Roadmap for Decarbonizing the French Space Sector

COSPACE

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▲ *Kourou and the Guiana Space Centre seen by SPOT 6. © Airbus DS, 2022*

Contents

A SHARED AMBITION TO MAKE SPACE MORE SUSTAINABLE

The French space sector is central to the great challenges facing us today. Through its Earth-observation, geolocation and telecommunications capabilities, it plays a key role in economic, societal, sovereignty and environmental domains. The space sector thus contributes alongside the scientific community to climate modelling by producing data essential to monitoring the Earth system. Half of the Essential Climate Variables (ECVs) used to update IPCC scenarios are measured by instruments on board Earth-observation satellites. These instruments are irreplaceable tools over the long term and at a global scale for monitoring climate disruptions, detecting deforestation and sea-level rise, analysing the chemical composition of the atmosphere and more. These data are indispensable for supporting global environmental initiatives and concrete actions to protect living ecosystems. Further, space offers numerous applications supporting adaptation to climate change, providing, for instance, decision-support tools for communities and local authorities (urban heat islands, urban planning, agriculture, resource management, etc.). Finally, space is instrumental in mitigating natural disasters and providing assistance to affected populations.

The space sector also plays an essential role in preserving and guaranteeing national sovereignty and strategic independence. A sovereign launcher like Ariane 6 ensures independent access to space for France and Europe, launching all satellite missions that are helping to implement public policies, particularly in the fields of security and defence. Surveillance satellites make it possible, for example, to verify compliance with non-proliferation agreements, ensure the security of populations and act in the event of conflicts. These capabilities provide France and Europe with an independent decision-making capability that is vital in an uncertain and complex world.

French space sector stakeholders thus represent a vital pool of expertise, innovation and scientific talent that Europe must sustain in the long term. Their resilience to the socio-economic and geopolitical shifts being driven by climate change will require a concerted effort to maintain the sector's long-term competitiveness and fuel innovation. This roadmap therefore aims to initiate a first decisive step, predicated on determining the sector's environmental footprint and on the decarbonization efforts it can undertake.

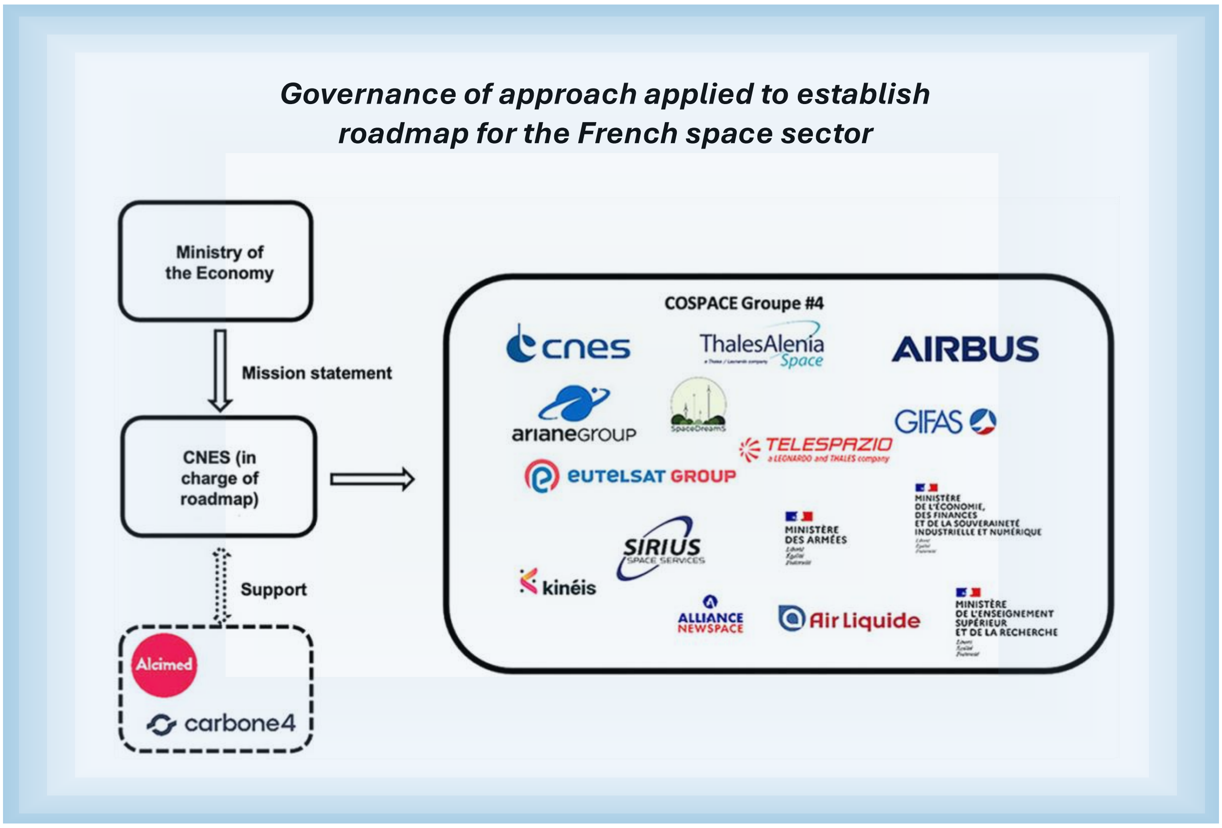
Like any industrial activity, the space sector has a carbon impact. Design, manufacturing, launch and operations: each stage in the process generates greenhouse gas emissions. The space sector has therefore taken ownership of these issues and proposes a collective approach to achieve France's objectives by 2050, thereby contributing to net-zero emissions.

A Voluntary and Structured Approach

The space sector **is not identified as a particularly high emitter** and is therefore not subject to the regulatory provisions of **Article 301 of the French Climate and Resilience Act**, which is reserved for the highest-emitting industrial sectors.

Nevertheless, under the impetus of the Ministry of Economy, Finance and Industrial and Digital Sovereignty, the sector has decided to step up its efforts and play its part in decarbonizing French industry by proposing trajectories for 2040 and 2050.

