoring[14] activities must operate within the framework of these international obligations, in particular:

- ITU Member States are obliged to take measures to prohibit and prevent the monitoring of radiocommunication on frequencies not intended for public use and the divulgence of the contents, simple disclosure of the existence, publication or any use whatsoever, unless carried out in compliance with a licence or a formal authorisation from the competent National Regulatory Authorities (Article 17 of ITU RR)
- Any RF data obtained through authorised RF monitoring is subject to strict limitations on its protection, use and sharing, in accordance with applicable provision of the Competent National Regulatory Authorities and/or any other relevant governmental bodies (Article 18.4 of ITU RR)

For those acquiring and/or handling real RF spectrum data[15] of frequencies not intended for public use, all participating entities are expected to consult competent National Regulatory Authorities and any other relevant governmental bodies. To ensure compliance and responsible conduct, ESA will request evidence of authorisation, proper security, and data governance measures as part of any procurements linked to *CleanWaves* initiative.

ESA CSC Directorate is actively working with regulatory bodies to support the development of a coherent framework for RF monitoring under ESA activities. These efforts aim to create clarity and alignment while respecting national and international rules. All ESA activities and projects will be developed in full compliance with ESA's Security Framework, including applicable ESA Security Regulations and ESA Security Directives.

13 https://www.itu.int/pub/R-REG-RR

14 For the purpose of this document, the term "RF monitoring" refers to the periodic observation, measurement, and technical analysis of radio frequency emissions within designated spectrum bands. This term should not be confused with the definition of RF monitoring as established under Article 16 of the ITU Radio Regulations.

15 The term "Real RF spectrum data" refers to emissions physically captured from actual radiating sources under real-world conditions. This excludes simulated or synthetic data.

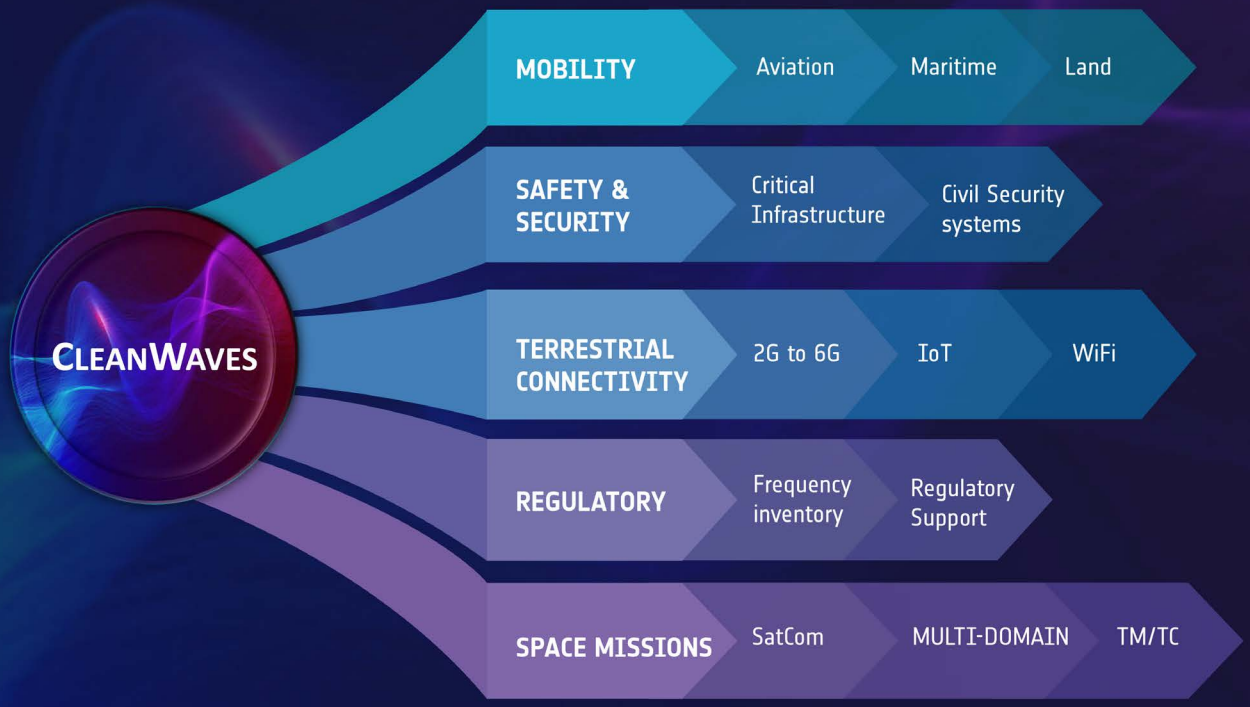


Figure 3: CleanWaves' multi-domain areas

2.2.4 INITIAL ESA PROCUREMENT ACTIVITIES UNDER CLEANWAVES INITIATIVE

Thanks to input from on-going collaborative efforts with CEPT and ITU, ESA CSC Directorate has issued 3 Invitations to Tender (ITTs) procurement of three activities aimed at demonstrating the practical benefits of space-based RF monitoring. These fully-funded ESA activities will serve as a first step in demonstrating how space-based capabilities can enhance existing spectrum monitoring frameworks. The three activities focus on:

- Enhancing current geolocation capabilities using satellites which are already in-orbit[16]
- Investigating and demonstrating the synergy between ground-based and space-based monitoring and geolocation[17]
- Demonstrating several use cases in which the usage of near real-time RF measurements from space-based and/or ground-based systems leads to more efficient spectrum usage[18]

16 https://esastar-publication-ext.sso.esa.int/ESATenderActions/details/159643
17 https://esastar-publication-ext.sso.esa.int/ESATenderActions/details/157958
18 https://esastar-publication-ext.sso.esa.int/ESATenderActions/details/157959

Figure 4: Potential added value of space-based assets for radio-frequency monitoring

The first step in these procurements is to identify and assess relevant use cases on specific situations or RF monitoring tasks where space-based systems provide added value to existing ground-based infrastructures, with particular emphasis on monitoring services relevant for National Regulatory Authorities. Once the use cases are assessed, development and demonstration efforts aim to effectively validate the selected use cases.

Based on preliminary assessments, satellite-based RF monitoring is expected to provide added value in several areas of application, including:

- Contributing to the geolocation of interferers in wide frequency ranges
- Long-term observation of a specific frequency channel/band to detect on- and off-times of signals of interest (e.g., an interfering signal)
- Occupancy measurements covering a large area or even the whole country

While progress is underway, the maturity of space-based technologies for RF monitoring, spectrum use optimisation, interference detection, location, and mitigation remain limited. This early phase is viewed as especially critical for institutional support. Mechanisms offered by ESA are considered essential, not only for advancing technology readiness and easing integration into operational environments, but also for reinforcing Europe's industrial base and ensuring long-term strategic capabilities in spectrum management.

These initial actions aim to deliver early insights and validation, supporting both regulatory and the broader community in understanding the role space-based assets can play in future spectrum management strategies.

2.2.5 EXPLORING A SYNTHETIC ENVIRONMENT OF SPECTRUM

As part of the broader effort to strengthen Europe's capabilities in RF monitoring, spectrum optimisation, and interference detection and mitigation, ESA CSC Directorate is currently evaluating the potential value and benefits of a synthetic environment for spectrum co-existence or interference cases under *CleanWaves* initiative. This environment would allow European stakeholders replicate near real-world spectrum usage scenarios in a secure and controlled setting, enabling testing and validation of advanced spectrum management concepts and techniques without disrupting live systems.

The synthetic environment of spectrum would serve several strategic purposes:

- De-risk technologies and techniques by enabling safe experimentation prior to real-world deployment.
- Streamline the demonstration and validation of complex spectrum scenarios, accelerating their readiness towards operational use.
- Provide a representative and safe environment for European Industry to test and refine interoperability and coexistence scenarios for emerging systems, such as Direct-to-Device (D2D) communications.

At this stage, this effort remains in an exploratory phase. Further work is needed to assess the technical feasibility of the environment, advance the maturation of relevant use cases, and engage further with end users to confirm both interest and practical relevance.

Should the concept be deemed valuable by end users and other key stakeholders—including ESA Member States' Delegates—its development foresees the use of existing ESA implementation mechanisms, following a use-case-driven approach aligned with operational needs, and the adoption of a modular implementation strategy.

