



EUROPEAN SPACE AGENCY

ELEVATING THE FUTURE OF EUROPE

SPACE WEATHER DEMONSTRATOR PHASE 2:

QUESTIONNAIRE RESULTS

1. EXECUTIVE SUMMARY

1.1. Purpose

This executive summary presents the principal interim findings of the Space Weather Demonstrator Phase 2 (Sectorial Phase). Within the following three high priority sectors, it provides an indicative, cross-sector view of service uptake, user needs, reported disruptions, and preparedness to inform follow-up engagement and the continued development of the ESA Space Weather Service Network. Sectors addressed by the Space Weather Demonstrator Phase 2:

- Spacecraft Operations
- Communications and/or PNT
- Power System Operation

1.2. Scope, method and interpretation

The interim findings are based on responses to an online questionnaire distributed by 18 National Points of Contact across 15 ESA Member, Associated and Cooperating States, from February to December 2025. The sample comprises 94 organisational responses, concentrated in three priority sectors: Power System Operation (29%), Communications and/or PNT (28%), and Spacecraft Operations (26%). Findings should be interpreted as indicative assessments; national and sub-sector sample sizes vary, and findings are self-reported. In some cases, impact information is unavailable or withheld for confidentiality reasons and in some cases (sub)sectors known to have limited awareness of space weather and its potential impacts were intentionally targeted by national contact points as a means by which to support awareness raising. The mapping exercise categorises respondents by functional role to reflect multi-role stakeholders; it is not intended as an exhaustive inventory or assessment of regional preparedness.

1.3. Key findings

Service uptake remains limited, but the short-term adoption potential is significant. Overall, 36% of respondents currently use space weather services, while 64% do not. Among non-users, 40% intend to adopt. Where adoption is planned, forecasts are the dominant entry point, requested by 96% of prospective adopters, ahead of measurements and nowcasts at 58% and post-event analysis at 33%.

Users align strongly on what constitutes a high-value service, yet satisfaction remains only moderate. Across current users, the highest-rated service attributes are accuracy at 4.44 out of 5, clarity at 4.29, accessibility at 4.21, and timeliness at 4.09. However, satisfaction scores are materially lower even on these fundamentals (3–4). The weakest satisfaction areas are customisation at 2.47, data enrichment and analysis at 2.59, and 24/7 expert support at 2.47.

Demand is principally for enabling operational knowledge rather than general awareness. Self-assessed understanding averages 3.53 out of 5, with a median of 4; 59% rate their understanding as high (4–5), while 19% rate it as low (1–2). Nevertheless, 79% of respondents request additional information on both space weather risks and space weather services. Preferred channels are consistently email and web, supported by online seminars and training, with email cited by 70% as their preferred channel for receiving further information on space weather risks and 74% citing this as their preferred channel for more information about space weather services, websites were cited by 47% for both, and online seminars were cited by 43% for more information about space weather risks and 42% for further information about space weather services.

Preparedness and integration of space weather information into operational workflows lag behind awareness. Only 26% of respondents report including space weather in formal risk or impact assessments, while 21% report having an emergency response framework for extreme space weather. Preparedness is self-rated at 2.57 out of 5 on average, and only 44% report knowing whom to contact for an urgent space weather query. Among organisations without an emergency response framework, only 9% plan to develop one (mostly in 2026-2028).

Disruptions are confirmed, and the recurrent-disruption subset also carries significant consequences. Impact information is available for 65% of respondents; among those, 36% confirm space weather-related disruptions. Severity was not limited to rare events, with 57% of organisations reporting regular or frequent disruptions also experiencing significant or severe impacts; however, further investigation is warranted given the small sample size (n=20).

The information landscape remains concentrated. NOAA is the most cited information source at 53%, followed by ESA at 35% and national meteorological or geophysical institutes at 32%.

1.4. Sectoral highlights

In **Spacecraft Operations** (n=24), engagement is comparatively strong, with 50% of respondents reporting current use of space weather services. Quantitative results and qualitative feedback converge on the need for clearer lead-time framing to support protective actions and for orbit-regime-specific information (e.g., LEO/MEO/GEO) to improve operational relevance. Willingness to engage further is high, with 79% expressing interest in follow-up. However, institutional readiness remains incomplete: only 46% report knowing whom to contact in an urgent case, and average preparedness is 2.88/5.

In **Communications and/or PNT** (n=26), uptake is lower and maturity uneven. Overall, 35% of respondents currently use space weather services, although an aviation-related sub-cluster exhibits markedly higher uptake, with 83% among aviation-primary organisations within the HF/VHF/UHF subgroup. Despite relatively high exposure, with 50% reporting disruptions, preparedness indicators remain particularly weak: only one organisation reports an emergency response framework, average preparedness is 2.38/5, and only 38% report knowing whom to contact urgently. Interest in additional support is nonetheless clear. 81% request further information on services and 73% on potential space weather risks, while 58% are open to follow-up; however, planned future uptake remains limited, with only 41% of non-users intending to adopt services. Qualitative feedback highlights a need for more graphical, operationally oriented products and clearer communication to end users, including flight crews.

In **Power System Operation** (n=27), uptake remains low to moderate, with 26% currently using space weather services and preparedness averaging 2.52 out of 5; 52% report knowing whom to contact urgently. Reported disruptions are limited among those with impact information, at 11%, but exposure appears uneven, including at least one high-latitude TSO reporting regular disruptions with significant impact. However, reported figures may underestimate sector exposure: when excluding DSOs—typically less exposed due to shorter, lower-voltage networks and smaller transformers, which tend to reduce geomagnetically induced current impacts—reported disruptions rise to 20%. Engagement indicators are also comparatively low: 59% request additional service information, 33% are open to follow-up, and 25% of non-users plan adoption. Emergency preparedness appears

comparatively higher, with 30% reporting emergency frameworks, likely reflecting regulatory drivers. Expert input from Canada provides an example for what “actionable” looks like in this sector, centred on grid-relevant outputs such as regional geoelectric fields, direct GIC values, network maps, and threshold-triggered alarms, embedded in structured risk management cycles.

1.5. Stakeholder mapping implications

Stakeholder mapping indicates that current engagement is strongest within core operational communities, particularly in the power domain, where DSOs and TSOs represent 76% of mapped stakeholders. Enabling actors, including governance and regulatory bodies, standardisation organisations, and risk-management stakeholders, are comparatively underrepresented in the current sample of respondents and may be further contacted in future phases.

1.6. Recommended actions and next steps

A limited set of time-efficient actions follows directly from the interim findings:

- i. In collaboration with the National Points of Contact participating in the Phase 2 Demonstrator, a Europe-wide TSO space weather exercise was identified as a high priority first action following on from the questionnaire results. Initial contacts with ENTSO-E have been established in order to initiate such an exercise. If agreed, this should be treated as the principal cross-European operational activity for 2026, supporting validation of practical requirements, escalation practices, and decision triggers in the power sector.
- ii. 50 requests were received from questionnaire respondents for follow-up meetings. This reflects the very significant interest in the three sectors consulted for further information. Individual meetings and regional workshops are currently in preparation under the leadership of the National Points of Contact. These follow-up activities should be used to convert willing organisations through onboarding support, to close the impact evidence gap where information is missing or withheld, and to encourage less mature end users to engage with the capacity-building offer (see iv) and preparedness materials (see iii).
- iii. Preparedness can be strengthened by prioritising the establishment and confirmation of escalation pathways, clarifying who should be contacted, when, and through which channel, and supporting basic inclusion of space weather in organisational risk processes where relevant.
- iv. Capacity-building should be delivered through identified preferred channels, notably concise web and email products and short webinars, structured around concrete sector use cases and focusing equally on how to use services in practice and why space weather matters for operational resilience.

Follow-up engagement through individual meetings and workshops as part of the end of Phase 2 is planned for completion before summer 2026. A final Phase 2 report could be targeted for PB-SSA in September 2026, alongside consideration of a subsequent Phase 3 to extend engagement to enabling actors and consolidate long-term implementation.

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2. INTRODUCTION AND LINK TO THE ARTIC PHASE OF THE SPACE WEATHER DEMONSTRATOR

General Introduction

Space weather presents a growing challenge to the resilience of critical infrastructure, particularly for sectors dependent on satellite-based services, high-frequency communication systems, and the stability of electrical grids.

As indicated in ESA's PB-SSA#78 [Item 5.5] Space Weather Status Report, solar activity peaked around the 2024-2025 timeframe and is now gradually evolving beyond the maximum phase. However, solar activity follows an approximately 11-year cycle, meaning that today's risks are not isolated: similar or greater disturbances are expected during future peaks and major events may also take place at other times during the cycle. Building resilience and enhancing the operational preparedness of European stakeholders is therefore not only urgent in the current context, but also essential for long-term continuity across space- and ground-based infrastructures.

Within this context, the Strategic Space Safety Initiatives – formerly known as the ESA Protect Accelerator – supports the establishment of an operational space weather service governance model for Europe. A key element of this effort is to strengthen engagement with relevant user communities in preparation for the establishment of European operational space weather services. Building on the ESA Space Weather Services and ongoing engagement work carried out within the Space Safety Programme, the Space Weather Demonstrator initiative contributes directly to this ambition by reviewing the needs, awareness levels, and existing service uptake among institutional and operational actors across Europe and gaining further insights into users' expectations for an operational service provision model.

The Demonstrator is structured in two successive phases:

- Phase 1, the Arctic Phase, was conducted in Finland and Norway between late 2023 and early 2024. It focused on high-latitude vulnerabilities and provided concrete use cases—from GNSS disruptions affecting autonomous vehicles and livestock tracking, to satellite anomalies and radar interference. The findings highlighted both the real-world impacts of space weather and the limited awareness and preparedness of many operators, as well as the need for more accessible, tailored services.
- Phase 2, presented in this report, expands the scope from regional to European level, adopting a sectorial perspective targeting three priority domains:
 1. Power System Operation
 2. Spacecraft Operations
 3. Communications and/or Positioning, Navigation and Timing (PNT)

Approach & Methodology

Phase 2 was implemented in collaboration with 18 National Points of Contact (NPOCs) from 15 ESA Member, Associated and Cooperating States¹ who supported national dissemination and stakeholder outreach.

It combines quantitative and qualitative insights drawn from responses to an online questionnaire collected between February and December 2025, complemented by inputs gathered through direct consultations. The survey captured organisational profiles, current use of space weather services (measurements/nowcasts, forecasts, post-event analysis), information sources, service

¹ Austria, Belgium, Canada, Czech Republic, Finland, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Portugal, Slovakia, Spain, Sweden.

feature priorities and satisfaction (1–5 scales), understanding and information needs, disruption experience, and preparedness indicators (risk assessment inclusion, mitigation measures, emergency response frameworks, preparedness self-rating, and knowledge of escalation contacts). Results are reported using descriptive statistics, with question-level denominators stated where response rates differ (e.g., “information not available” or skipped items).

Sectoral analyses in this report are based on respondents’ self-selected sector in the questionnaire. In addition, a complementary mapping exercise categorises respondent organisations by functional role within each ecosystem to reflect multi-role stakeholders; this mapping is not intended as an exhaustive stakeholder inventory.

The findings should be interpreted as an indicative assessment of readiness and service uptake rather than a statistically representative measurement of European-wide exposure or risk. Response volumes vary across countries and sub-sectors, limiting comparability where sample sizes are small, and several indicators rely on self-reporting (e.g., disruption experience, preparedness, satisfaction), sometimes constrained by confidentiality—leading to “information not available” responses or potential under-reporting. In addition, a voluntary survey disseminated through operational networks is subject to response bias: organisations that have already experienced disruptions may be more likely to perceive immediate relevance and therefore to engage, while organisations that have not observed impacts—or do not systematically monitor them—may be less inclined to respond even where latent vulnerability exists.

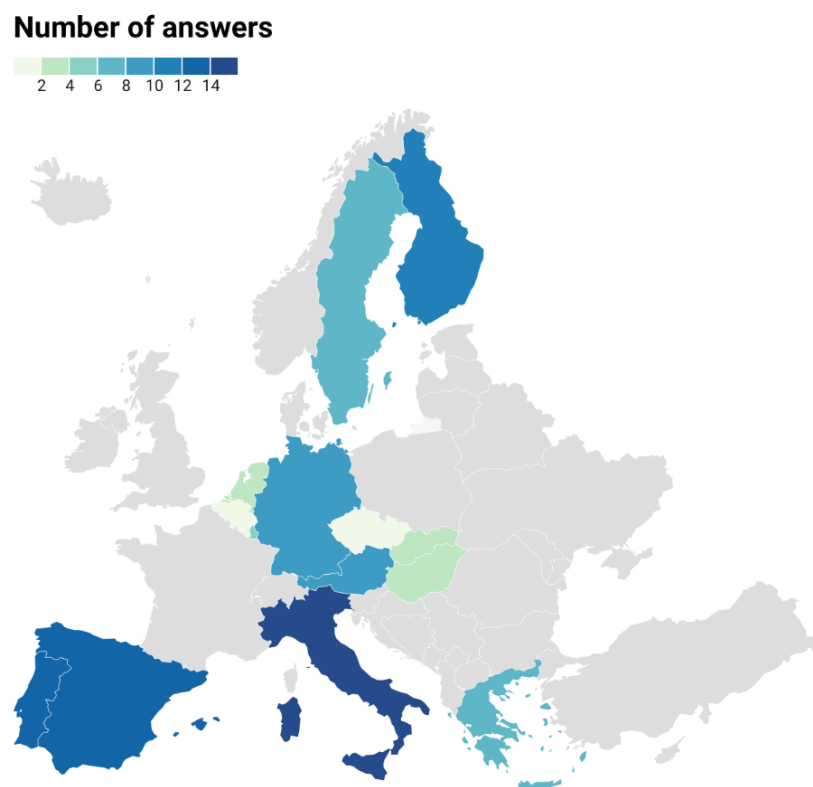


Figure 1: Number of answers per country

The results of Phase 2 aim to inform the ongoing development of the ESA Space Weather Service Network, while also supporting strategic planning for a future European operational space weather capability that is responsive, relevant, and user driven.