The roadmap is the result of close collaboration throughout 2024 within the French space ecosystem, under the 'Sustainable Development' working group of the **Government-Industry Space Consultation Committee (COSPACE)**. Work was led by the French space agency CNES, Thales Alenia Space (TAS) and the French enterprise agency DGE. Around 20 stakeholders from the ecosystem were actively involved in shaping this roadmap, including the principal ministries concerned, the French aerospace industries association GIFAS, the NewSpace France Alliance, prime contractors, satellite operators, space equipment manufacturers and operators. After 18 months of collaborative work, expert workshops and interviews, the COSPACE working group produced, with the support of Carbone 4 and Alcimed, a first working document in the form of a preparatory technical report for the development of this roadmap. This report defined all of the methodological choices, input data and factsheets necessary for implementation and monitoring of the roadmap by the sector's stakeholders. It also proposes a decarbonization trajectory aligned with France's objectives and levers for achieving it. The report is thus the result of a far-reaching effort by government representatives, CNES and industry to produce this roadmap.



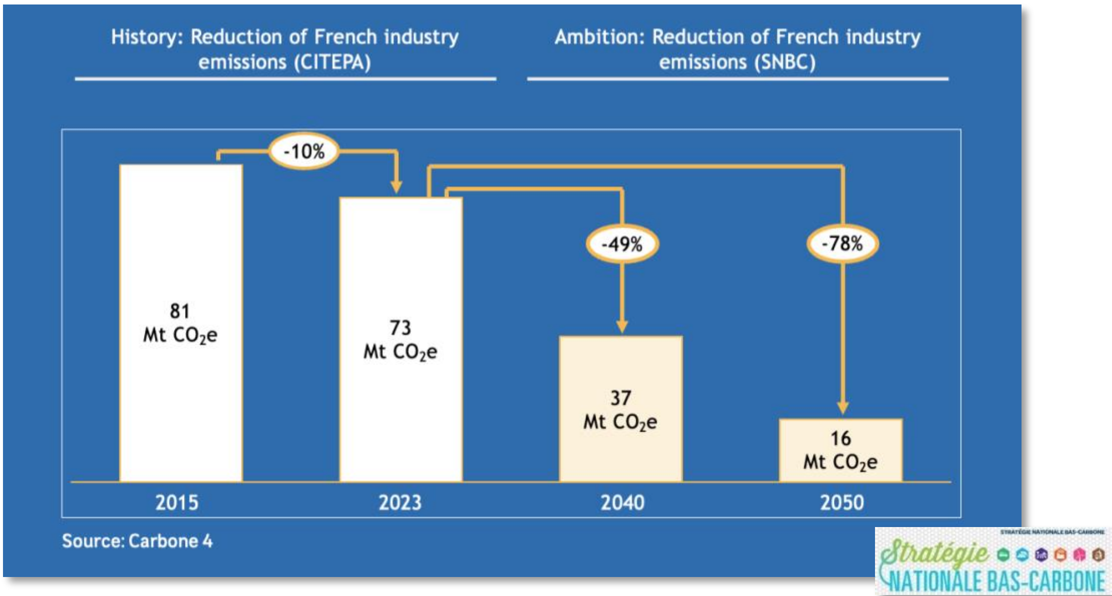
Governance of approach applied to establish roadmap for the French space sector

This initiative is a world first among leading space powers and positions France as a pioneer in undertaking a sector-wide decarbonization approach. It also aims to prepare the entire space ecosystem for the strategic challenges of accessing the resources and energy it needs to ensure France and Europe's independence in space. In this sense, the roadmap is intended to accompany the evolution of a sector whose sustainability and longevity appear essential to our societies.

DECARBONIZATION AMBITION FOR THE SPACE SECTOR

The space sector proposes an ambitious reduction scenario aligned with the National Low-Carbon Strategy (SNBC), namely to **reduce emissions by 49% by 2040** (an objective aligned with the SNBC's 'industry' trajectory).

This trajectory will be regularly updated in later versions of the roadmap, to achieve a 78% reduction in CO2 emissions relative to 2023 by 2050. The planned release of SNBC 3 in autumn 2025 may provide the necessary adjustment elements. Likewise, discussions with the General Secretariat for Ecological Planning (SGPE) may allow the final ambition for 2050 to be adjusted, potentially accounting for the specific characteristics of the space sector.



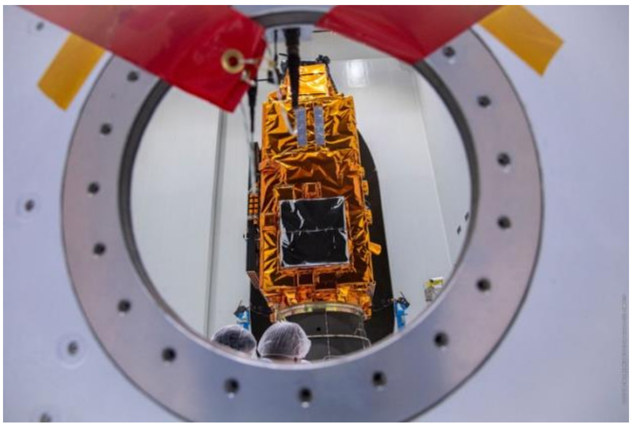
▲ *Decarbonization ambition of the roadmap for the French space sector, aligned with the trajectory set by SNBC-2 for the industrial sector.*

AN UNPRECEDENTED BASELINE ASSESSMENT

A first collective assessment has quantified the sector's annual emissions at **1.8 million tonnes of CO2 equivalent (MtCO2e)**, encompassing satellites, launchers, ground segments and user terminals. This represents **0.3% of France's national emissions**.

The portion of emissions from **ground and user segments** is primarily tied to electricity consumption and is therefore strongly influenced by the French energy mix, which has already made significant reduction efforts and is relatively low-carbon. In 2024, 95% of electricity produced in France was low-carbon, with more than 70% of electricity consumption coming from nuclear power (compared to an average of 25% in Europe). This estimate is based on quantified data available in 2024 and relies on assumptions established from life-cycle analyses by the sector's stakeholders.

This carbon footprint estimate does not include effects related to other types of emissions, notably in the upper atmosphere. Unlike other industrial sectors, the space sector has certain specific characteristics given its influence on the Earth's global radiation budget. **It is the only industry generating emissions in the upper atmosphere**: during the orbital insertion and atmospheric re-entry phases of space objects, particles are emitted (soot, alumina and water vapour generated during launch or re-entry phases) from the break-up of certain components. Preliminary scientific studies suggest these particles could have a significant impact on the upper atmosphere. Consequently, one of the roadmap's recommendations is to rapidly launch in-depth research to quantify the climate impact of these upper-atmosphere effects and identify appropriate reduction actions.