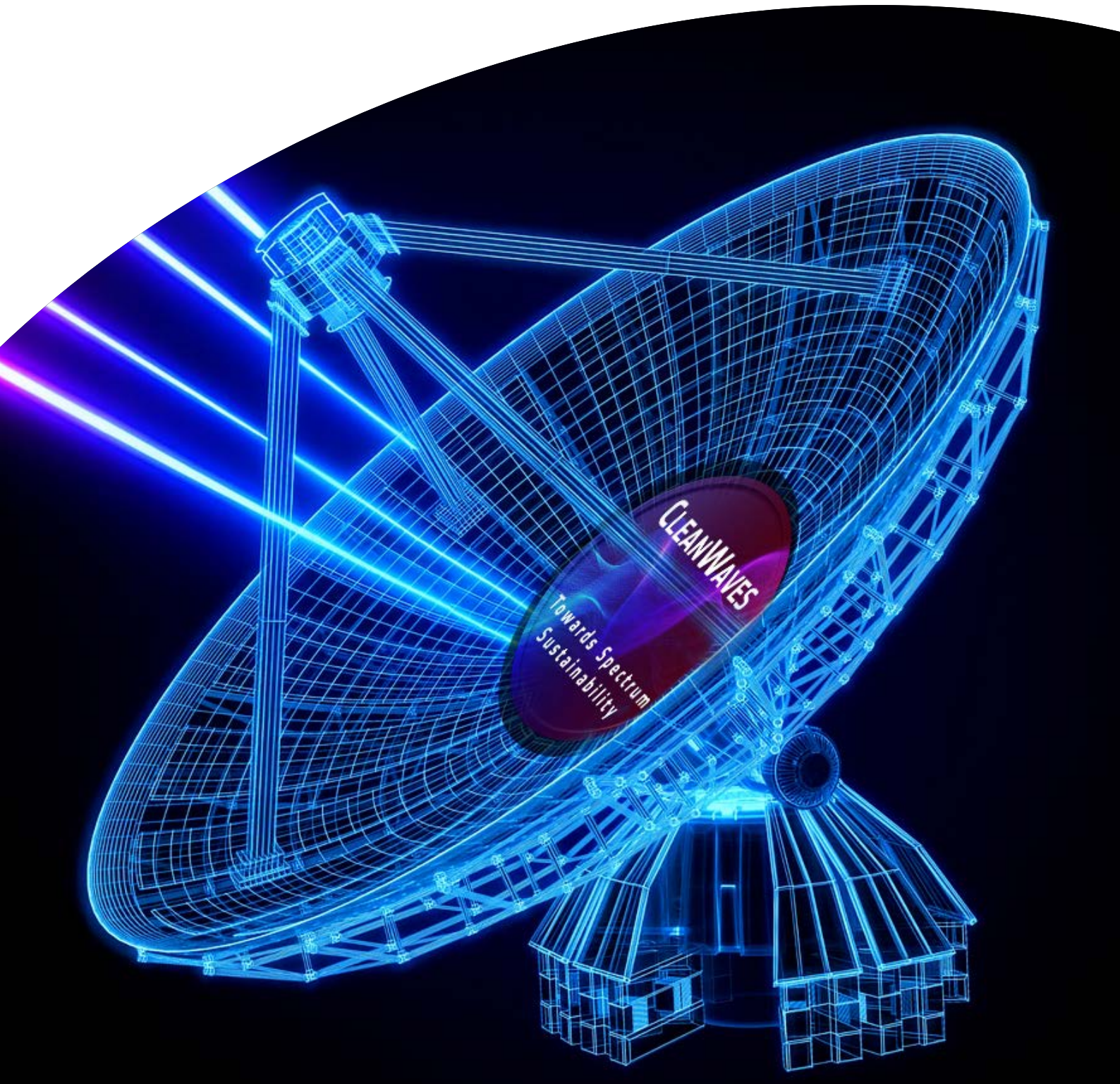
2.3 CLEANWAVES – NEXT PHASE AND STRATEGIC PRIORITIES

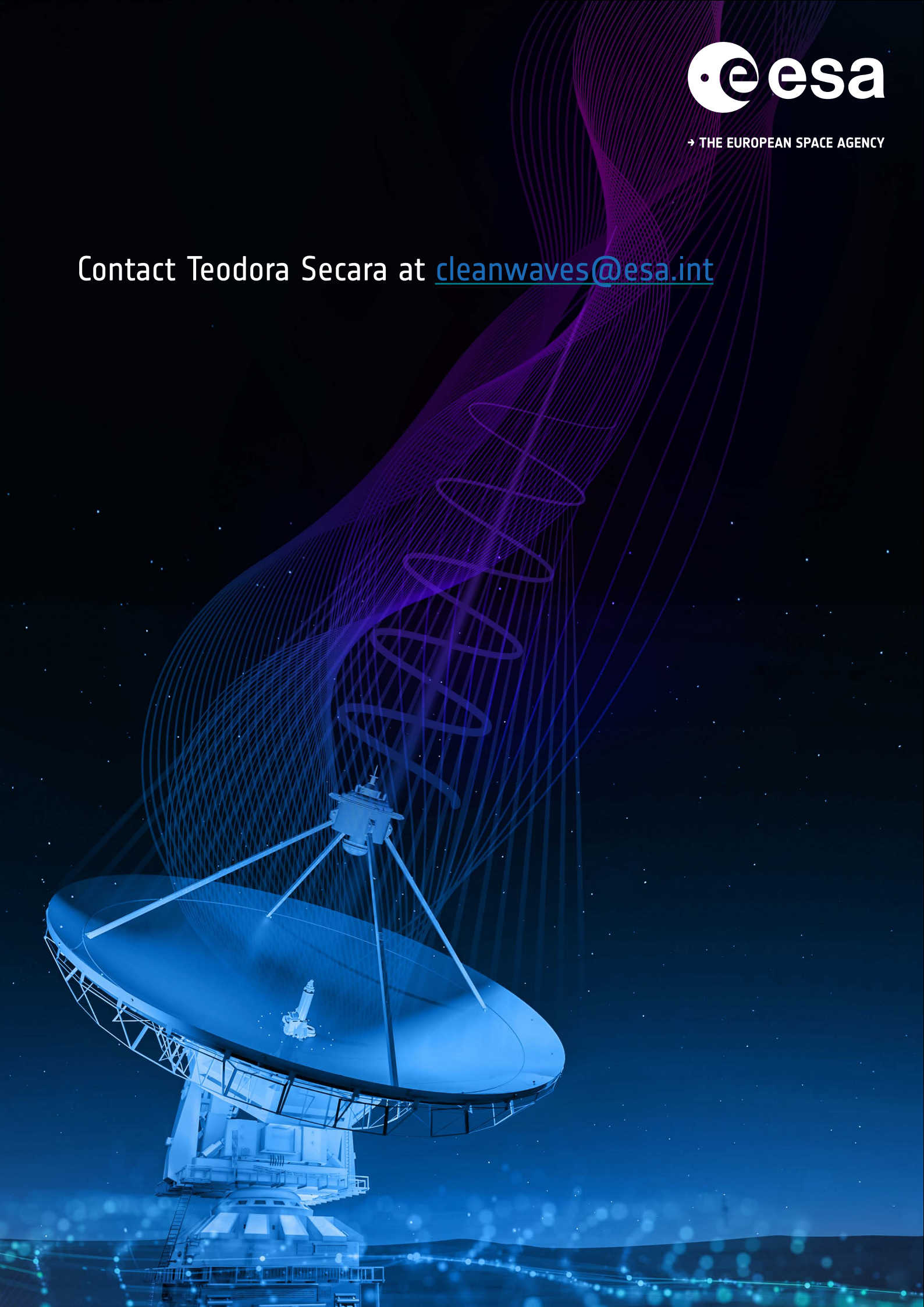
Building upon the foundation established to date, *CleanWaves* initiative is entering its next phase, aimed at translating strategic intent into practical developments to further consolidate Europe's capabilities on spectrum sustainability. Key areas of focus include:

- **Support the European industrial base**, through development and validation of key capabilities in the areas of RF monitoring, interference detection, location and mitigation, and spectrum use optimisation, as well as the inception of forward-looking ones, such as the development of an SDR-based payload capable of monitoring the RF spectrum and selectively unlocking designated frequency bands upon authorisation. These efforts aim to address current and emerging needs driven by the European commercial and institutional connectivity networks, to support the evolution of the European regulatory landscape, and to reduce dependencies on non-European capabilities.
- **Strengthening ecosystem collaboration**, with continued efforts to mobilise the commercial sector and a significant expansion towards institutional and governmental actors.
- **Integrate regulatory considerations and data governance into ESA frameworks** to ensure compliance with ITU Radio Regulations for activities related to RF monitoring across ESA, in alignment with ESA Member States.
- **Explore synergies with relevant institutional initiatives** and advance the maturation of key technology and capabilities that could serve as a foundation for future incorporation into institutional flagship programmes, such as Infrastructure for Resilience, Interconnectivity and Security by Satellite (IRIS^2) and European Resilience from Space (ERS).
- **Support for ESA-wide coordination on spectrum-related activities** to strengthen alignment, foster multi-domain collaboration, leverage synergies, and minimise overlap.

CleanWaves initiative reflects a timely and strategic effort to reinforce Europe's position in the evolving domain of RF spectrum monitoring, spectrum use optimisation, and interference detection, location, and mitigation. By fostering and supporting collaboration across institutional and commercial stakeholders, investing in critical capabilities, and considering the evolution of regulatory frameworks, the initiative aims to reinforce Europe's long-term resilience, competitiveness, and autonomy in the space-based RF domain towards spectrum sustainability.

As the initiative progresses into its next phase, on-going engagement with key players, such as ESA Member States, users, regulators, industry will be essential to ensure that *CleanWaves* delivers meaningful impact to European stakeholders.





Contact Teodora Secara at cleanwaves@esa.int