3. CROSS-SECTOR ANALYSIS

3.1. General

Sector Representation

A total of 94 responses were received across the Space Weather Demonstrator Phase 2, with the majority coming from the three designated priority sectors: Power System Operation (29%), Communications and/or PNT (28%), and Spacecraft Operations (26%). Together, these three domains accounted for over 82% of the total responses, reflecting both the focus of the initiative and its resonance with the sectors deemed most at risk from space weather impacts.

The remaining 18% of responses came from organisations classified under “Other”, a category enabled by the distribution model employed during this phase. On request, National Points of Contact (NPOCs) were given the flexibility to circulate the questionnaire beyond the priority sectors to other entities they considered to be important national stakeholders. The presence of these responses confirms that interest in space weather extends beyond the predefined domains targeted for this phase of the Space Weather Demonstrator and that additional user communities may be targeted in by future phases of the Demonstrator.

Use of Space Weather Services

Among the 94 participating organisations, 36% reported current use of space weather (SW) services, while 64% do not. Of those currently engaged, 41% are registered users of the ESA SWE Service Portal, indicating an active user base for ESA-provided space weather resources.

With regard to information sources, the National Oceanic and Atmospheric Administration (NOAA, incl. SWPC/spaceweather.gov) was the most frequently cited provider, selected by 53% of respondents. This was followed by ESA (35%), NASA (18%), and national meteorological and geophysical institutes (32%). Additionally, 32% of respondents rely on specialised space weather or SSA centres, and 15% on collaborative research/data networks. Only 3% identified civil protection agencies as a primary source. These results suggest that end-user capability is primarily anchored on NOAA/ESA services, while national and specialist providers most often extend or contextualise those core products.

Across 34 current users, information accuracy was the top priority (mean 4.44/5; 94% rated it 4–5, 56% rated 5), closely followed by information clarity (mean 4.29; 94% rated 4–5) and accessibility (mean 4.21; 85% rated 4–5). Timeliness of updates was also rated highly (mean 4.09; 79% rated 4–5). User interface quality was mid-ranked (mean 3.65; 59% rated 4–5). Lower priorities were API² standardisation (mean 3.15) and data enrichment/analysis (mean 3.00), while customisation/personalisation (mean 2.71; 41% rated 1–2) and 24/7 expert support (mean 2.82; 41% rated 1–2) were least emphasised. Four respondents (12%) added priorities—technical documentation, confidentiality, and improved/longer lead time/advance warning—all rated 5.

On satisfaction with current services (1–5), respondents were most satisfied with information accessibility (mean 3.76/5; 56% rated 4–5) and clarity (3.62; 56% rated 4–5), with timeliness similar (3.59; 47% rated 4–5). Accuracy was more mixed (3.44; 47% rated 4–5, 15% rated 1–2). UI quality (3.35) and API standardisation (3.09) sat mid-range. Lowest satisfaction concerned customisation (2.47; 47% rated 1–2), data enrichment/analysis (2.59; 50% rated 1–2), and 24/7 expert support (2.47; 50% rated 1–2). 18% (6/34) added improvements, including more graphical/sector-facing products, exploiting new-mission data, real-time radiation-effect monitoring, and orbit-specific (LEO/MEO/GEO) dashboards.

The combined results point to a clear gap: users prioritise high accuracy, clarity, accessibility, and timely updates, but report only moderate satisfaction with these fundamentals—while the largest dissatisfaction clusters around tailoring, added-value analytics, and expert support, suggesting that services are generally usable but not yet sufficiently decision-oriented or mission-specific.

² API: application programming interface

Among the 64% of respondents not currently using SW services, 40% indicated plans to adopt them in the future. These prospective users most frequently expressed interest in forecasts (96%), followed by measurements and nowcasts (58%), and post-event analysis (33%).

The remaining 60% of respondents reported no plans to adopt space weather services, citing low perceived relevance (39%), low priority (28%), limited resources (33%), and limited expertise (33%). These findings point to a combined effect of capability constraints (resources/expertise) and institutional perceptions (relevance/priority) that continues to limit service uptake across parts of the community.

Understanding of Space Weather Risks and Services

Across 94 respondents, self-rated understanding of space-weather risks averaged 3.53/5 (median 4), with 59% reporting high understanding (4–5) and 19% reporting low understanding (1–2).

A large majority want more information on both space-weather risks and space-weather services (79% each). For risks, preferred channels were email (70%), websites (47%) and online seminars (43%), followed by training (23%) and offline seminars (22%); social media was rarely selected (4%). Preferences for service information were very similar: email (74%), websites (47%), online seminars (42%), training (23%), offline seminars (22%), and social media (3%).

The pattern suggests a strong latent demand for capacity-building: even with generally moderate-to-high self-assessed understanding, most organisations still want more information—preferably through low-friction, operational channels (email and web) complemented by scalable training formats (webinars/training), while social media is not perceived as an effective route.

Experienced Disruptions

65% of organisations indicated that they have available information on space weather impacts. Among these, 36% confirmed that they had experienced operational disruptions related to space weather.

Among organisations reporting disruptions (n=22), frequency was most often occasional (45%), followed by frequent (18%), regular (14%), and rare (14%). 5% reported no disruptions (“never”) and 5% did not report frequency. Reported highest impacts were most commonly moderate (36%) and minimal (18%), with significant, severe, and no impact each at 14% (plus 5% unspecified).

Severity appears to rise with frequency: 57% (4/7) of organisations with regular/frequent disruptions reported significant or severe impacts, versus 14% (2/14) among those with rare/occasional/never disruptions. The findings imply that improving monitoring and mitigation for the minority experiencing recurrent disruptions may yield outsized resilience benefits compared with broad, generic measures.

Given the sensitivity of impact reporting in several organisations—35% reported information was not available—and that major space weather events are rare but potentially far-reaching in their impact, a logical next step for NPOCs is to follow up bilaterally to better characterise the types of disruptions experienced and to contextualise reported frequency and severity across user segments.

Preparedness Levels

Out of 94 respondents, 26% reported that their organisation includes space weather in its risk/impact assessments, while 74% reported no inclusion or were unsure. Where space weather is included (n=24), assessments are typically recent: 58% were conducted within the last year, 25% within the last five years, and 17% more than five years ago. Looking ahead, 58% plan the next assessment within the next two years, 8% within five years, and 33% have no defined schedule.

Among organisations that include space weather in assessments (n=24), 67% reported having taken mitigation measures, while 33% reported no mitigation or were unsure.

Mitigation measures were most often described as operational procedures/contingency actions (25%; 4/16) and engineering/design measures addressing radiation and spacecraft effects (25%; 4/16); modelling-oriented measures (e.g., orbit/drag-related improvements) were cited by 19% (3/16). Training/awareness and monitoring/alerting practices were each mentioned by 13% (2/16), while grid-related operational measures appeared in 6% (1/16). A notable share of mitigation detail was withheld or deferred (25%; 4/16 reported “confidential” or “bilateral”).

For the 8 organisations that included space weather in assessment but reported no mitigation/unknown, the most common stated barriers were low priority (25%), limited resources (25%), and limited expertise (25%). Less frequent reasons (each 13%, 1/8) included low relevance, perceived low probability/impact, and “New Space” mission profiles limiting exposure.

Among organisations not including space weather in assessments (n=70), the main reasons were low relevance (37%), low priority (36%), limited resources (31%), and limited expertise (26%).

Out of 94 respondents, 21% reported having an emergency response framework in place for an extreme space weather warning. Among organisations with a framework (n=20), plans are predominantly in-house: 80% reported an in-house emergency response plan and a further 10% reported both in-house and national plans (i.e., 90% (18/20) mention an in-house plan in some form). 5% rely on a national emergency response plan only, and 5% cited ISS response plans.

Among organisations without a framework or unsure (n=74), only 9% said they plan to develop one. All 7 prospective adopters provided a timeline, which cluster around 2026–2028: 29% target 2026, 14% target 2027, 29% target 2028, and 29% indicate a 2026–2027 window.

For the 67/74 organisations that do not plan to develop a framework or are unsure, the most frequently cited barriers were limited resources (36%), low relevance (34%), low priority (30%), and limited expertise (27%).

Self-reported preparedness levels averaged 2.57 out of 5, suggesting a general state of limited readiness, even as awareness and perceived need begin to increase. 44% of the organisations indicated that they knew who to contact in the case of an urgent question about a space weather risk or impact.

Finally, 53% of the organisations indicated willingness to engage in follow-up discussions regarding their space weather information needs and to learn more about ESA's space weather services.

3.2. Geographical Analysis³

3.2.1. Italy

A total of 15 responses were received from Italian organisations participating in the Space Weather Demonstrator Phase 2. The majority of respondents (53%; 8/15) were from the spacecraft operations sector, followed by 3 (20%) from communications and/or PNT, and 1 (7%) from the power system operation sector.

Use and Interest in Space Weather Services

Of the 15 respondents, 7 organisations currently make use of space weather (SW) services. Among these users, 100% utilise measurements and nowcasts services, while 71% use forecasting tools and 57% make use of post-event analysis services. These figures indicate a strong emphasis on both real-time monitoring and retrospective evaluation among Italian users.

³ Only countries from which we received more than eight responses are included.

For the 8 organisations not currently using SW services, 3 indicated an intention to adopt such services in the future. All three expressed interest in both measurements and nowcasts services and forecasts ones, with two also citing post-event analysis.

Service Priorities and Areas for Improvement

Italian organisations placed particularly high value on information accuracy (average rating: 4.43), information accessibility (4.43), and information clarity (4.29). By contrast, lower importance was attributed to customisation and personalisation (2.57), API standardisation (2.86), and 24/7 expert support (2.43), suggesting that these features may be less immediately relevant to the Italian user base or currently underutilised.

In terms of service satisfaction, Italian organisations were quite satisfied with information accessibility (4.00), information clarity (3.86), information accuracy (3.57), followed by user interface (3.57), and timeliness of updates (3.43). Customisation and 24/7 support were again identified as the least satisfying areas (both under 2.5/5).

Understanding and Disruption Experience

The average self-assessed understanding of space weather risks among Italian respondents was 3.93 out of 5, suggesting a strong foundational awareness. Nonetheless, 12 out of 15 respondents indicated a desire for more information on space weather risks, and 13 out of 15 expressed interest in additional information on available services.

Among those with information available on past disruptions (11 organisations), 4 reported having experienced disruptions, with 3 describing them as occasional and 1 as regular. Reported impact levels included one case of critical effects, one of substantial disruption, one moderate, and two minimal impacts, illustrating a range of operational consequences associated with SW conditions.

Risk Assessments and Preparedness

Only 2 out of 15 organisations indicated that space weather is currently included in their formal risk or impact assessments. Both had conducted their assessments within the past year and planned to update them within the next two years. The key risks identified were orbit determination issues and radiation effects, with mitigation strategies including radiation-hardened component testing (RHA), drag modelling improvement, and collision risk assessment and avoidance.

When it comes to emergency planning, only 1 out of 15 organisations reported having an emergency response framework, which was developed in-house. A further 1 organisation (of the remaining 14) stated that it planned to develop such a plan by 2027. The average preparedness level reported to respond to an extreme SW event was 2.67 out of 5, indicating moderate but incomplete readiness.

Only 5 out of 15 respondents reported that they would know whom to contact in the event of an urgent space weather-related issue. Identified contact points included the Italian Space Agency, the Sardinian National Base, and the Space Weather Italian Community (SWICO), as well as the companies Telespazio and Planetek.

Finally, 11 out of the 15 organisations indicated willingness to engage in follow-up discussions regarding their space weather information needs and to learn more about ESA's space weather services.

Conclusion

Italy shows relatively high reported uptake (7/15), driven mainly by a respondent base concentrated in spacecraft operations. Current users rely systematically on measurements/nowcasting, with substantial use of forecasting and post-event analysis (among users), suggesting a balanced operational approach spanning monitoring, anticipation, and learning. Respondents prioritise accuracy, accessibility, and clarity, and report generally solid satisfaction, with comparatively weaker ratings for timeliness and for customisation/support. Despite good awareness and strong willingness to engage (11/15), formalisation remains limited (risk assessments: 2/15; emergency frameworks: 1/15; clear contact pathways: 5/15), indicating scope to strengthen governance and escalation practices alongside service uptake.

3.2.2. Germany

A total of 9 responses were received from German organisations. These responses represent a cross-section of sectors, with 3 organisations each from the spacecraft operations and communications/PNT sectors, and 1 from power system operation. The remaining responses came from the military and aviation sectors, reflecting a diverse set of operational contexts engaging with space weather (SW) issues.

Use and Interest in Space Weather Services

7 out of 9 respondents confirmed that their organisation currently uses space weather services. Among these users, 57% (4/7) reported using measurements and nowcasts services, and 71% (5/7) make use of forecasts services. Interestingly, none of the users reported utilising post-event analysis, indicating a potential area for further service awareness or development. Among the 2 organisations not using SW services, neither indicated plans to adopt them in the near future.

Service Priorities and Areas for Improvement

German users ranked timeliness of updates (4.71), information accuracy (4.57), and information clarity (4.43) as their top priorities for operational SW services. These were followed by information accessibility (4.29) and user interface usability (3.86). Lower priority was assigned to customisation and personalisation (2.71), data enrichment (2.86), and 24/7 expert support (2.57), suggesting a core focus on service quality and speed rather than tailored or support-heavy tools.

When evaluating areas for improvement, users again were quite satisfied with timeliness of updates (4.0) and information accessibility (3.86). Information clarity (3.43) also remained high, while forecast accuracy notably received a lower score (2.57), possibly reflecting lower confidence or adequacy in forecasting capabilities. The highest improvement needs were reported for customisation, data enrichment, and 24/7 support, each scoring under 2.0, consistent with their lower initial prioritisation.

Understanding and Disruption Experience

Respondents self-reported a relatively high average understanding of space weather risks, scoring 3.89 out of 5. At the same time, there is still a strong demand for further information: 7 out of 9 respondents wished to receive more information on SW risks, and 8 out of 9 requested additional insights on SW services.

Notably, all 5 organisations that had information available on past disruptions confirmed having experienced SW-related disturbances. Of these, 3 described such disruptions as frequent, and 1 as occasional. The severity of impacts ranged from moderate (2 cases), to substantial (1), and severe (1), pointing to a tangible operational risk across sectors.