◂ *The European Biomass satellite, built by Airbus Defence & Space and launched from the Guiana Space Centre on 29 April 2025, is encapsulated in its fairing.*

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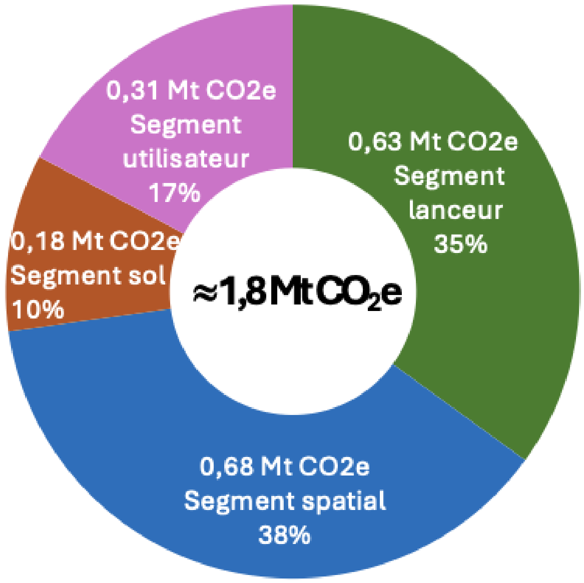
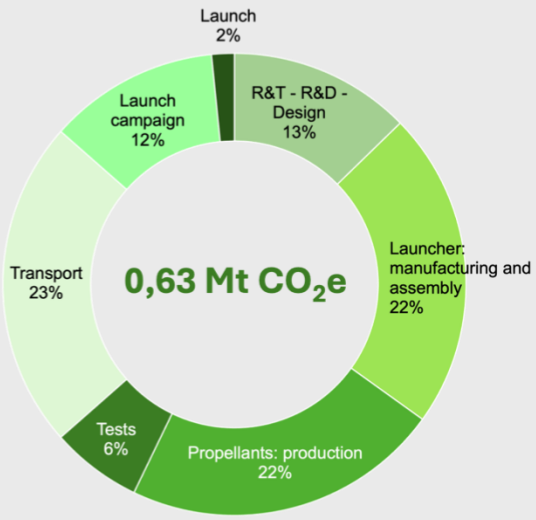
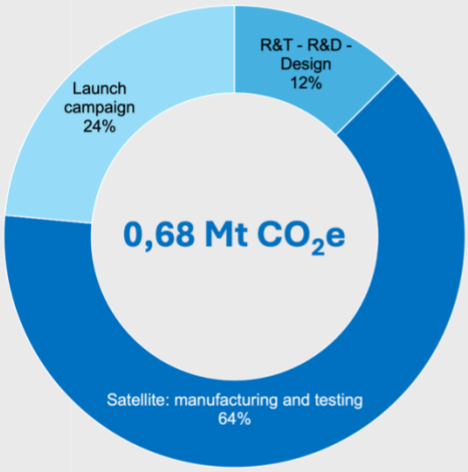
Carbon footprint breakdown of the French space sector

Source: Carbone 4

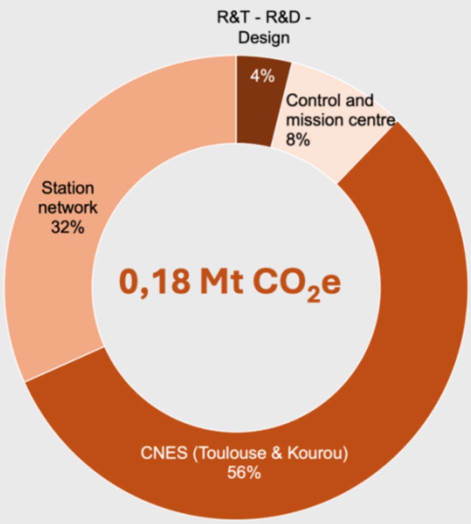




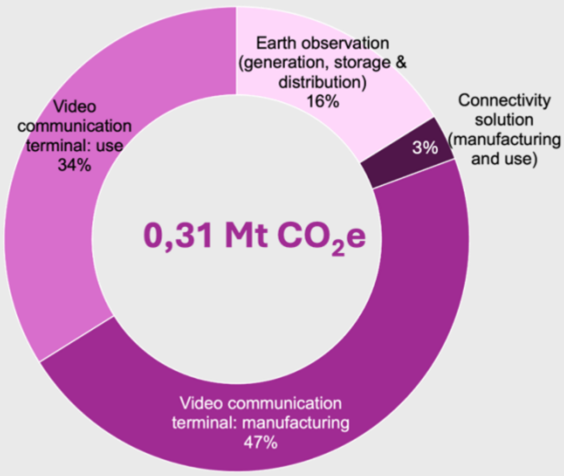
Launcher segment



Space segment



Ground segment



User segment

ACTION LEVERS FOR A TRAJECTORY ALIGNED WITH THE SNBC

To translate ambition into concrete actions, **12 action levers** have been identified, organized into six major themes.

Within this framework, proposals for changes to public policy have been put forward in order to ensure the sector's economic sustainability and to account for its specific characteristics, such as the preservation of sovereign access to space, the emergence of new players, the ESA geographical return principle, interdependence with other industrial sectors and its dual-use (civil/military) nature.

Each lever is structured as follows:

- Desired impact: Main objectives pursued.
- Barriers to overcome: List of potential obstacles that could compromise implementation.
- Actions: List of measures necessary to ensure success.
- Proposals for changes to public policy: Modifications to public policies required to facilitate application.
- Share of the footprint in 2040: Proportion of the carbon footprint concerned, expressed in %.
- Reduction potential in 2040: Maximum estimated reduction of the carbon footprint share, expressed in %.

Levers to be implemented at this stage across the sector to curb its carbon footprint are detailed hereafter. Example actions are not meant to be exhaustive. The technical report proposes other initiatives from which the sector's stakeholders could draw inspiration, while monitoring of the roadmap's implementation by the COSPACE sustainable development WG will enable new actions to be identified.

Theme 1: Energy

Lever 1: Reduce energy and material consumption during development, qualification and manufacturing phases

The development phases of space systems are particularly energy-intensive, involving diverse processes such as work in design offices or laboratories, the creation of mock-ups at different scales, numerical computations and travel. These activities can be organized in a more sober manner, for example by limiting the number of prototypes developed or by using more efficient means of production.