Risk Assessments and Preparedness

3 out of 9 organisations currently include SW in their formal risk or impact assessments. Two of these conducted assessments within the past year, and one less than five years ago; most plan to update them within the next two years. The key risks identified include:

- Radio signal interference (e.g., ionospheric effects, solar radio bursts)
- Radiation and orbit determination issues
- Space debris impact and related manoeuvrability concerns

Corresponding mitigation measures reported include:

- Awareness training for operational teams
- Use of alternative data sources and proxies

- Application of atmospheric density models
- Acknowledgement that some legacy systems were developed prior to the availability of space weather forecasts and thus remain vulnerable

In terms of emergency preparedness, 3 out of 9 organisations stated that they have an emergency response framework in place. Of these, two maintain in-house plans, and one has protocols connected to the International Space Station (ISS). No additional respondents reported plans to establish such frameworks in the near future. The average preparedness rating across the sample was 2.67 out of 5, reflecting moderate readiness but also room for improvement.

Only 4 out of 9 respondents reported that they would know who to contact in the case of an urgent space weather-related issue. Named points of contact include an in-house space weather forecaster, the German Space Situational Awareness Center, DLR Space Agency, and NASA.

Finally, 5 organisations indicated willingness to engage in follow-up discussions regarding their space weather information needs and to learn more about ESA's space weather services.

Conclusion

Germany reports high current use among respondents (7/9) across a diverse mix (including military and aviation), with priorities centred on timeliness, accuracy, and clarity. Satisfaction is strongest for timeliness and accessibility, while information accuracy is rated lower, indicating a perceived performance gap. No respondents reported post-event analysis, suggesting a weaker perceived fit of such services. Within this respondent subset, disruption experience is substantial among those who provided data, and preparedness indicators remain mixed (risk assessments: 3/9; emergency frameworks: 3/9; known contact points: 4/9).

However, these findings should be interpreted with caution. The German NPOC highlighted a likely self-selection bias: organisations opting to respond appear disproportionately interested in space weather. This is consistent with the well-above-average service uptake reported in the sample and the respondent profile (e.g., comparatively limited representation from the power system domain). As a result, the results likely overstate the level of maturity and adoption across the broader German ecosystem, and may also overrepresent disruption experience relative to non-responding organisations.

3.2.3. Finland

A total of 11 responses were received from Finnish organisations participating in the Space Weather Demonstrator Phase 2. The respondent profile is heavily concentrated in the power system operation sector (9 out of 11), with 1 organisation from communications and PNT, and 1 from healthcare. Notably, no spacecraft operations organisations participated in the Finnish sample.

Use and Interest in Space Weather Services

Only 1 out of 11 responding Finnish organisations currently uses space weather (SW) services. This user reported relying on forecast services, specifically alerts for local conditions that may lead to severe geomagnetically induced currents (GICs). However, they do not currently use measurement and nowcasting or post-event analysis services. Among the 10 organisations not using SW services, only 1—from the communications/PNT sector—expressed an intention to adopt them in the future, with interest shown across all three service types: nowcasts, forecasts, and post-event analysis.

Among the 9 non-users who are not planning to adopt SW services, the most frequently cited barriers were limited expertise, low priority, limited resources, and low perceived relevance. These reasons point to both a lack of internal capacity and a broader perception that space weather risks are not immediately critical for their operations.

Service Priorities and Improvement Areas

Given that only one respondent currently uses SW services, reported priorities and improvement needs are limited to a single organisational perspective. Nevertheless, this user rated information clarity and accuracy as highest in importance (score of 4), followed by moderate emphasis on accessibility and timeliness (score of 3). Features such as user interface quality, customisation, data enrichment, and API standardisation received lower scores (2), with 24/7 expert support slightly higher at 3.

When asked about improvements, the same respondent suggested being quite satisfied with information accuracy (4), followed by improvements to clarity, accessibility, and timeliness (3 each). Customisation and support services again received the lowest satisfaction scores (1–2).

Awareness and Experience of Space Weather Risks

Self-assessed awareness of space weather risks is relatively low across Finnish respondents, with an average understanding score of 2.36 out of 5. Despite this, 7 out of 11 organisations expressed interest in receiving more information on space weather risks, and 6 out of 11 are similarly interested in learning more about SW services.

Interestingly, all 10 organisations that responded to the question on disruption history reported no known disruptions from space weather events. As a result, no data were provided regarding disruption frequency or impact levels, reinforcing the perception that SW effects have not yet directly influenced their operations in a measurable way.

Risk Assessments and Preparedness

Only 2 of the 11 Finnish organisations include space weather in their risk or impact assessments. One of these assessments was conducted within the past year, with a plan to update it within the next two years; the other was conducted less than five years ago, but the next review date is not yet defined. Risks identified include threats to information networks and the critical services they support. However, neither of these two organisations has implemented mitigation measures to date.

Emergency response planning is also limited. Just 1 organisation reported having an in-house emergency response framework for extreme space weather conditions. Overall, the average preparedness rating across the Finnish cohort was 2.09 out of 5, the lowest among the national samples reviewed so far, indicating significant room for development in readiness and response capabilities.

When asked whether they would know whom to contact in the event of an urgent space weather risk, 4 out of 11 organisations answered positively. Identified points of contact included the Finnish Meteorological Institute, and Huoltovarmuuskeskus (National Emergency Supply Agency).

Finally, only 2 organisations indicated willingness to engage in follow-up discussions regarding their space weather information needs and to learn more about ESA's space weather services.

Conclusion

Finland shows very low reported uptake among respondents (1/11) within a sample intentionally targeting predominantly DSOs (9/11) with the aim to increase awareness and engagement among this group. Within this respondent subset, non-adoption is mainly explained by practical and perceptual barriers (limited expertise/resources, low priority, and low perceived relevance), and disruption history is generally reported as "none known" among those who provided data. Reported service priorities and satisfaction should also be interpreted cautiously, as they reflect a single current user.

3.2.4. Portugal

A total of 12 responses were received from Portuguese organisations across a diverse range of sectors. These included 5 spacecraft operations, 5 communications and/or PNT, and 2 power system operation.

Use and Interest in Space Weather Services

4 out of 12 organisations currently use space weather services. Among these, 3 utilise measurements and nowcasts services, 1 rely on forecasts, and 2 also use post-event analysis, indicating a balanced but selective uptake across available service types. Of the 8 organisations not currently using SW services, 3 stated an intention to adopt them in the future, with all expressing interest in forecasting, two in post-event analysis, and one in measurements and nowcasts.

Among the non-users not planning to adopt SW services (5 organisations), the most common barriers cited were limited expertise, limited resources, and low perceived relevance, along with concerns around integration complexity with mission operations.

Service Priorities and Areas for Improvement

Portuguese respondents gave high importance to information accuracy (4.8/5), information clarity (4.5), and information accessibility (4.0). Other key attributes such as timeliness of updates, user interface quality, and 24/7 expert support received moderate scores (3.0–3.8). Features such as customisation, data enrichment, and API standardisation were considered less critical, averaging around 2.5–2.8.

In terms of satisfaction with current services, information accuracy (4.0), accessibility (3.8), clarity (3.5) and timeliness (3.5) were the highest-rated dimensions, while data enrichment and analysis and customisation were rated lower (all below 3/5).

The pattern indicates that Portuguese respondents prioritise core information quality and availability, while the main improvement opportunity lies in better tailoring and added-value analytical products.

Awareness and Disruption Experience

Self-assessed understanding of space weather risks among Portuguese organisations averaged 3.58 out of 5, reflecting a moderate level of awareness. A strong majority expressed a desire for more information: 9 out of 12 organisations wished to know more about SW risks, and 10 out of 12 about SW services.

Of the 9 respondents who provided information on operational impacts, 3 organisations (33%) reported having experienced space weather-related disruptions. Two reported occasional disruptions and one reported regular disruptions; impacts were described as minimal (2/3) or moderate (1/3).

Risk Assessments and Preparedness

5 out of 12 Portuguese organisations currently include space weather in their risk or impact assessments. The timing of these assessments varied, with three conducted within the past year, one within the last five years, and one more than five years ago. Most planned to update their assessments within the next two years, while one organisation had not yet defined a review timeline.

Reported risks included a wide spectrum of concerns:

- Onboard software corruption, spacecraft power system damage, and life extension determination
- Orbit determination and propagation errors, satellite collision risk, and tracking degradation
- Communication and GNSS signal disruptions, data latency or loss, and signal blackouts, particularly during solar storms

Four out of five organisations that conduct assessments have already implemented mitigation measures, such as:

- Operational awareness and contingency procedures
- Use of predictive models to adjust orbital operations

- Software-side resilience in CubeSat designs
- Coordination with satellite operators and space weather alert monitoring

Emergency Planning and Institutional Readiness

4 out of 12 organisations reported having an in-house emergency response framework to address extreme space weather scenarios. Among those without a plan, only one reported intent to develop one within the next two years. The average preparedness rating was 2.5 out of 5, indicating that while certain organisations have strong internal frameworks, overall readiness remains modest.

When asked whether they would know whom to contact in the event of an urgent SW incident, 7 organisations responded positively. Points of contact included:

- Autoridade Nacional de Emergência e Proteção Civil
- Portuguese Space Agency
- ESA SWE Services and ESA Space Weather Office
- Space-Track and ESA, particularly for conjunction or collision alerts
- International aviation and space weather providers such as SITA, ARINC/COLLINS, Australian and NOAA Space Services
- Eurocontrol

Encouragingly, 8 out of 12 respondents indicated they would be open to a follow-up meeting to explore their space weather information needs further and to learn more about ESA's space weather services.

Conclusion

Portugal shows moderate uptake (4/12) across a broad respondent mix, with priorities focused on core information quality (accuracy, clarity, accessibility). Inclusion of space weather in risk/impact assessments is relatively high within this set of national samples (5/12), accompanied by reported mitigation among most assessors (4/5), although overall preparedness remains modest (2.5/5) and emergency planning is uneven. Disruption experience is reported by a subset of respondents and indicates occasional/regular impacts in some cases. Overall, the findings suggest steady progress toward institutionalisation, with scope to increase consistency of preparedness planning and to develop added-value analytical outputs where respondents see improvement potential.

3.2.5. Austria

A total of 9 responses were received from Austrian organisations. An important share of respondents (4 out of 9) were from the communications and/or PNT sector, with the remainder representing satellite test systems, research, transport infrastructure, and non-sector-specific entities. No organisations from spacecraft operations or power system operations participated.

Use and Interest in Space Weather Services

Only 2 organisation—one from the communications/PNT sector and one research organisation—reported current use of space weather services. One relies on forecasts services, specifically for the detection of geomagnetic events, but does not use measurement/nowcast or post-event analysis tools. And, on the contrary, the other uses measurement and nowcasting alongside post-event analysis – specifically on Kp Index. Among the 7 non-users, 2 indicated plans to adopt SW services in the future, showing interest in nowcasting (2) and forecasting (1), but not in post-event analysis.

The remaining 5 non-user organisations cited a mix of limiting factors including limited expertise, limited resources, low priority, and low relevance, indicating both capability and perception-related barriers to SW service adoption.

Service Priorities and Areas for Improvement

As only two Austrian organisations reported current use of space weather services, the priority and improvement ratings reflect a very small sample and should be interpreted with caution. Both respondents gave the highest score (5/5) to information clarity, accuracy, accessibility and data enrichment. Slightly lower ratings were assigned to timeliness of updates and user interface quality (4.5/5), followed by customisation and API standardisation (4/5). The lowest score was given to 24/7 expert support (3/5).

In terms of satisfaction with current services, the two users reported the highest satisfaction with user interface quality (4.5/5), followed by information clarity (4/5), timeliness (4/5) and customisation (4/5). Satisfaction with information accessibility was slightly lower (3.5/5), as was satisfaction with data enrichment and API standardisation (both 3.5/5). The lowest satisfaction was reported for 24/7 expert support (2.5/5).

Awareness and Disruption Experience

The average self-assessed understanding of space weather risks among Austrian respondents was 3.44 out of 5, suggesting moderate awareness across the sample. 7 out of 9 organisations expressed a desire for more information about SW risks, and 6 indicated interest in learning more about SW services.

Only 3 organisations provided information on operational impacts. Of these, one reported experiencing rare disruptions, but with no measurable impact, underscoring a relatively limited perception of immediate space weather effects in current operations.

Risk Assessments and Preparedness

None of the Austrian organisations reported including space weather in their formal risk or impact assessments, making Austria the only national sample (thus far) with a 0% inclusion rate. Consequently, no mitigation strategies were reported, and specific risk types remain unarticulated.

In terms of preparedness, 1 organisation indicated that an emergency response framework is in place, aligned with the national emergency plan. Among the remaining 8 organisations, only one plans to develop such a framework within the next three years. The average preparedness rating was 2.55 out of 5, suggesting low-to-moderate readiness and a clear opportunity for improvement.

When asked about contact pathways for urgent SW concerns, 4 organisations responded affirmatively. Identified contact points included:

- GeoSphere Austria / Austrian Space Weather Office
- BM für Klimaschutz – Crisis Management Unit

Encouragingly, 4 out of 9 organisations expressed openness to a follow-up meeting to explore their space weather information needs and to learn more about ESA's space weather service offerings.

Conclusion

Austria reports low uptake (2/9) and no inclusion of space weather in formal risk/impact assessments (0/9) within a sample that does not include spacecraft operations or power system operators, which may influence comparability with other countries. Service priorities and satisfaction are based on two current users and should be treated as indicative; within this small base, core information quality is rated highly. More broadly, results suggest that space weather is not yet systematically embedded in risk governance and planning, despite moderate awareness and interest in further information. Potential value lies in

supporting basic integration into assessment practices, improving preparedness planning, and clarifying escalation pathways (known contacts: 4/9), aligned where relevant with existing national emergency structures.

3.2.6. Spain

A total of 12 responses were received from Spanish organisations (including three responses from GMV covering its different activities). The sample is dominated by spacecraft operations (42%) and communications and/or PNT (33%), with additional representation from power system operation, earth observation, and civil protection (each 1/12; 8%).