The qualification and manufacturing phases are long and require clean rooms and a lot of energy-intensive technical equipment such as thermal vacuum chambers. These phases therefore offer opportunities for implementing a new approach aimed at reducing energy consumption and material use.

Examples of actions:

- **Quantify the consumption** of test equipment, individual tools and consumables before planning their reduction, then track progress over time. **Extend** this quantification requirement to all stakeholders, notably suppliers. **Communicate regularly about objectives and results** to ensure transparency and shared commitment.
- **Promote reuse of equipment** (machines, IT, raw materials, ground support equipment — GSE) across space programmes and among partners.
- **Encourage recycling** to optimize resource use and reduce consumption of new materials.

Lever 2: Optimize energy consumption of ground segments

Ground segments, comprising telemetry and tracking stations, antennas and launch facilities, incorporate large volumes of computing and data storage hardware, as well as spaces dedicated to testing or assembling elements sensitive to temperature and humidity variations. These segments are therefore energy-consuming, as a controlled and healthy atmosphere must be maintained continuously. It is therefore essential to optimize not only the equipment, but also its environment and usage.

Examples of actions:

- **Optimize energy consumption** of ground segments and industrial equipment
  - **Gradually improve the thermal properties of buildings.**
  - **Apply energy-efficiency best practices** for heating and air conditioning.
  - **Streamline the quantity of hardware** according to real needs, while ensuring resilience and redundancy.

- **Renew equipment** by questioning its lifespan, weighing embodied energy against daily energy consumption, and taking into account obsolescence and market standards.

Lever 3: Use low-carbon energy to operate industrial equipment (incl. suppliers), to produce propellant and for ground segments

The adoption of low-carbon energies is essential to meet the electrical and heat needs of space sector industrial facilities, as well as for propellant production. Promoting self-consumption — for example, via the installation of photovoltaic panels near ground segments — is also an effective solution, provided its carbon footprint is lower than that of grid electricity, especially for facilities outside metropolitan France. In regions where access to energy is limited or constrained, priority should be given to deploying renewable electricity solutions. This approach will help not only to reduce dependence on fossil fuels and generate savings as prices increase, but also improve energy independence through self-consumption.

More broadly, the energy roadmap for buildings and infrastructures provides a useful basis for making energy improvements to ground equipment and industrial facilities, since they consume energy like any other industry. Emissions from energy consumption at specific facilities like Kourou and ground stations around the globe could be significantly reduced by improving the current energy mix. This would also enable development of lower-carbon propellants.

Examples of actions:

- **Define energy solutions adapted to each geographic region** (including local energy mix, local climate characteristics and each use case, leveraging experimental systems).
- **Promote self-consumption**, for example by installing photovoltaic panels near ground segments.
- **Opt for electricity with renewable guarantees of origin** in countries where low-carbon energy is difficult to access.
- **Use low-carbon energy** for electricity needs and heating, cooling and propellants for the sector's industrial equipment and ground segments.

Lever 4: Optimize energy consumption of user terminals

A significant portion of the carbon footprint in the digital sector is directly attributable to user terminals, the growing number of which is fuelling increased energy consumption, exacerbated by constantly improved device performance. This phenomenon is also present in satellite telecommunications, where the expanding number of terminals is contributing significantly to the sector's carbon footprint. Reducing the consumption of such terminals would limit the increase in emissions from acquiring and using them.

Energy efficiency and reducing ecological impacts are key issues for the development of electronically scanned arrays (ESA) for satellite telecommunications antennas. Existing active antenna solutions have the disadvantage of high energy consumption and a significant environmental footprint due to their reliance on semiconductor components using rare earths.

Examples of actions:

- **Strengthen R&D on user terminals and network usage** to limit their energy consumption while controlling costs, particularly for antennas and terminal standby mode.
- **Conduct system analyses** to identify architectural modifications that could relax terminal requirements, offering additional levers to reduce their energy consumption.
- **Maximize provision of solar power systems with satellite terminals**, especially in regions not served by low-carbon energy.
- **Optimize end-to-end satellite architectures** (space + ground segment) to optimize user terminal architecture and consumption.

Theme 2: Transport

Lever 5: Optimize transport of people, launchers, satellites and parts throughout the supply chain

The French space sector's supply chains are often dispersed across France and Europe, lengthening and complicating logistics, and generating a significant carbon footprint. Moreover, launch sites (such as the Guiana Space Centre) are often a long way from production or test facilities for launchers and space objects, requiring transatlantic crossings by ship or plane, for example when conducting assembly on the launch pad and during launch operations.

Optimizing these logistics flows, through rationalizing movements, better site location and low-carbon multimodal transport strategies, would significantly reduce the environmental footprint of assembly and launch activities.

Examples of actions:

- **Streamline the supply chain**, in particular by:
  - **Reducing cumulative distances.**
  - **Shifting to transport modes with a lower carbon footprint.**
  - **Locating facilities within existing hubs or clusters.**
  - **Using carriers with a virtuous carbon label** (e.g. 'objectif CO_2e'), where available.

- **Streamline the transport of people**, by:
    - **Promoting the design of remote operation, action and maintenance systems** to allow centralization and pooling of operational teams, thereby reducing the need for travel to operational sites.
    - **Implementing digital twins** to dispense with on-site visits.

Theme 3: Low-Carbon Materials, Propellants and Processes

Lever 6: **Develop and use low-carbon materials and processes for the manufacture of launchers, satellites, ground segments and the sector's industrial resources**

Manufacturing processes and material consumption in the space industry contribute significantly to carbon emissions. This is further accentuated by the fact that space systems require complex materials, either to miniaturize technologies (e.g. semiconductors) or to harden them for the extreme conditions of space.

Several solutions can be envisioned to reduce the carbon footprint of materials and processes, both inside and outside the space industry. Using low-carbon-impact materials such as recycled materials (aluminium, titanium, copper, etc.), substitute materials (e.g. silicon instead of germanium where possible), materials from low-carbon production, improving material utilization rates (buy-to-fly ratio versus testing), product lifetimes and the recovery and reuse of launcher stages (after relevance analysis factoring in atmospheric re-entry emissions) are all promising avenues to be explored to reduce the environmental footprint of space missions.