Use and interest in Space Weather services

4 out of 12 organisations (33%) reported current use of space weather services (two in communications/PNT, one in spacecraft operations, and one in power system operation). All current users reported using measurements and nowcasting (100%) and forecasts (100%), while post-event analysis was reported by two users (50%) (none of the communications/PNT users reported post-event analysis).

Among the eight non-users, six (75%) indicated an intention to adopt space weather services in the future. All prospective adopters expressed interest in forecasting (6/6; 100%), while three (50%) also indicated interest in measurements/nowcasting, and two (33%) in post-event analysis. The two non-users not planning adoption cited limited resources and low perceived relevance.

Service Priorities and Areas for Improvement

Spanish respondents assigned the highest priority to information accessibility (4.50/5) and timeliness of updates (4.25/5). Information accuracy, user interface quality, and API standardisation and cataloguing followed closely (each 4.00/5). Customisation/personalisation, data enrichment and analysis, and 24/7 availability of expert support were rated lower (each 3.25/5).

Satisfaction ratings were broadly high, with API standardisation and cataloguing scoring highest (4.25/5). Information clarity, accessibility, and user interface quality each scored 4.00/5, while accuracy and timeliness scored 3.75/5. Customisation and 24/7 expert support were rated 3.50/5, and data enrichment and analysis 3.25/5.

Overall, Spanish respondents report relatively strong satisfaction with current service delivery, particularly in relation to usability and data access, while placing continued emphasis on timely and accessible operational information.

Awareness and Disruption Experience

Respondents reported a generally good level of familiarity with space weather risks, with an average self-rating understanding of 3.92/5. A large majority requested additional information: 10/12 (83%) for space weather risks and 11/12 (92%) for space weather services. Among those interested in risk information (n=10), preferred channels were email (60%) and online seminars (50%), followed by websites (30%) and training (30%); offline seminars and social media were each selected by 10%. Preferences for service information (n=11) were similar, with a stronger emphasis on email: email (82%), online seminars (45%), websites (36%), training (27%), and offline seminars (9%).

Only four organisations (33%) provided information on disruption experience; results should therefore be treated as indicative. Among these, three (75%) reported having experienced disruptions (equivalent to 25% of the full Spanish sample). Reported cases ranged from rare disruptions with no impact to occasional or frequent disruptions with moderate impact.

Risk Assessments and Preparedness

3 organisations (25%) reported including space weather in their risk or impact assessments. Two assessments were conducted within the last year (67%), and one within the last five years (33%). Two organisations plan to revisit the assessment within the next two years (67%), while one reported that an update schedule is not yet defined (33%).

2 of these organisations reported having implemented mitigation measures (2/3; 67%), including daily monitoring of geomagnetic activity and solar radiation and materials choices to reduce absorbed radiation. One respondent reported no mitigation or uncertainty, citing limited expertise/uncertainty. Among those not including space weather in assessments (n=9), the most frequently cited reasons were low relevance (33%), low priority (22%), limited resources (22%), and limited expertise (11%), alongside individual responses indicating that inclusion is under consideration or addressed “at safety level”.

Emergency Planning and Institutional Readiness

Only 1/12 (8%) reported an in-house emergency response plan for an extreme space weather warning. Among the 11 without a plan, 1/11 (9%) plans to develop one within one to two years. Reported barriers to developing emergency planning centred on limited resources, limited expertise, and low relevance, with several respondents indicating uncertainty (“I don’t know”).

The mean self-assessed preparedness level was 2.67/5, indicating that low-to-moderate preparedness overall, with limited formalised emergency planning.

When asked whether they would know whom to contact in case of an urgent space weather risk today, only 3/12 (25%) responded positively, citing: UAH and the Spanish National Geographic Institute (IGN), AEE, and the Observatori de l'Ebre.

Notably, 6/12 (50%) indicated openness to a follow-up meeting to discuss needs in more detail and to learn more about the ESA Space Weather Services.

Conclusion

Spain shows low current uptake (4/12) but high stated intention to adopt among non-users (6/8), suggesting significant latent demand. This aligns with the relatively high disruption experience among those with available data (3/4, 75%). Respondents prioritise accessibility and timeliness, and satisfaction among users is broadly high, particularly for usability and data access, while timeliness and accuracy remain slightly lower. Across governance indicators, the evidence points to limited institutionalisation (risk assessments: 3/12; emergency plans: 1/12; known urgent contact points: 3/12) despite comparatively strong awareness and high demand for additional information. Overall, this suggests scope to convert interest into practice through targeted onboarding and support for risk assessment integration, emergency planning, and clear contact pathways.

3.2.7. Canada

While Canada did not submit individual organisational responses to the questionnaire, a consolidated and expert-based input was provided by D.H. Boteler (Canada’s NPOC), detailing the national context, practices, and needs of the Canadian power system operation sector in relation to space weather (SW). This expert narrative captures the structural, operational, and regulatory environment within which Canadian utilities address geomagnetic hazards.

National Context and Sectoral Specificity

Unlike most European countries, Canada comprises 12 separate power systems, each independently managed. This structural fragmentation, combined with Canada’s unique experience of historical space weather events—most notably the March 1989 geomagnetic storm, which caused a major blackout in Hydro-Québec’s system—has deeply shaped awareness and response practices in the Canadian power industry.

Canadian utilities have since undertaken nationally coordinated studies (e.g. via the Canadian Electrical Association) and collaborative research with Natural Resources Canada to model geomagnetically induced currents (GIC), assess vulnerability, and develop mitigation strategies. These initiatives laid the groundwork for the advanced methodologies currently in place.

Current Practices and Service Requirements

Canadian power utilities are actively engaged in risk assessment, modelling, and mitigation, driven in part by regulatory requirements from the North American Electric Reliability Corporation (NERC). Under NERC standards, all North American utilities—including Canadian ones—must:

- Conduct geomagnetic hazard assessments every five years.
- Implement mitigating actions (engineering or operational) where GIC thresholds are exceeded.

Canadian utilities use the full spectrum of SW-related services:

- Measurements and nowcasts: for near real-time situational awareness.
- Forecasts: to support proactive operational planning.
- Post-event analysis: for system response validation and future risk modelling.
- Risk assessments: using extreme value statistics and earth conductivity models to simulate GIC and assess equipment/system vulnerability.

Additionally, real-time GIC simulations and research into GIC forecasting are underway, reflecting Canada's leading position in SW service application for power infrastructure.

Operational Needs and Service Gaps

Canadian power companies require granular, system-relevant space weather information. Traditional indices such as dB/dt or general geomagnetic alerts are not sufficient. Instead, utilities prioritise:

- Geoelectric field forecasts and nowcasts, tailored to regional conductivity profiles.
- Direct GIC values, generated through network-specific modelling.
- Visualisation tools (e.g. network maps showing GIC intensity).
- Alarm systems triggered when GIC thresholds are exceeded.

In this context, priorities like accessibility, accuracy, and timeliness are considered secondary, provided that information is relevant, interpretable by power engineers, and operationally actionable. Canadian users are well aware of the modelling limitations and accept a degree of uncertainty as inherent to the science.

Preparedness and Mitigation

All Canadian power utilities include space weather in formal risk assessments, aligning with NERC compliance. Mitigation strategies include:

- Engineering upgrades to transmission infrastructure.
- Special operational procedures during high-risk periods.
- Alarm-triggered actions based on GIC simulations.

This preparedness extends across executive and technical levels: executives support compliance efforts, while planning engineers actively integrate SW data into real-time and long-term decision-making.

3.2.8. European-wide perspective

The responses from European countries in the Space Weather Demonstrator Phase 2 reveal a diverse and uneven landscape in terms of awareness, usage, and preparedness for space weather (SW) impacts. Differences stem from national sectoral priorities, infrastructure maturity, and institutional engagement with SW issues. Importantly, the data varies in representativeness—while countries such as Italy, Spain, Portugal, and Finland had broader response samples, countries like Slovakia, and The Netherlands had only one, two or three responses, and their data should therefore be interpreted with caution.

Sectoral Composition and SW Service Uptake

Across countries, responses were largely concentrated in the communications/PNT, spacecraft operations, and power system operation sectors. Some countries showed strong representation from specific sectors, such as:

- Finland: Predominantly power system operators.
- Austria and Slovakia: Primarily communications/PNT.
- Italy, Spain and Portugal: Balanced across spacecraft operations, communications, and other domains.

The share of organisations currently using SW services also varies:

- Germany (78%), Greece (67%), and Italy (47%) show significant engagement.
- Sweden (33%), Spain (33%), Portugal (33%), and Luxembourg (25%) show moderate uptake.
- Austria (22%), Finland (9%), Hungary (0%), and Slovakia (0%) indicate low uptake.

Share of organisations using Space Weather services (in %)

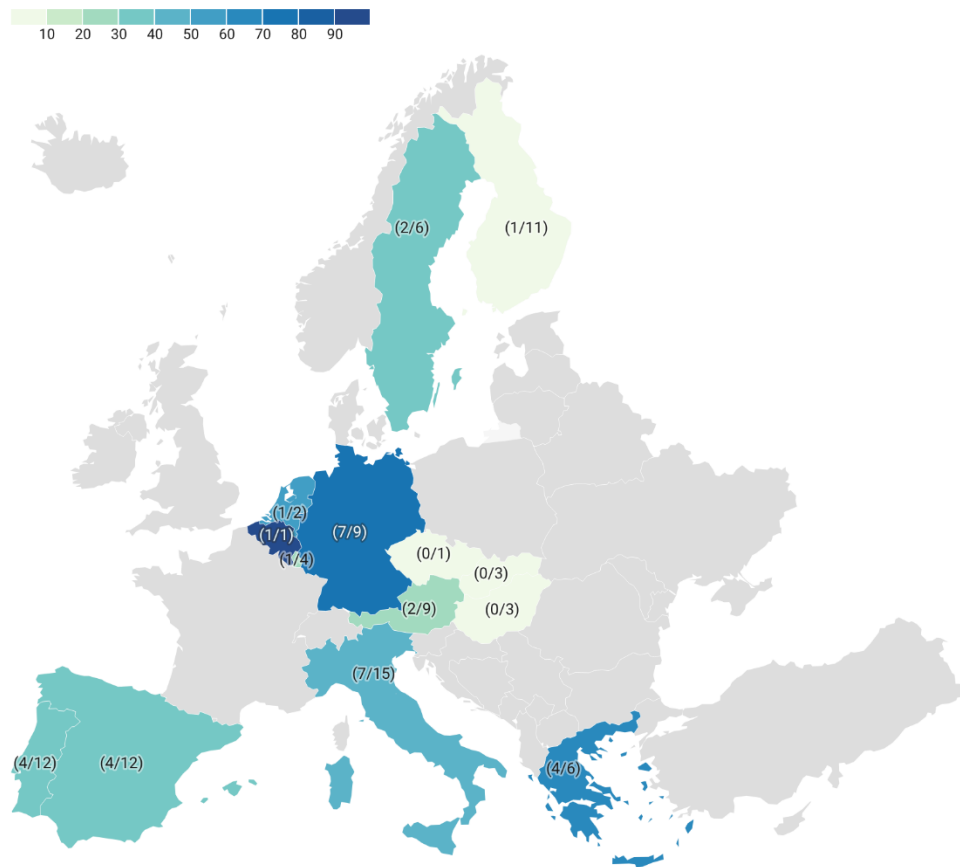


Figure 2: Share of organisations using SW services

However, there is clear interest in future adoption, especially in Spain [75%], Slovakia [67%], Hungary [67%], and Luxembourg [67%], suggesting growing recognition of the need for operational SW support.

Share of non-users planning to use Space Weather services (in %)

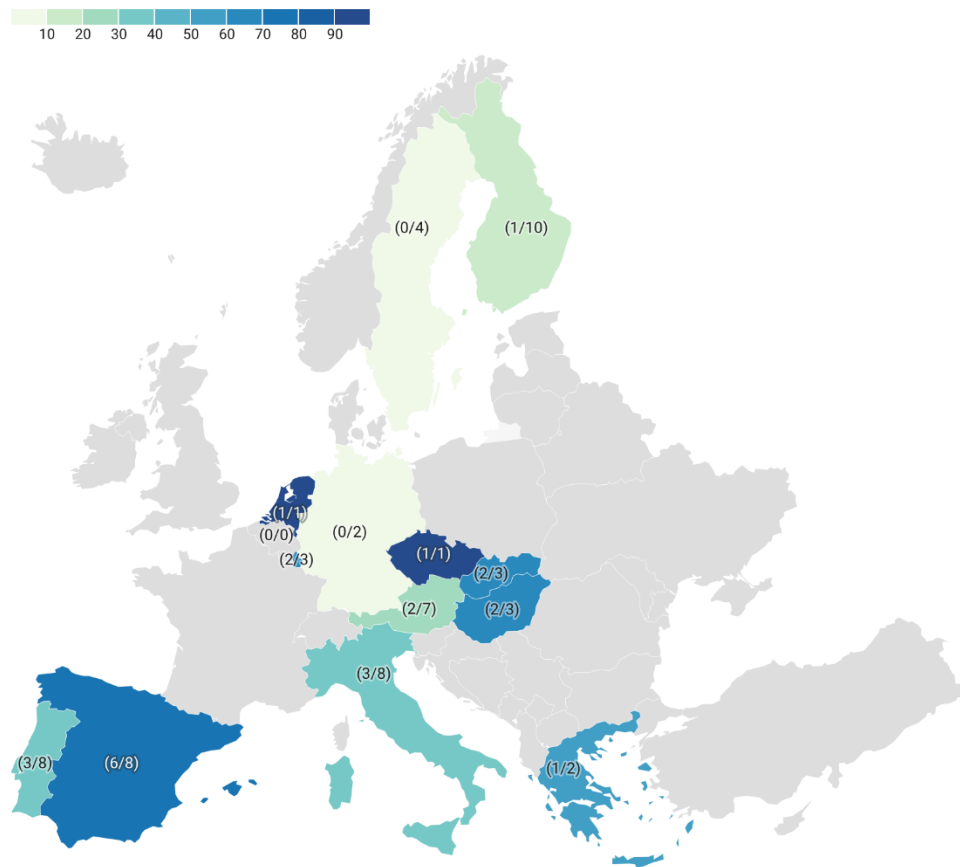


Figure 3: Share of non-users planning to use SW services

Understanding, Disruption Experience, and Risk Management

The average self-reported understanding of space weather risks is generally moderate:

- Germany [3.89], Greece [3.83], Italy [3.93], Portugal [3.58], Luxembourg [3.5], and Hungary [3.67] show high awareness.
- Finland [2.36] and Slovakia [2.33] suggest the need for targeted awareness-raising.

Avg. self-reported understanding of Space Weather services

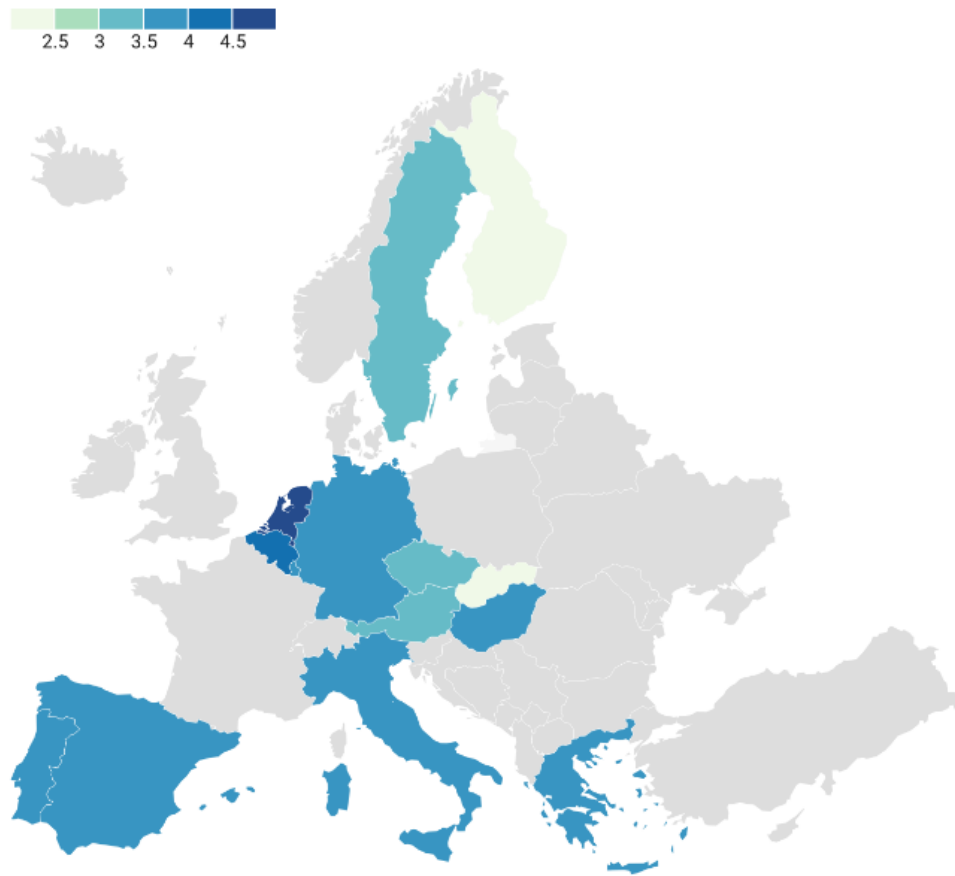


Figure 4: Average self-reported understanding of SW services

Experience with SW-related disruptions is another key indicator:

- Germany (100%), Spain (75%), Italy (45%), The Netherlands (50%), and Hungary (50%) report high rates of disruption experience.
- Finland, Slovakia, Greece, Belgium, and Czechia reported none—though Belgium and Czechia's data is based on a single respondent, making broad conclusions unreliable.

Share of organisations that have experienced Space Weather related disruptions (in %)

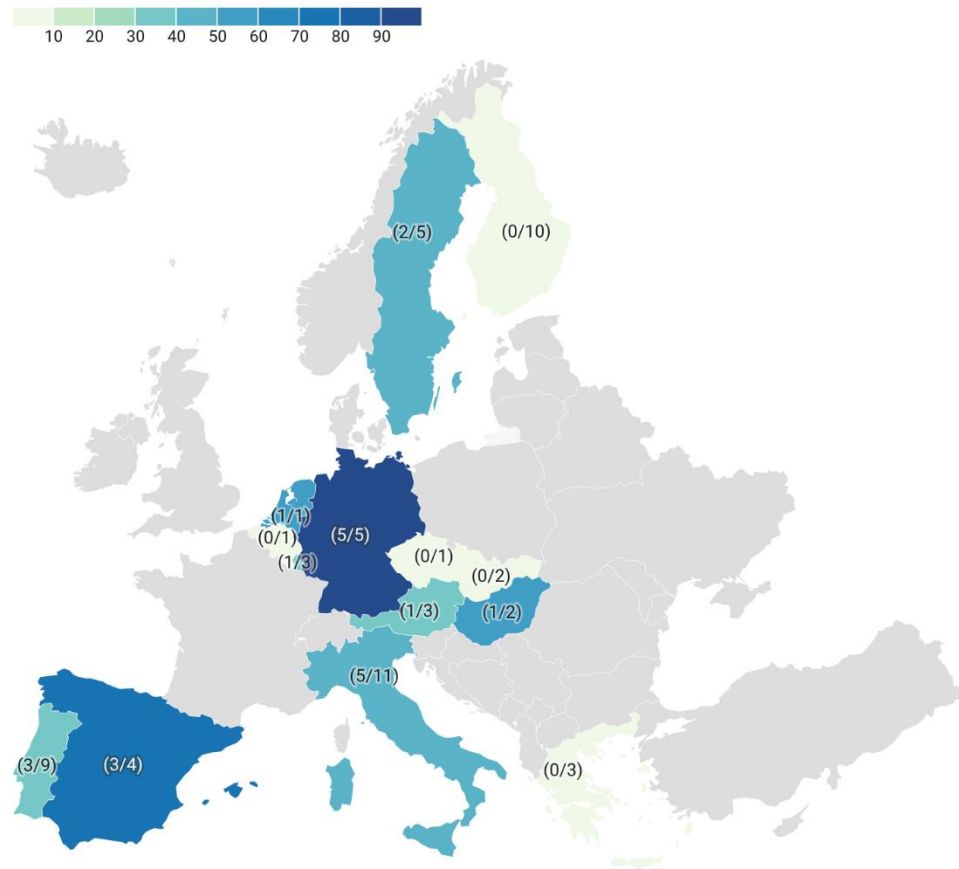


Figure 5: Share of organisations that have experienced SW related disruptions

Incorporation of SW in formal risk or impact assessments is strongest in Sweden [67%], Portugal [42%], Hungary [33%], and Germany [33%], but absent in countries such as Austria, Greece, and Slovakia, underscoring significant variation in institutional preparedness.

Share of organisations that have incorporated Space Weather in their risk or impact assessment (in %)

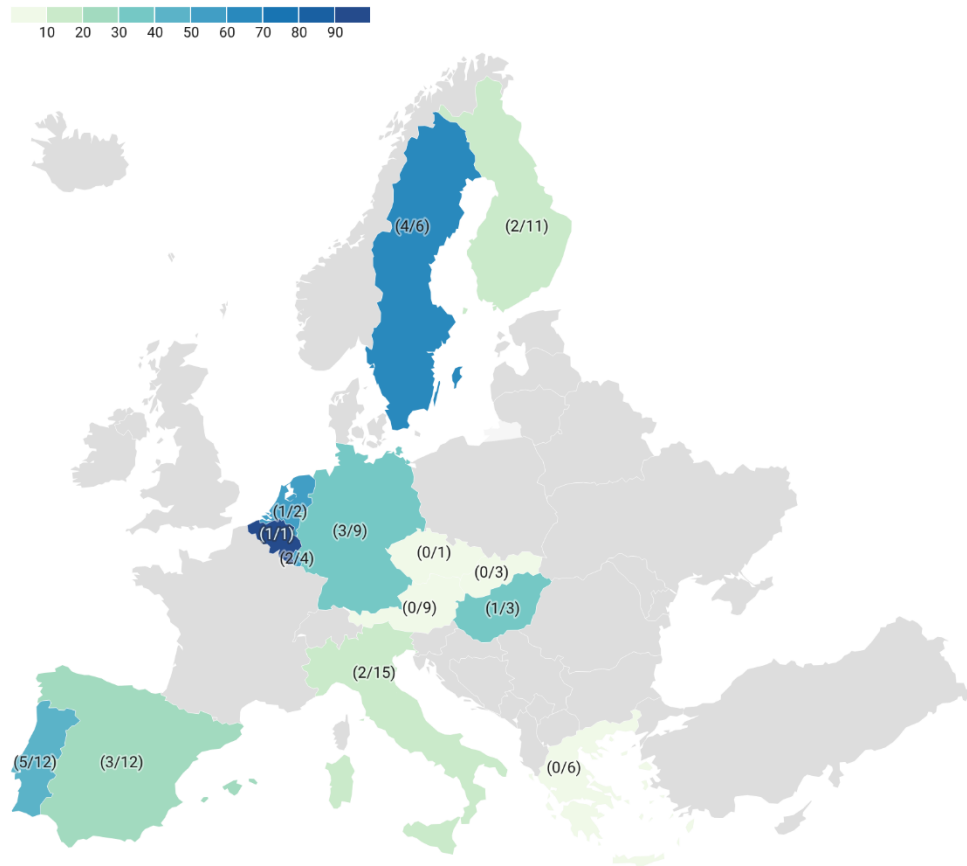


Figure 6: Share of organisations that have incorporated SW in their risk or impact assessment

Emergency Planning and Institutional Readiness

Responses collated from only a few countries demonstrate space weather inclusion in emergency response frameworks:

- Sweden [83%], Portugal [33%], Slovakia, and Germany [33%] lead in emergency preparedness for space weather.
- Austria [11%], Italy [7%], Finland [9%], Spain [8%], Hungary [0%], and Greece [0%] show gaps in formal response planning.

Share of organisations that have included Space Weather in their emergency response frameworks (in %)

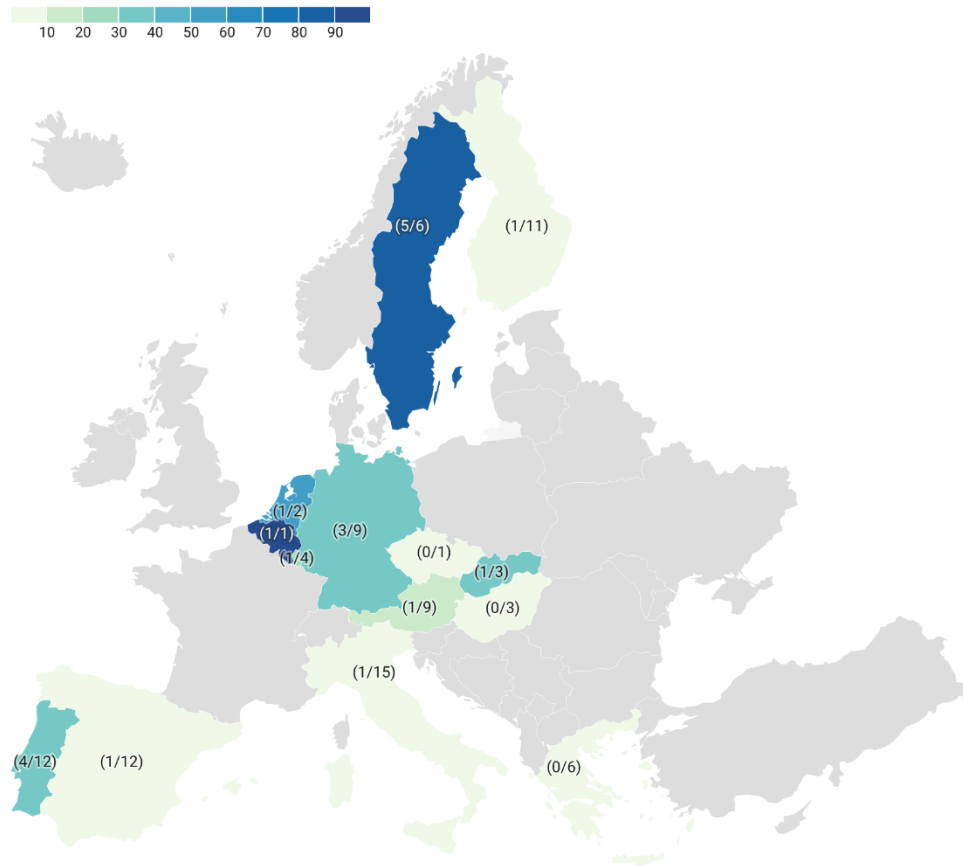


Figure 7: Share of organisations that have included SW in their emergency response framework

The average preparedness scores align with these findings:

- Sweden (3.5) report higher readiness.
- Slovakia (1.67) and Luxembourg (1.75) indicate more limited capacity.