Examples of actions:

- **Align all French space sector stakeholders** with a common definition of 'low-carbon' materials.
- **Incorporate eco-design processes** in the design phase of each French space sector player.
- **Draw on the roadmaps of other sectors** to identify materials and processes that could also reduce carbon impact in the space sector.
- **Investigate scenarios for the availability of recycled materials and elements**, including recovery of certain launcher stages, used equipment, recycling of materials from other sectors and circular processes to minimize machining wastage, while evaluating the resulting potential for use.

Lever 7: **Develop and use low-carbon propellants for launchers and satellites**

This lever addresses the decarbonization of propellants from a chemical process perspective (choice of one process over another), rather than from the perspective of using decarbonized energy, which is addressed by Lever 3. The development and use of low-carbon propellants for launchers and satellites aim to reduce their carbon footprint at several levels. These propellants can reduce emissions from production processes, which are often energy-intensive and a long way from the propellants are used, provided a local low-carbon source is available. They also lower carbon emissions during combustion on Earth and should attenuate upper-atmosphere effects. However, upper-atmosphere effects generated during launch are not solely correlated with the use of lower-emission propellants, as they involve distinct dynamics. It is therefore vital that the sector address these issues in other ways and that conduct in-depth research.

Examples of actions:

- **Align all French space sector players with a common definition of 'low-carbon' propellant**, which involves better quantification, through research, of the climate impact of the manufacture and combustion of different propellants (see UA lever).
- **Incorporate eco-design processes** in the design phase of each French space sector player.
- **Study the carbon reduction gains** from 'low-carbon' propellants.
- **Align the entire propulsion system evolution strategy** with those in the chemical industry roadmap.

Lever 8: **Reduce the material impact of user terminals**

User terminals have a significant impact on the carbon footprint of satellite telecommunications. Moreover, demand for user terminals is growing strongly, notably due to the emergence of constellations enabling low-cost satellite telecommunications. It is therefore essential to use this lever to reduce this impact effectively.

Examples of actions:

- **Initiate R&D for eco-design of terminals** at the raw materials level, while taking into account strategic supply issues (controlling the supply chain and ensuring it is maintained during a crisis).
- **Consider modularity and interoperability** to enable the reuse of a single terminal across different SATCOM systems. For example, the same modem could be used for several systems or a modem could be changed out without changing the antenna. This implies the use of a terminal and a single standard or compatible interfaces, thus easing integration and flexibility of satellite network equipment. At this stage, actions are limited to France.
- **Promote multi-frequency-band (K_u and K_a) and multi-orbit (GEO/LEO) antenna technologies.**

- **Promote the 'Terminal as a Service' model** for certain mass-market applications that use a single system at a time.

Theme 4: Shared Resources

Lever 9: Promote and support sharing of industrial tools within the sector

To optimize existing resources and avoid duplication of infrastructure, we must prioritize the use of existing industrial resources. This means increasing the utilization rate of this equipment and pooling certain industrial tools within the space sector, both at national and European level. This lever is especially important given that some infrastructures are very energy-intensive (e.g. clean rooms).These infrastructures and test equipment are often costly to develop and maintain, and would benefit from being used by a greater number of stakeholders.

Examples of actions:

- **Foster connections between stakeholders** by consolidating the map of shared and shareable resources for design, manufacturing, testing and operations of space infrastructures.
- **Standardize shared-resource offerings**, notably via standardization of interfaces for shared industrial resources and tools, as well as products requiring the use of such resources.
- **Implement specific cleaning procedures** including post-test cleaning quality control.
- **Maximize virtualization of tests** to reduce the number of real tests and duration of use of common test resources, thus increasing their availability for other users and reducing their consumption of energy, fuel, etc.

Lever 10: Share and standardize launch bases, launcher and satellite control and mission centres, and ground stations

More satellite launches and launch systems are driving a trend towards more launch bases, control and mission centres for launchers and satellites, and associated ground stations. The overall carbon footprint of these infrastructures can be reduced despite growing needs by limiting their number through sharing and by increasing the utilization rate of existing sometimes under-used facilities. This will enable continued guaranteed access to space for all, without systematically building new infrastructures.

Examples of actions:

- **Develop European standards**, notably for launcher, satellite and fuel interfaces.

- **Design and operate a launch base** capable of accommodating different types of launchers on the same launch pad.
- **Design launchers compatible with launch pad standards** (this action depends on the results of ESA's European Launcher Challenge at its ministerial conference scheduled in 2025).
- **Standardize, virtualize and cybersecure control and mission centres and ground stations** to make them 'multi-mission' with a streamlined approach at French and European level.

Theme 5: Data

Lever 11: Optimize generation, storage and processing of science and Earth-observation data

Currently, data storage systems are often redundant and involve duplicating data to ensure the security and availability of critical information. However, this practice requires significant hardware infrastructure and energy consumption. By reducing the volumes of data to be stored or limiting the frequency and systematic nature of their transmission, it would be possible to reduce equipment and energy needs. This would not only reduce the carbon footprint attached to the production and operation of these systems, but also optimize the energy efficiency of space operations as a whole.

Examples of actions:

- **Streamline the volume of science and Earth-observation data** processed, stored and distributed, drawing on work already accomplished by CNES.
- **Identify upstream the necessary data** based on societal need and interest in order to reduce the collection, storage and processing of superfluous data.
- **Foster international partnerships**, beyond the major space powers, to encourage the sharing of science data and optimize the use of global resources.
- **Explore on-demand access and computing strategies rather than systematic ones**, depending on use cases, to reduce resource consumption.
- **Develop data acquisition and transfer strategies directly on board satellites**, in order to reduce the quantity of data transferred between satellites and ground stations.

Theme 6: Upper Atmosphere

UA Lever: Reduce the proportion of materials and propellants with a high radiative impact and/or ozone-depletion potential, during the propelled phase and atmospheric re-entry of launchers and satellites

In-depth research must be conducted to better understand upper atmosphere phenomena. This research must guide the development and selection of materials and propellants with a lower impact for the launchers and satellites of tomorrow. Although the magnitude of the impact of certain materials and propellants in the upper atmosphere is still poorly understood, their contribution to radiative forcing is now almost certain. It is essential to reduce the proportion of materials and propellants with a high radiative impact or contributing to ozone layer depletion. Studies on improving the combustion efficiency of engines can also help to reduce the proportion of these emissions.

Given the expected orders of magnitude, deploying this lever is a priority.

Examples of actions:

- **Conduct research** including simulations, modelling and characterizations to better understand the phenomena occurring in the upper atmosphere during launch and re-entry phases.
- **Develop** materials or propellants with low radiative impact and/or ozone depletion potential, minimizing upper-atmosphere effects.
- **Help the sector to fund this transition** by prioritizing R&D, notably on bio-sourced materials.

▲ *Ariane 6 on the launch pad at the Guiana Space Centre.*

ADDITIONAL ENABLING ACTIONS TO IMPLEMENT THE ROADMAP

To support implementation of the roadmap around a shared ambition, enabling actions have been identified to harmonize efforts. These aim to align players with shared objectives, establish common criteria and promote the adoption of good environmental practices across the sector. They must also help preserve the sector's competitiveness, provide the financial support needed to implement the levers and incorporate an employment and skills component and a research component.

☞ **Enabling Action 1 – Establish shared objectives within the sector to reduce the carbon intensity of different types of objects (launcher, space, ground and user segments)**

Adopting a shared 'systems vision' would allow each stakeholder to assess environmental impacts holistically and to avoid rebound effects or carbon transfers between sub-systems (launchers, satellites, ground segments, user segments).

☞ **Enabling Action 2 – Integrate environmental and societal impact criteria into investment programmes**

To orient investments towards more sustainable and responsible space programmes, it is necessary to define a specific methodology and evaluation criteria based on several key focuses:

- carbon footprint;
- societal and environmental utility of the mission;
- comparison with alternatives (comparing space programmes to other solutions for an equivalent service).

☞ **Enabling Action 3 – Define common carbon criteria in supplier specifications at sector level**

To strengthen the transition towards a more sustainable space sector, common carbon criteria should be established in specifications for suppliers of parts, equipment and services. These criteria may include assessment of the carbon footprint of materials and components, use of sustainable materials, optimization of manufacturing processes and reduction of the logistical footprint. This approach, already initiated for government contracts, should be applied across the board.

☞ **Enabling Action 4 – Promote good environmental practices in space at national, European and international level**

While it is beyond doubt that a decarbonized, low-environmental-footprint space sector is the only way to ensure the full exercise of Europe's space sovereignty in the future, the ecosystem must first undergo a difficult and critical transformation phase. Its deployment must be protected by establishing a level playing field between the French industry and its European and non-European competitors, including notably a carbon border adjustment mechanism at the EU level.

☞ **Enabling Action 5 – Promote transparency of the environmental impact of space services to end users**

Several initiatives already exist to raise awareness and provide training on environmental issues in the space sector. The task is now to structure and systematize this approach, by integrating these themes in a cross-domain manner into training programmes and specialized conferences. This notably implies that dedicated training modules should be introduced into engineering and university curricula, including content specific to the space sector, such as concrete case studies.

☞ **Enabling Action 6 – Raise awareness and train academics, engineers, policy-makers and French space sector stakeholders and their suppliers on the environmental issues of space**

Several initiatives already exist to raise awareness and provide training on environmental issues in the space sector. The task is now to structure and systematize this approach, by integrating these themes in a cross-domain manner into training programmes and specialized conferences. This notably implies that dedicated training modules should be introduced into engineering and university curricula, including content specific to the space sector, such as concrete case studies.

☞ **Enabling Action 7 – Initiate demonstration programmes on the carbon optimization of launchers and satellites**

To accelerate the decarbonization of the space sector, it is essential to establish demonstration programmes focused on the environmental optimization of launchers and satellites. These programmes must build on current technologies to prove that it is possible to improve the sustainability of spacecraft without compromising their operational performance.

Such initiatives will enable testing and validation of innovative solutions, like the use of low-carbon materials, life-cycle optimization or improvement of energy efficiency. By demonstrating the real-world environmental benefits, they will encourage wider adoption by industry.

☞ **Enabling Action 8 – Initiate R&D work on 'decarbonized space systems'**

Systemic analyses of space mission architectures should be conducted when performing carbon footprint assessments, encompassing the launcher segment, space segment, ground segment and user segment. These analyses must take into account the entire ecosystem and include aspects such as the interoperability of terrestrial and space systems at a global scale, as well as upper-atmosphere effects.

By adopting this broad vision, potential interactions and synergies can be identified to reduce the carbon footprint. This would make it possible to optimize systems throughout the value chain and facilitate coordination between ground and space infrastructures to ensure a lower environmental impact.

☞ **Enabling Action 9 – Initiate R&D work on the circularity of satellites**

Lastly, a special effort is required in research and development focused on satellite circularity in two key areas: in-orbit services and space logistics.

In the field of in-orbit services, the objective is to develop technologies and solutions to extend satellite lifetimes, notably through maintenance, repair, payload addition or in-orbit refuelling operations.

Research in the field of space logistics should focus on its optimization, in particular on the functional boundaries between launchers and satellites. This includes studying coordination and complementarity between launch systems and satellites to make space operations more efficient and sustainable.

These initiatives would help to significantly curb space debris while fostering a circular approach to managing in-orbit resources, thereby reducing the number and mass of payloads to be manufactured and launched.

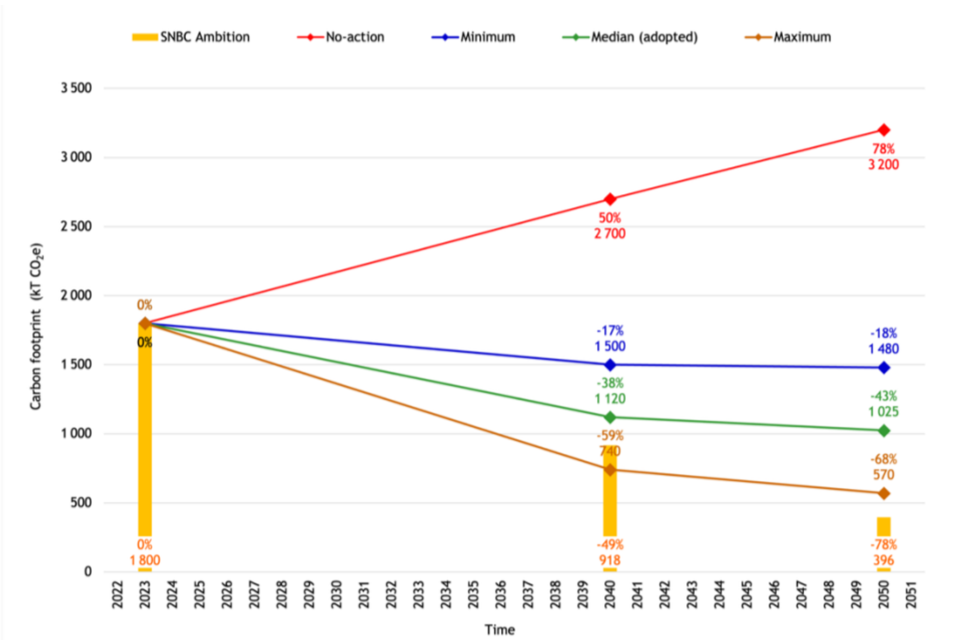
THREE SCENARIOS, ONE REALISTIC TARGET

Three possible trajectories have been modelled. Only the 'maximum' scenario, integrating all the levers detailed above, would achieve the 49% reduction in carbon emissions by 2040. However, it assumes a very high level of commitment and carries uncertainties tied in particular to the technical maturity of the proposed solutions and the effectiveness of their deployment in the field.