Avg. self-reported preparedness level to respond to extreme Space Weather events

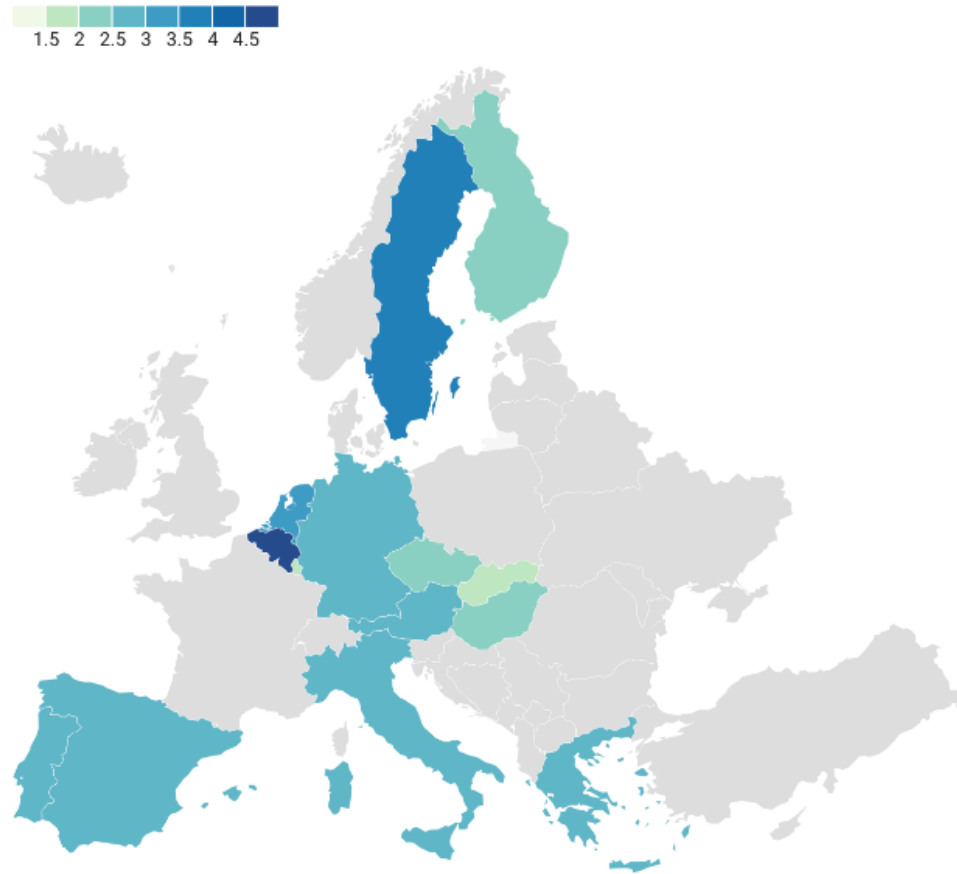


Figure 8: Average self-reported preparedness level to respond to extreme SW events

Regarding contact knowledge in the event of an SW emergency, Sweden [67%], Slovakia [67%], Portugal [58%], and Greece [50%] stood out, while Italy [33%], Hungary [33%], and Luxembourg [25%] had limited awareness.

Share of organisations that know who to contact if they had an urgent Space Weather-related question (in %)

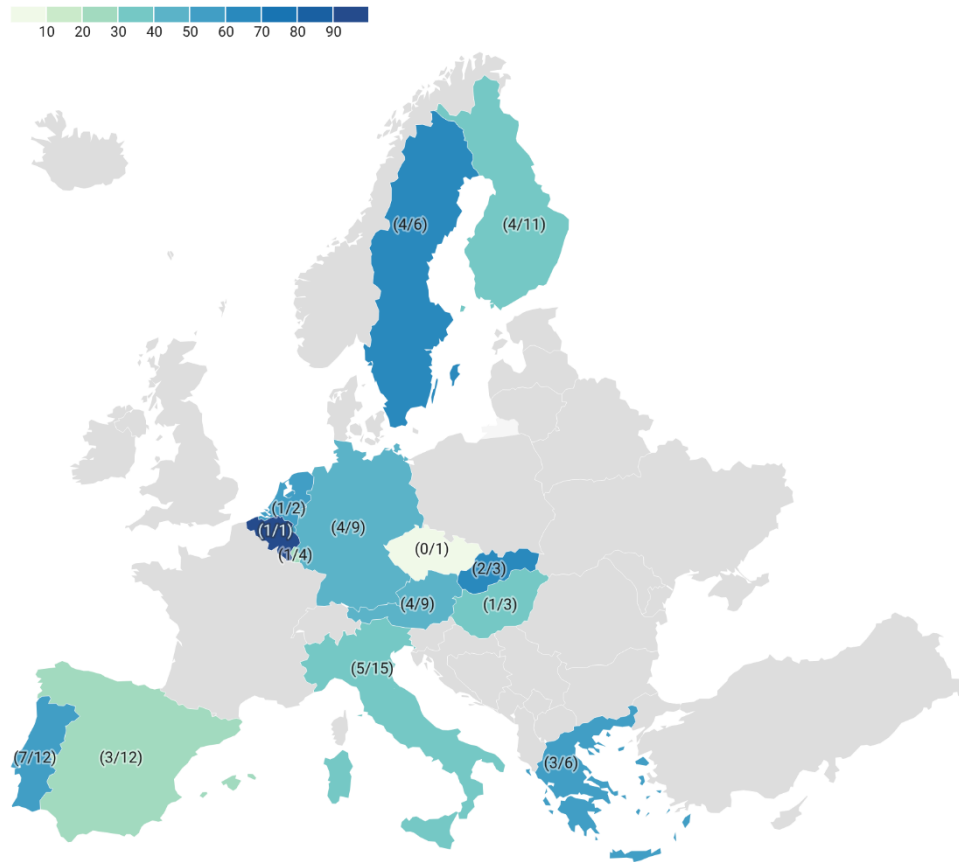


Figure 9: Share of organisations that know who to contact if they had an urgent SW-related question

4. SECTORAL ANALYSIS

4.1. Spacecraft Operations

4.1.1. Responders' Profiles

The spacecraft operations sector was one of the most represented domains in the Space Weather Demonstrator Phase 2, with responses spanning multiple mission types, orbital regimes, and national contexts. A total of 24 organisations across Germany, Italy, Portugal, Luxembourg, Spain and The Netherlands identified themselves as active in spacecraft operations, offering a broad perspective on the space weather needs of this operationally complex and technically demanding sector.

National Representation

The Italian space sector is particularly prominent, accounting for 8 of the 24 respondents. These organisations operate across various orbital regimes—primarily Low Earth Orbit (LEO) and Geostationary Orbit (GEO)—and support a diverse set of missions, including Earth observation (EO), communications, and science. Notably, one Italian organisation is currently transitioning a

ground station to support deep space and interplanetary missions, indicating a forward-looking interest in high-performance ground segment capability for future deep space operations.

Spain contributed five responses, covering space traffic coordination, communications, military space operations, and Earth observation. Most activities are focused on Low Earth Orbit, with additional representation in Geostationary Orbit and a dual LEO–GEO military operations profile, reflecting a portfolio spanning both operational services and strategic missions.

Germany contributed three responses, with spacecraft operations linked to communications, human spaceflight, and space traffic coordination. These missions span from LEO to Geostationary Orbit, and even extend to lunar operations, reflecting Germany's active role in both crewed spaceflight and space safety initiatives.

Luxembourg provided two entries, both focused on Earth observation missions in LEO, while Portugal contributed five additional responses, focused on communications, Earth observations, and space traffic coordination in LEO. These activities reflect a growing operational capacity in smaller national programmes with strong commercial and strategic interests in orbital sustainability.

The Netherlands reported spacecraft operations across LEO, MEO, and GEO, in connection with communications missions, suggesting a broad coverage of orbital altitudes and a need for space weather services tailored to multiple mission environments.

Sectoral Distribution

Across the 24 responses, primary activities are concentrated in Earth observation (EO) and communications, which together account for 17/24 (71%) of the sample. EO is the largest category with 10/24 responses (42%), followed by communications with 7/24 (29%), reflecting strong interest from data-intensive missions and operational service providers. Space traffic coordination is also a significant focus area, representing 4/24 responses (17%), underlining the operational importance of space weather for conjunction assessment and safe manoeuvre planning. The remaining activities—human spaceflight, science, and military space operations—are each represented by 1/24 responses (4%), indicating additional, more specialised use cases alongside the dominant EO and communications segments.

In terms of orbital distribution, the vast majority of activities are situated in Low Earth Orbit. Of the 24 listed, 17 (71%) operate exclusively in LEO, and a further 3 (13%) include LEO alongside other regimes (LEO–Moon, LEO–GEO, and LEO/MEO/GEO), bringing the share with a LEO component to 20/24 (83%). At the same time, there is meaningful representation in higher and more diverse regimes: 3 activities (13%) are GEO-only, and GEO features in 5/24 (21%) when including multi-orbit profiles. Beyond Earth orbits, 1 activity (4%) is identified as interplanetary/deep-space, and 1 (4%) explicitly includes lunar operations—each with distinct exposure to solar activity and space weather-driven impacts.

Spacecraft Operation organisations

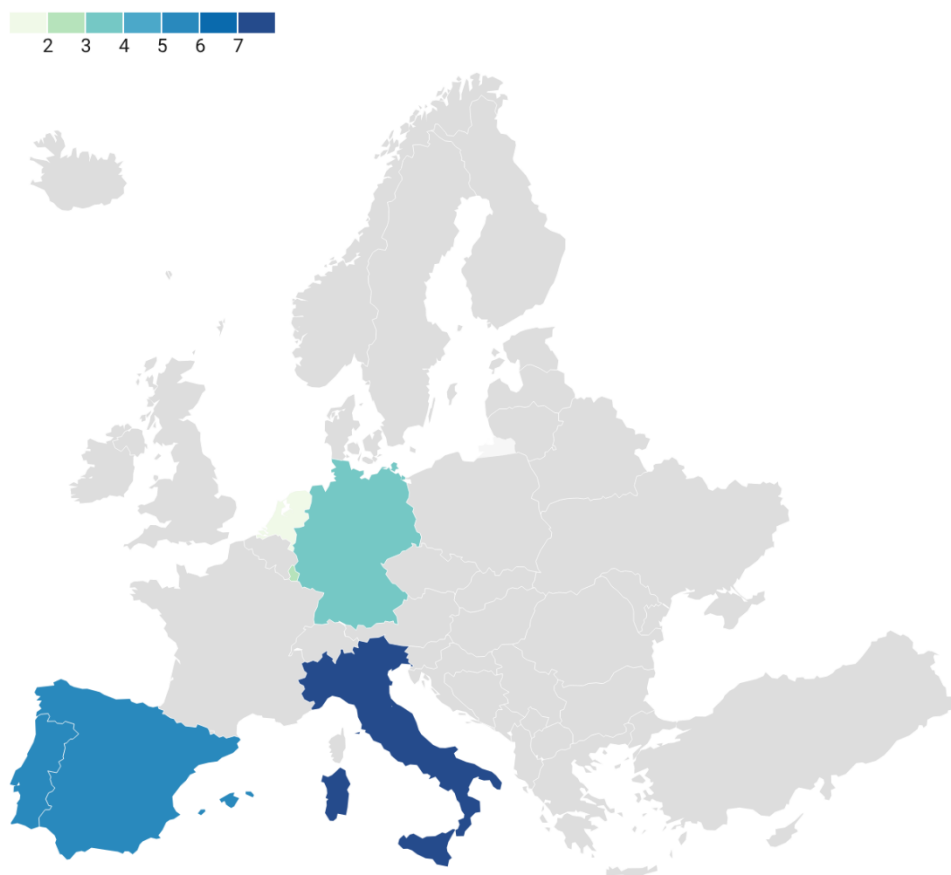


Figure 10: Spacecraft Operation organisations per country

4.1.2. Responders' Use of Space Weather Services

Among the 24 respondents from the spacecraft operations sector, 12 organisations (50%) reported that they currently use space weather services, while 12 (50%) indicated they do not or were unsure. This suggests that half of spacecraft operators already recognise and incorporate space weather information into their operational workflows, underscoring the relevance of space weather for satellite safety, system resilience, and mission continuity.

Measurements & Nowcasts

Among the 12 spacecraft operations organisations that reported using space weather services, 9 indicated that they make use of "Measurements & Nowcasts" services (75%), highlighting a strong reliance on near real-time monitoring within the operator community.

Within this group (n=9), 8 organisations (89%) reported using "Continuous real-time assessment of space environment conditions" services. The associated data inputs are dominated by solar activity indices (100%) and geomagnetic indices (75%). Atmospheric data for drag calculation was also frequently cited (50%). More specialised datasets were referenced by individual respondents, including ionospheric disturbances (1/8; 13%) and in-situ energetic particle data and ground-based magnetometer data (1/8; 13%).

Use of "SW event detection" services is also widespread: 7 of the 9 measurements/nowcasts users (78%) reported employing event detection capabilities. Data usage patterns are consistent with continuous monitoring, with solar activity indices used by

all event-detection users (100%) and geomagnetic indices by 6/7 (86%); atmospheric drag-related data was cited by 3/7 (43%), while in-situ energetic particle data, ground magnetometer data, and ionospheric disturbance data were each cited by 1/7 (14%).

By contrast, uptake of “Nowcast of specific space environment effects on user spacecrafts” services is more limited: 4 of 9 (44%) reported using these effect-focused nowcasts.

Finally, 2 organisations (22%) noted additional measurements/nowcasts sources beyond the listed categories, explicitly referencing external institutional products and portals (including NOAA SWPC, ESA’s SWE services portal, and UK MOSWOC outputs), illustrating selective integration of third-party operational services alongside internal workflows.

Forecasts

Among the 12 spacecraft operations organisations that reported using space weather services, 8 indicated that they make use of forecast services (67%), reflecting a substantial reliance on predictive information to support planning and operational decision-making.

All forecast users (100%) reported using “Forecast of space environment conditions” services. The data inputs most commonly referenced were solar activity indices (100%), followed by geomagnetic indices (75%) and atmospheric data for drag calculation (63%). Ionospheric disturbances were cited by 2/8 (25%), while in-situ energetic particle data and ground-based magnetometer data were mentioned by 1/8 (13%), indicating more specialised use in a small subset.

Use of “Forecast with probability and level of confidence of SW events” services was reported by 5 of the 8 forecast users (63%). These organisations consistently relied on solar and geomagnetic indices (100% each), and most also included atmospheric drag-related data (80%), suggesting that probabilistic products are typically anchored in the same core environmental indicators.

Uptake of “Forecast of specific space environment effects on user spacecrafts” services was more limited, reported by 4 of 8 forecast users (50%), indicating that impact-targeted forecasting remains less common than general condition forecasting. Identically, only 4 of the 8 forecast users (50%) reported using “Assessment of mission/system risks and susceptibility before operations phase” services.

Finally, 2 organisations (25%) reported using additional forecast services beyond the listed categories (described as “various” or referencing external portals such as NOAA SWPC and ESA SWE), illustrating selective integration of supplementary third-party forecast products.