At this stage, in the interest of realism, the roadmap therefore adopts an **intermediate scenario targeting a 38% reduction in emissions by 2040**. It highlights the need to **identify new levers by 2050** to close the remaining gap. The 'median' scenario will require an additional emissions reduction of 904 ktCO2e over the period 2040–2050, to achieve the final reduction target of 78% by 2050. This finding underlines the need to conduct further studies to increase the effectiveness of the envisioned levers and identify new ones.

The diversity of levers highlights the varying maturity and implementation effort specific to each segment. Thus, some levers can be activated more easily, while others will require more substantial effort and investment.

Decarbonization trajectories



A STRATEGIC TURNING POINT FOR THE SPACE SECTOR

Decarbonization is much more than an environmental obligation: it offers a **strategic opportunity** to strengthen the French space sector's technological independence, resilience and attractiveness. In this sense, this roadmap aims to play its part as a lever for transforming industrial policy in the space sector. By charting this course, France also invites its European partners to join it, to build together a space industry that is **stronger, more sustainable and forward-looking**.

COSPACE GT#4 working group responsible for drawing up the roadmap will ensure operational monitoring of these actions and regularly update the roadmap (levers, assumptions, growth, etc.). This operational monitoring will also allow for the regular updating of data and necessary actions. It also invites the entire sector to act on the conclusions of this roadmap and the associated technical report in order to achieve this transition, and calls for a collective commitment shared by all stakeholders and by public policies.

The harmonization of objectives within the European Union and the guarantee of consistency of actions between Member States will obviously be essential to ensure fair and effective implementation of this roadmap and to maintain the competitiveness of the entire sector at European level. A specific governance structure will be put in place to ensure operational monitoring and regular updating of the roadmap. Its accomplishment will depend in particular on creating the conditions for success and on removing a certain number of obstacles to achieving its goals.

In the long term, this roadmap aims to strengthen the competitiveness and independence of French stakeholders to support an ambitious, sustainable, decarbonized and lasting European space policy. This approach will also contribute to France's international influence while extending the impact of decarbonization levers to other nations, in a sector marked by strategic dependencies and competitive challenges at a global scale.

▲ *Toulouse, the emblem of France's space industry, seen by the Pleiades Neo satellite.*

ACTIONS ALREADY UNDER WAY

COSPACE members are already gearing up for the low-carbon transition and emphasize that the identified levers are in line with ongoing research, investment and overall skills development within their teams. The expertise companies possess in environmental impact analysis — particularly through institutional programmes — constitutes a strong foundation for future technical developments.

While this document makes no claim to be exhaustive, it intends to highlight some actions already undertaken that provide a solid foundation for pursuing the roadmap's ambitions. They are detailed here as illustrations to underline the current momentum across the space sector.

At **Airbus**, particular attention is currently paid to assessing the impacts of products and missions, to material circularity, to reducing the impacts of its industrial facilities, and to developing environmental impact analysis methodologies in collaboration with the sector (for example within the framework of the European Product Environmental Footprint Category Rules consultation for space). This roadmap should accelerate the emergence and development of sustainable technological alternatives that preserve technical performance while developing cooperation with the supply chain and customers.

All of **ArianeGroup**'s activities contribute significantly to the country's economic, scientific and technological development, and in this context the group is aware of its role in protecting the environment. ArianeGroup is already taking action in this direction through its climate roadmap, including the reduction of the transport impact of Ariane 6 to French Guiana via the hybrid cargo ship *Canopée*. Environmental product impact is increasingly integral to the group's strategy. Thus, its MaiaSpace subsidiary applies eco-design principles from the earliest stages of launcher definition.

For **Thales**, an ambitious low-carbon strategy reflecting its commitment to combating climate change has been deployed since 2019. This approach aims to significantly reduce the group's emissions and those from its supply chain. Thales has defined emission reduction trajectories for 2030 compatible with the Paris Agreement and validated by the SBTi (Science Based Targets initiative). It is also pursuing a broader eco-design approach to improve the performance of its products, optimize their life cycle and reduce their environmental footprint.

Thales Alenia Space developed in 2022 a strategic transformation approach, including the development of specific tools for assessing the environmental footprint of its solutions and analyzing market performance and sustainability. The company is also at the forefront of developing solutions to make space more sustainable, such as space robotics technologies (on-orbit servicing) aimed at extending satellite lifetimes and curbing space debris.

Eutelsat integrated greenhouse gas emission reduction objectives, validated by the Science Based Targets initiative (SBTi) in January 2025. Aligned with the Paris Agreement, these objectives provide for a 50% reduction in absolute emissions (Scopes 1 and 2) and a 52% reduction in carbon intensity per satellite Mbit (Scope 3) by 2030. The carbon footprint is published annually in accordance with the GHG Protocol methodology.

Eutelsat adheres to the transparency requirements of the EU Corporate Sustainability Reporting Directive (CSRD), which it sees as a strategic tool for monitoring its CSR performance.

Eutelsat is also a committed actor for responsible use of space, with a zero-debris objective in protected orbital regions, in connection with its GEO activities.

Within the NewSpace ecosystem, several initiatives are being deployed to meet the decarbonization objectives of the space sector. These are based partly on the development of technologies with a lower environmental impact. For example, Greenerwave designs low-consumption SATCOM user terminals reducing the semiconductor material footprint, and MECANO ID develops eco-designed and eco-produced mechanical parts.

Other levers complement this dynamic by promoting more sustainable use of space: SpaceLocker offers shared space missions to reduce the carbon footprint of missions and the creation of debris, while SpaceDreamS works on sharing infrastructure with the development of a shared launch pad.