Post-Event Analysis

Among the 12 spacecraft operations organisations that reported using space weather services, 5 organisations indicated that they also make use of post-event analysis services (42%). This suggests that a bit less than half of operator users undertake retrospective assessments to examine links between spacecraft behaviour and space weather conditions.

All five post-event analysis users (100%) reported performing correlation of housekeeping data with space environment parameters, making this the most consistently applied approach. In four out of five cases (80%), organisations also correlate housekeeping data with space weather event data, adding an event-based temporal dimension to their analyses.

A more detailed, system-specific approach is reported by three organisations (60%), which correlate specific spacecraft vulnerabilities with space environment parameters. In addition, two organisation (40%) reported fleet-level anomaly reporting across predefined fleets, indicating a more structured and operationalised capability for anomaly tracking and post-event diagnostics.

Other

Finally, beyond post-event analysis itself, 3 organisations (25%) reported using other space weather-related services, including NASA space weather forecasts for ISS operations and the use of internal tools/resources/sensors.

Service priorities & satisfaction

In terms of service priorities, spacecraft operators again assigned the highest importance to core information features. On a scale from 1 to 5, the attributes rated highest were information accuracy (4.58) and information accessibility (4.50), closely followed by information clarity (4.42). Timeliness of updates (4.25) was also rated highly, while user interface quality (3.83) was viewed as moderately important. Lower average scores were given to more specialised aspects, including customisation and personalisation (3.08), data enrichment and analysis (3.33), API standardisation and cataloguing (3.50), and 24/7 availability of expert support (2.92). One respondent additionally highlighted lead time for protective actions (rated 5)—notably in the context of astronaut protection—indicating that advance warning horizons can be a critical operational requirement for specific mission types.

When asked to rate their satisfaction with current services, respondents reported lower scores than their stated priorities, suggesting a gap between expectations and perceived performance. Satisfaction was highest for information accessibility (3.75) and timeliness of updates (3.67), followed by information clarity (3.58) and information accuracy (3.50). Satisfaction with user interface quality and API standardisation and cataloguing were rated at a moderate level (3.33 and 3.25, respectively). By contrast, the lowest satisfaction levels were reported for customisation and personalisation (2.83), data enrichment and analysis (2.83), and 24/7 expert support (2.50), indicating these as the most salient areas for improvement. One respondent additionally highlighted the value of orbit-regime-specific dashboards (LEO/MEO/GEO) as an improvement need (rated 4 in terms of importance).

Future adoption

Among the organisations not currently using space weather services that answered this question (n=12), 7 (58%) expressed plans to adopt such services in the future. Intended uptake is broad across service types: all prospective adopters plan to use forecasts (100%), while post-event analysis and measurements & nowcasts are each planned by 5/7 (71%). Overall, this points to a demand profile that combines predictive support with both near real-time monitoring and retrospective analysis.

The remaining 5 organisations (42%) did not indicate plans to adopt space weather services (“No / Don’t know”). Reported barriers were primarily limited resources (80%). Low priority, limited expertise, and operational data integration difficulties (20%), and difficulties integrating space weather data into mission operations were each cited by 1/5 organisations (20%). Overall, the responses suggest that capacity constraints are the primary limiting factor for uptake in this group, with a smaller number pointing to perceived relevance and integration challenges.

4.1.3. Responders' Knowledge of Space Weather Risks and Services

Among the 24 spacecraft operations respondents, the average self-assessed understanding of space weather risks was 3.96/5, indicating a generally high level of familiarity across the sample.

Despite this, 19/24 respondents (79%) expressed interest in receiving more information on space weather risks. Preferred delivery channels (multiple selections allowed) were led by websites (68% of those interested) and email (68%), followed by online seminars (53%) and trainings (42%). Offline seminars were selected less frequently (26%), as was social media (11%).

Interest in learning more about space weather services was even higher, with 22/24 respondents (92%) requesting additional information. Here again, the dominant channels were email (73%) and websites (59%), followed by online seminars (50%) and trainings (41%). Offline seminars (27%) and social media (9%) remained secondary options.

Overall, the results indicate strong engagement on both risks and services, with a clear preference for accessible digital channels (email/web) complemented by seminars and training formats for deeper engagement.

4.1.4. Responders' Experienced Disruptions

Based on the responses provided by spacecraft operators (n=24), 15 organisations (63%) reported having information available on whether their operations had ever been affected by space environment conditions (i.e., answered Yes or No), while 7 (32%) selected "Information not available". Among those with information available (n=15), 11 organisations (73%) reported having experienced disruptions and 4 (27%) reported none (equivalent to 50% and 18% of the full sample, respectively).

In terms of disruption frequency among those reporting disruptions (n=11), the most common response was "occasionally" (64%), corresponding to events occurring a few times per decade. Two organisations (18%) reported disruptions frequently (several times a year or more), and one (9%) reported disruptions rarely (less than once a decade). One response selected "never" in the frequency field despite indicating disruptions elsewhere; this should be treated as an internal inconsistency in the reporting.

When asked to assess the highest level of impact experienced (n=11), responses ranged from no impact (9%) and minimal impact (18%) to moderate impact (45%), significant impact (9%) and severe impact (18%). Overall, while reported disruption frequency is most often low-to-moderate, the impact distribution indicates that a non-negligible subset of operators have encountered high-consequence outcomes (notably two severe cases), with one additional "significant impact" report that should be interpreted cautiously due to the frequency inconsistency.

4.1.5. Responders' Preparedness Levels

Among the 24 spacecraft operations respondents, 10 organisations (42%) reported that they include space weather in their risk or impact assessments. Of these, 7/10 (70%) conducted an assessment less than one year ago, 2/10 (20%) did so less than five years ago, and 1/10 (10%) more than five years ago. Regarding future updates, 7/10 (70%) plan to revisit their assessments within the next two years, while 3/10 (30%) have not yet defined an update timeline.

Reported risks and impacts span both spacecraft health and service continuity. Respondents highlighted radiation-driven effects (including cosmic radiation), ranging from software/data corruption and equipment malfunction to surface charging/ESD, and in the most severe framing, irreversible damage to electronics and potential propulsion subsystem damage. Several organisations emphasised orbit-related vulnerabilities, notably increased atmospheric drag driving orbit determination and propagation errors, affecting manoeuvre planning, phasing, orbital lifetime, and raising conjunction/collision risk (often discussed alongside space debris and degraded tracking/monitoring). On the service side, risks include RF link quality degradation, communication and GNSS disruptions up to signal blackout, data latency/loss, and downstream service provision outages or customer traffic disruption.

Most of the organisations that include space weather in assessments also reported mitigation actions: 8/10 (80%) answered "Yes" to having implemented mitigation measures, while 2/10 (20%) selected "No / Don't know". The latter cited limited expertise in one case, and low priority due to perceived lower exposure in the other, linked to New Space projects with shorter mission lifetimes and therefore reduced cumulative exposure to space weather. Reported mitigation measures span both technical and procedural approaches, including the use of alternative data sources/proxies and atmospheric density models, drag modelling improvements, collision risk assessment and avoidance, spacecraft design adaptations (including CubeSat software-side detection and recovery procedures), materials choices to reduce absorbed radiation, and operational planning measures such as using predictive models, scheduling critical activities outside forecasted storm windows, and systematic alert monitoring.

Among the 14 organisations (58%) that did not report including space weather in their assessments, the most frequently cited barriers were low priority (50%) and limited resources (50%), followed by low relevance (21%) and limited expertise (7%).

Regarding emergency response planning, 8 out of 24 organisations (33%) reported having an emergency response framework in place for an extreme space weather warning. These frameworks are predominantly described as in-house emergency response plans (88%), with one respondent referring to ISS response plans (13%).

Among the remaining 16 organisations (67%) that did not report having a framework, 3 (19%) indicated plans to develop one, with anticipated timelines of within 2027, within two years, and within one to two years, respectively. Most non-planners selected barriers consistent with broader adoption constraints, notably limited resources (38%) and low relevance (25%), alongside low priority (25%). One respondent (6%) added limited expertise.

When asked to rate their level of preparedness to respond to extreme space weather events on a scale from 1 (unprepared) to 5 (fully prepared), the average across respondents was 2.88, suggesting moderate readiness across the sector.

Only 11 out of 24 organisations (46%) stated they would know who to contact in the event of an urgent space weather-related issue, while 13/24 (54%) answered negatively.

The named contact points span a mix of institutional, national, and internal channels. Institutional/service-level contacts include the German Space Situational Awareness Center, NASA, the ESA SWE Service, the ESA Space Weather Office, and ESA more broadly (including reference to Space-Track for urgent conjunction or collision alerts potentially affected by space weather). National points of contact include the Italian Space Agency (cited by two respondents, including the Sardinian National Base), SWICO (Space Weather Italian Community), and Spanish entities such as UAH and the Spanish National Geographical Institute (IGN) and AEE. One respondent also referenced internal subject matter expertise alongside external alert providers (SWPC, MOSWOC, and BAS), illustrating that escalation pathways can combine in-house expertise with external operational services.

Finally, 19 out of 24 respondents (79%) expressed willingness to participate in a follow-up meeting to further discuss their information needs and learn more about ESA's space weather services.

4.2. Communications and / or PNT

4.2.1. Responders' Profiles

Based on the responses from 26 organisations operating in the Communications and/or Positioning, Navigation and Timing (PNT) sector, the dataset reflects a broad geographic and technical diversity across European countries.

Sectoral Distribution

Out of the 26 organisations:

- 15 identified PNT as their primary focus (58%)
- 11 identified Communications as their primary focus (42%)

This shows a fairly balanced representation, with a slight leaning toward PNT-related services.

National Representation

The most represented country in this dataset is Portugal with 5 respondents, followed by Austria, Portugal, and Spain, each with 4 respondents. Austrian organisations are predominantly engaged in PNT (3/4), with 1/4 in communications. Portugal shows the reverse profile, with 3/5 active in communications and 2/5 in PNT. Spain mirrors Austria, with 3/4 respondents focused on PNT and 1/4 on communications. Germany and Italy follow with 3 respondents each, and in both cases all respondents are engaged in PNT (3/3). Greece and Slovakia are each represented by 2 organisations, both entirely in

communications (2/2 each). Finally, Luxembourg and Finland each have 1 communications respondent, while Hungary is represented by 1 PNT respondent.

Communications and / or PNT organisations

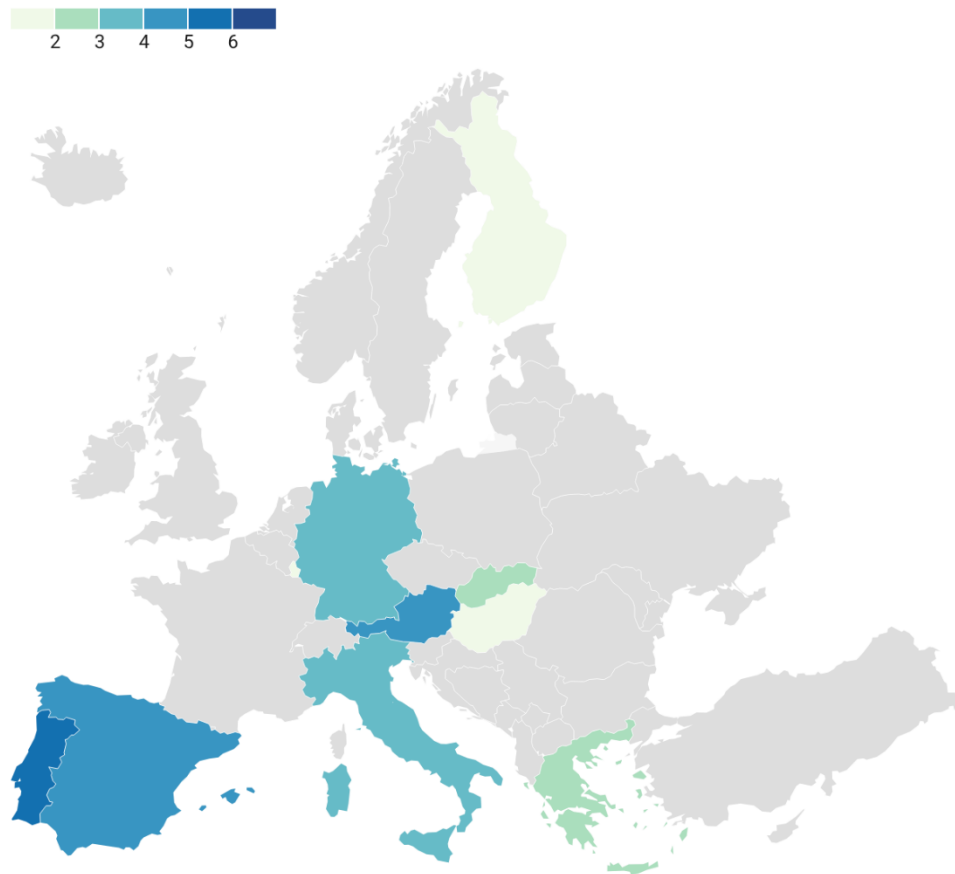


Figure 11: Communications and / or PNT organisations per country

Frequency Band Usage

Organisations reported operations across a broad spectrum of frequency bands (n=26):

- UHF (300 MHz – 3 GHz): 7/26 (27%) – used by 4 communications and 3 PNT respondents.
- SHF (3 GHz – 30 GHz): 6/26 (23%) – used by 4 communications and 2 PNT respondents.
- VHF (30 MHz – 300 MHz): 5/26 (19%) – primarily PNT (3) plus 1 communications case.
- HF (3 MHz – 30 MHz): 3/26 (12%) – mainly PNT (2) plus 1 communications case.
- GNSS-specific bands: 2/26 (8%) – both in PNT (incl. GNSS bands and E1/E5/E6).
- EHF (30 GHz – 300 GHz): 1/26 (4%) – communications (radio).
- L band (1–2 GHz): 1/26 (4%) – PNT (R&D).
- All bands: 1/26 (4%) – communications (mixed radio/aviation context).
- Not specified: 1/26 (4%).

Several organisations indicated multi-band contexts (e.g., VHF+HF for oceanic control) or broad coverage (“All”), consistent with complex or geographically dispersed operational needs.