CNES is deploying an ambitious decarbonization strategy for the Kourou space base in order to provide all users with resilient, low-emission infrastructure. The deployment of solar farms will provide all industrial operators on the base with renewable electricity within two years, and the Hyguane programme (Guiana Green Hydrogen) will deploy the first green hydrogen supply chain overseas in the medium term.

Aware of its role as a space agency, CNES is committed to supporting the entire sector in its decarbonization efforts through its Responsible Purchasing Promotion Scheme.

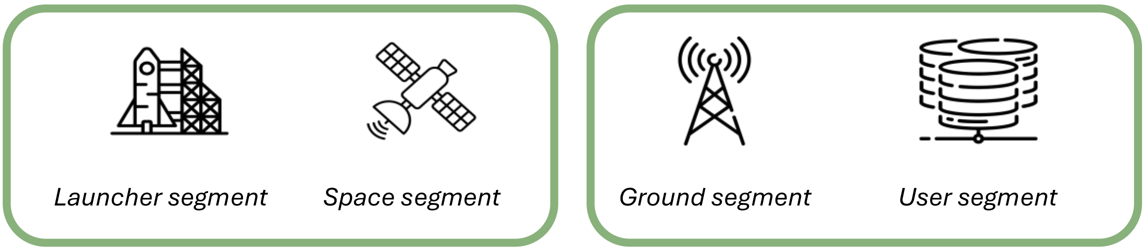
CNES is also committed to supporting the space sector through open life-cycle analysis tools for all segments, and through studies and research work for the benefit of all.

The production of this roadmap has also elicited numerous enthusiastic responses from SMEs who may propose their own actions. Future reviews of the roadmap will relay these best practices and share findings.

Annex

Methodology for Calculating the Footprint of the French Space Sector

The **segments considered** for assessing the carbon footprint of the space sector are launchers, the space segment, the ground segment and the user segment.



A **launcher** is a spacecraft designed to carry a payload (e.g. a satellite) from the surface of Earth into space. Launchers may be reusable or expendable and be powered by different kinds of propulsion (solid, liquid or hybrid), depending on their design.

The Launcher segment covers all stages of the life cycle of spacecraft, from assembly to the launch campaign. It encompasses research and development (R&D), component integration, manufacturing and reliability testing, through to transport to launch sites, final preparation for lift-off and launch. It also encompasses the production of propellants required for launch.

The Space segment comprises all physical elements in space necessary to operate a space system (e.g. satellites, space stations, space probes, service modules, etc.), as well as elements operating in the stratosphere (balloons, HAPS, etc.). It encompasses the entire life cycle of space segments (satellites, probes, etc.), from design through to commissioning and use. It includes R&D, component manufacturing, module assembly, reliability testing, transport to launch sites and final pre-launch preparations. However, as with launchers, it does not encompass the end of life of satellites or their possible re-entry, due to a lack of data and significant uncertainty regarding upper-atmosphere effects.

There are two types of ground segment: the management and operation of satellites and their data, and the ground support equipment necessary for carrying out a space mission.

The “satellite” ground segment comprises all infrastructure necessary to control and operate satellites, but also to receive and analyse space data. It also includes R&D, control centres, field centres, telemetry, tracking and command (TTC) stations, telecommunication and data reception, storage and processing systems, ground space situational awareness (SSA) systems like radars and telescopes, and launch sites (or launch bases) such as the CSG, ideally located and designed for space launch. Launch bases generally comprise a range of infrastructures, including ground support equipment (power generation, telemetry systems, payload preparation facilities, etc.). The ground segment does not include user-owned equipment, which is part of the user segment.

The user segment comprises the infrastructure and equipment necessary for users to exploit space data. The segment includes terminals that receive signals from satellites, as well as data centres where this information is processed, stored and analysed by users. It also encompasses the data and energy consumption of associated data centres for downstream applications such as weather forecasting, navigation, Earth observation and the Internet of Things (IoT), which use these data for a range of applications on Earth.

Scope of activities: Both civil and military activities.

Operational scope: All objects manufactured or operated by a French space sector stakeholder, whether located on national territory or abroad, in order to account for the sector's full footprint.

Reference period: The year 2023, with the exception of launchers and satellites, whose activities are averaged over the period 2018–2023 to smooth out sectoral variability.

Scope of available data: The calculation does not yet include certain potentially significant upper-atmosphere effects (soot, alumina, water vapour during launches and re-entries) due to insufficient scientific data. The roadmap provides for research work to address this gap.

Initial data and their limits were detailed for each type of object:

- **Launcher segment**: Analysis includes and averages out all launcher segment CO2e emissions between 2018 and 2023. However, as with launchers, it does not factor in the end of life of satellites or their possible atmospheric re-entry, due to a lack of data and significant uncertainty regarding upper-atmosphere effects. These effects, notably those generated by soot and alumina during launches, and the consequences of atmospheric re-entry were not factored in due to insufficient scientific data.
- **Space segment**: All space segment CO2e emissions between 2018 and 2023 were also factored in and averaged out. These emissions were assessed on the basis of a reference life-cycle analysis (LCA) for each category of satellite (telecommunications, science, Earth observation, etc.). As with launchers, upper-atmosphere effects due to atmospheric re-entry at the end of life of satellites were not factored in due to a lack of available data.
- **Ground segment**: Reference LCAs were applied to antennas and control centres, regardless of size. Emissions generated by research and development (R&D) were accounted for using monetary factors, a still imprecise method. Guiana Space Centre and Toulouse Space Centre data were supplied by CNES and are based on available LCAs.
- **User segment**: Assessment of energy consumption of user terminals, notably for LEO and GEO telecommunications, and of the volume of stored Earth-observation data required numerous sizing hypotheses due to the inherent uncertainties of these data.

This broad scope paints a more precise picture of the sector's carbon footprint, while highlighting certain avenues for improvement with regard to data availability and factoring in of upper-atmosphere effects. It is therefore crucial to develop and maintain reliable data sources to guarantee transparency, verifiability and the credibility of findings and resulting actions.

The roadmap is thus predicated on an initial set of available data, meaning that it needs to be improved and has its limits. However, this first classification of data provides essential elements for prioritizing actions. While it is perfectible, this initial study must serve as a blueprint and master plan in the years ahead, guiding future efforts through a structured and stepwise approach that must be pursued robustly and with the greatest transparency possible.

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COSPACE

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