Application Domains

Reported primary application areas are similarly diverse (some responses combine multiple domains):

- Aviation: 8 mentions (6 PNT; 2 communications)
- Internet / Broadband: 5 mentions (4 communications; 1 PNT)
- Radio: 4 mentions (3 communications; 1 PNT)
- Mobile Network: 4 mentions (3 communications; 1 PNT)

Other domains were each cited once, including public administration, agriculture, engineering/geodesy, DTH, research & development, IAS service development/piloting, and multi-domain GNSS applications spanning maritime/aviation/rail.

In the subsequent analysis, particular attention will be given to the 18 organisations operating within the HF, VHF, and UHF frequency bands. These bands are of particular interest due to their role in ground-to-ground communications, including propagation beyond line of sight, and their relevance across a range of civil and defence-adjacent applications. In terms of primary application domains, the subgroup is dominated by aviation-related activities (6/18 in aviation alone, plus 1/18 in IAS service development and 2/18 in multi-domain profiles that include aviation), followed by radio (2/18) and mobile networks (2/18, with an additional 1/18 spanning mobile and internet). The remaining domains are each represented by a single organisation: PNT (1/18), public administration (1/18), engineering/geodesy (1/18), and research and development (1/18).

4.2.2. Responders' Use of Space Weather Services

Among the 26 organisations responding from the Communications and/or Positioning, Navigation, and Timing (PNT) sector, 9 organisations (35%) indicated that they currently use of space weather (SW) services. This includes 6 out of the 18 organisations (33%) operating within the HF, VHF, or UHF frequency bands—and notably, among these 18, all organisations (5/6; 83%) with aviation as their primary application domain reported using space weather services.

Among the 9 users, the majority—5 organisations—are active in the PNT domain, while 4 are focused on communications. This distribution suggests a slightly greater uptake of space weather services within the PNT subgroup of this sector.

Measurements & Nowcasts

Among the nine organisations from the communications and/or positioning, navigation and timing (PNT) sector that reported using space weather services, seven (78%) indicated that they make use of “Measurements & Nowcasts” services, confirming strong engagement with near real-time monitoring tools in this community.

Within this subgroup (n=7), four organisations (57%) reported using “Continuous real-time assessment of space environment conditions” services. The data referenced for continuous assessment is predominantly ionosphere-focused, including TEC maps and ionospheric scintillation metrics, as well as monitoring of ionospheric correction model accuracy. One respondent also cited the use of energetic particle and magnetic field data.

Use of “SW event detection” is widespread among measurements/nowcasts users: six out of seven (86%) reported employing event detection capabilities. These detection approaches frequently reference monitoring ionospheric phenomena linked to regional electron density disturbances (including European-scale effects) and detection of geomagnetic events, with one organisation additionally relying on energetic particle and magnetic field data for event detection.

Finally, three organisations (43%) reported using additional or complementary measurements/nowcasting services beyond the standard offerings. Examples include self-acquired solar flux measurements to monitor solar activity, alerts/warnings and related products from multiple national and international providers (including UK MOSWOC, BGS, NOAA SWPC, and ROB/SIDC), and the tracking of localised positioning-service outages (e.g., EGNOS, Galileo, GPS) attributed to space-weather-related impacts and anomalies.

Forecasts

Among the nine organisations in the communications and/or PNT sector that reported using space weather services, four (44%) indicated that they use forecast services.

Within the group that confirmed forecast use (n=4), three organisations (75%) reported using “Forecasts of space environment conditions” services. The associated data types are predominantly ionosphere- and propagation-relevant inputs, including ionospheric scintillation (2 mentions) and TEC maps (1), alongside geomagnetic indices (1) and more specialised datasets such as energetic particle and magnetic field measurements (1).

All organisations that confirmed forecast use (100%) also reported using “SW event detection” services. Event detection inputs are centred on geomagnetic event detection (cited by all four) and, in some cases, monitoring of ionospheric phenomena causing regional (including European) electron density disturbances (2 cases). One respondent additionally cited energetic particle and magnetic field data as part of event detection.

Finally, two of the four forecast users (50%) reported using additional forecast services, including the setup of a short-term (few days) F10.7 forecast and the use of NOAA SWPC products. In addition, one respondent forecasts covering a broader set of phenomena, including solar flares, solar energetic particles (SEP), coronal hole high-speed streams (CH HSS), relativistic electrons, and geomagnetic disturbances, illustrating the breadth of forecasting needs within the sector.

Post-Event Analysis

Among the nine organisations in the communications and/or PNT sector that reported using space weather services, two organisations (22%) indicated the use of post-event analysis services. In both cases, respondents referenced access to historical space environment data and space weather event archive data, suggesting that post-event activities are primarily oriented towards reviewing past conditions and supporting after-action understanding of anomalies or performance degradations.

Overall, uptake of post-event analysis remains limited in this sector compared with measurements/nowcasts and event detection, indicating that retrospective assessment is not yet systematically embedded in operational workflows for most communications/PNT respondents.

Other

Among the nine organisations in the communications and/or PNT sector that reported using space weather services, two respondents (22%) indicated that they use other kinds of space weather services beyond measurements/nowcasts, forecasts, or post-event analysis. One organisation described relying on additional datasets, including in-situ energetic particle data, ground-based magnetometer data, and space-based magnetometer data, suggesting a comparatively specialised implementation. The second organisation referred more generally to the use of public-domain sites, indicating a lighter-weight approach based on open-access information sources.

Service Priorities and Satisfaction

When asked to prioritise operational space weather service features (n=9), respondents assigned the highest importance to information accuracy (4.44/5), followed by information clarity (4.33/5) and information accessibility (4.33/5). Timeliness of updates was also rated highly (4.11/5). Mid-range priorities were given to quality of the user interface (3.44/5) and API standardisation and cataloguing (3.44/5). Lower priorities were assigned to customisation and personalisation (2.22/5), 24/7

expert support (2.67/5), and data enrichment and analysis (2.89/5), indicating a stronger emphasis on core information quality and delivery than on advanced tailoring or support features.

Responses on satisfaction with current services broadly align with the priority pattern, with respondents expressing the strongest satisfaction with foundational attributes. The highest average scores were reported for information accessibility (3.89/5) and timeliness of updates (3.78/5), followed by information clarity (3.67/5) and API standardisation and cataloguing (3.67/5). Information accuracy and user interface quality were rated at a similar, moderate level (3.56/5 each). By contrast, the lowest satisfaction scores were recorded for customisation and personalisation (2.00/5), 24/7 availability of expert support (2.44/5), and data enrichment and analysis (2.56/5), suggesting that more advanced tailoring and added-value analytical layers are currently perceived as weaker or less mature. One respondent also highlighted a need for improved operational communication to end users—particularly more graphical products (preferred over textual coordinates) and broader provision of space weather advisories to flight crews.

Future Adoption

Among organisations in the communications/PNT sector not currently using space weather services (17 in total), 7 indicated an intention to adopt them in the future (41%). Of these, 6/7 belong to the group of 12 non-users operating within the HF, VHF, or UHF frequency bands. Their interest spans the full range of service types. Measurements & nowcasts were cited 4 times (57%) and forecasts were cited 6 times (86%), making forecasting the most consistently requested capability. Post-event analysis was mentioned 2 times (2/7; 29%), indicating a smaller but present demand for retrospective services.

For the 10 non-users not planning adoption, the most frequently cited barriers were limited expertise (50%), low relevance (40%), and limited resources (40%), followed by low priority (30%). Several respondents reported combinations of constraints (50% cited two or more factors), indicating that both internal capacity limitations (expertise/resources) and perceived operational need (priority/relevance) shape non-adoption at this stage.

4.2.3. Responders' Knowledge of Space Weather Risks and Services

The average self-assessed understanding of the risks posed by space weather among respondents in the communications and/or PNT sector is 3.80 out of 5, indicating a fairly high level of awareness across the group. This suggests that many organisations in the sector are at least somewhat familiar with the potential operational implications of space weather phenomena.

Notably, the six organisations within the HF-VHF-UHF group whose primary application domain is aviation reported a higher average understanding level of 4.17/5, reflecting a heightened awareness likely linked to the sector's relatively strong engagement with the space weather domain through the existing ICAO service.

A large majority—19 out of 26 organisations (73%)—expressed a desire to receive more information about space weather risks. Preferences for information delivery formats (multiple selections allowed) were led by email (79% of interested respondents), followed by online seminars (53%) and website resources (42%). Training sessions were selected 4 times (21%), while offline seminars were mentioned 3 times (16%); social media was cited once (5%). Overall, respondents favour accessible digital formats, with a smaller but visible interest in more structured or interactive engagement.

Interest in learning more about space weather services was similarly high, with 21 out of 26 organisations (81%) indicating a desire for further information. Preferred delivery channels were dominated by email (81% of interested respondents), followed by websites (43%) and online seminars (38%). Offline seminars and training sessions were each selected 2 times (10%). Overall, the pattern mirrors that seen for risk-related information, underscoring the central role of direct, accessible digital channels—especially email—supplemented by a smaller demand for interactive formats.

4.2.4. Responders' Experienced Disruptions

Of the 26 organisations in the communications and/or PNT sector, 18 provided information on space weather-related disruptions. Among them, 9 organisations (50%) reported having experienced disruptions, while 8 stated they had not.

A similar pattern is observed within the HF-VHF-UHF group, where 11 organisations had available information. Of these, 5 (45%) reported having experienced space weather-related disruptions. Notably, 2/5 (40%) of these cases involved organisations whose primary application domain is aviation, underscoring the sector's particular awareness of space weather impacts.

Among the organisations that reported having experienced disruptions (n=9), disruption frequency information was available for 8 (with 1 selecting "Information not available"). Within the 8 with usable frequency data, disruptions were most commonly reported occasionally (38%), followed by frequently (25%) and regularly (25%), with rare occurrences reported by 1/8 (13%).

Reported highest impact levels span a wide range. Excluding the single "information not available" entry, impacts include severe (13%) and significant (13%) cases, alongside moderate impacts (38%). Minimal impacts were reported by 2/8 (25%), and no impact by 1/8 (13%). Overall, while disruption frequency is often described as occasional to frequent, the impact distribution indicates that a non-negligible subset of cases reaches high-consequence levels (significant or severe).

The disruption profile includes one regularly occurring case associated with severe impact, and two frequently occurring cases with significant or moderate impacts, underlining the importance of sustained monitoring, early warnings, and mitigation measures for certain actors within the communications and PNT sector. At the same time, the diversity in reported frequencies and impact levels suggests a broad spectrum of vulnerability and experience across different organisations.

4.2.5. Responders' Preparedness Levels

Only 3 out of 26 organisations (12%) in the communications and/or PNT sector reported including space weather in their formal risk or impact assessments. Two out of the three (67%) are organisations from the HF-VHF-UHF group, specifically within the aviation domain. All assessments were conducted less than one year ago, and the organisations indicated plans to update them within the next two years.

These organisations identified a range of key risks, including equipment failure or malfunction, degradation or loss of air-ground communications (notably affecting HF and VHF radio links), and broader operational impacts such as orbit determination issues, communication blackouts or partial loss, GNSS signal degradation, radar system blackouts, and increased radiation exposure/effective dose affecting spacecraft operations.

All organisations that conduct risk assessments also confirmed that they have implemented mitigation measures, although one described the measures as confidential. The others cited operational awareness and contingency procedures, as well as daily monitoring of space weather conditions, particularly geomagnetic activity and solar radiation.

For the remaining 23 organisations not including space weather in their risk assessments, the most frequently cited barriers were low relevance (43%) and low priority (43%), followed by limited resources (26%) and limited expertise (26%). Barriers were often cumulative: 9/23 (39%) cited two or more constraints in combination, pointing to both capacity limitations and perceived operational need as persistent blockers.

Emergency preparedness planning is similarly limited. Only 1 out of 26 organisations reported having an emergency response framework—an organisation from the HF-VHF-UHF group, specifically within the aviation domain—which was described as an in-house plan. Among the 25 without a plan, just 1 (4%) stated an intention to develop one within the next three years. The reasons for not having a framework largely echoed those for the absence of risk assessments: low priority, limited resources, and low perceived relevance were the most common themes.

When asked to assess their level of preparedness for responding to an extreme space weather event, respondents gave an average score of 2.38 out of 5, indicating a generally low level of readiness within the sector. 16 out of the 26 (62%) answered

1-2/5, suggesting that most organisations of this sector do not feel operationally ready. In the HF–VHF–UHF aviation subgroup (n=6), average preparedness was marginally higher (2.50), yet remains clearly low and suggests limited operational readiness.

Only 10 out of 26 organisations (38%) reported that they would know whom to contact in the event of an urgent space weather-related question. Cited contact points include GeoSphere Austria, Eurocontrol, UK MOSWOC, NOAA SWPC, SWICO, the Slovak Academy of Sciences, and national authorities (e.g. Portugal's civil protection), alongside in-house teams and a small number of private providers (e.g. Telespazio, Planetek, SITA, ARINC/COLLINS).

Finally, 15 out of 26 organisations (58%) indicated they would be open to a follow-up meeting to further discuss their space weather information needs and explore the services offered by ESA, highlighting a moderate level of engagement and interest in improving future preparedness and service use.

4.3. Power System Operation

4.3.1. Responders' Profiles

The power system operation sector was represented by 27 respondents across twelve European countries: Belgium, Czechia, Greece, Italy, Finland, Sweden, Hungary, Germany, Portugal, the Netherlands, Luxembourg, and Spain.

A substantial majority—24 out of 27 (93%) organisations—identified electricity transmission as their primary activity or area of relevance within the energy system. The remaining three respondents identified nuclear power, electricity distribution, and other renewables (e.g. hydrothermal, hydroelectric, tidal) as their primary operational domains.

Finland is the most strongly represented country in this sector, accounting for 8 of the 27 responses, followed by Sweden with 6. The rest of the sample includes 3 responses from Greece, 2 responses from Portugal, and 1 response from the other countries.

Overall, the dataset captures a well-defined cross-section of Europe's power system operators, with a consistent orientation toward the high-voltage transmission level and a geographic distribution that includes both Nordic and southern European grid stakeholders.

Power System Operation organisations

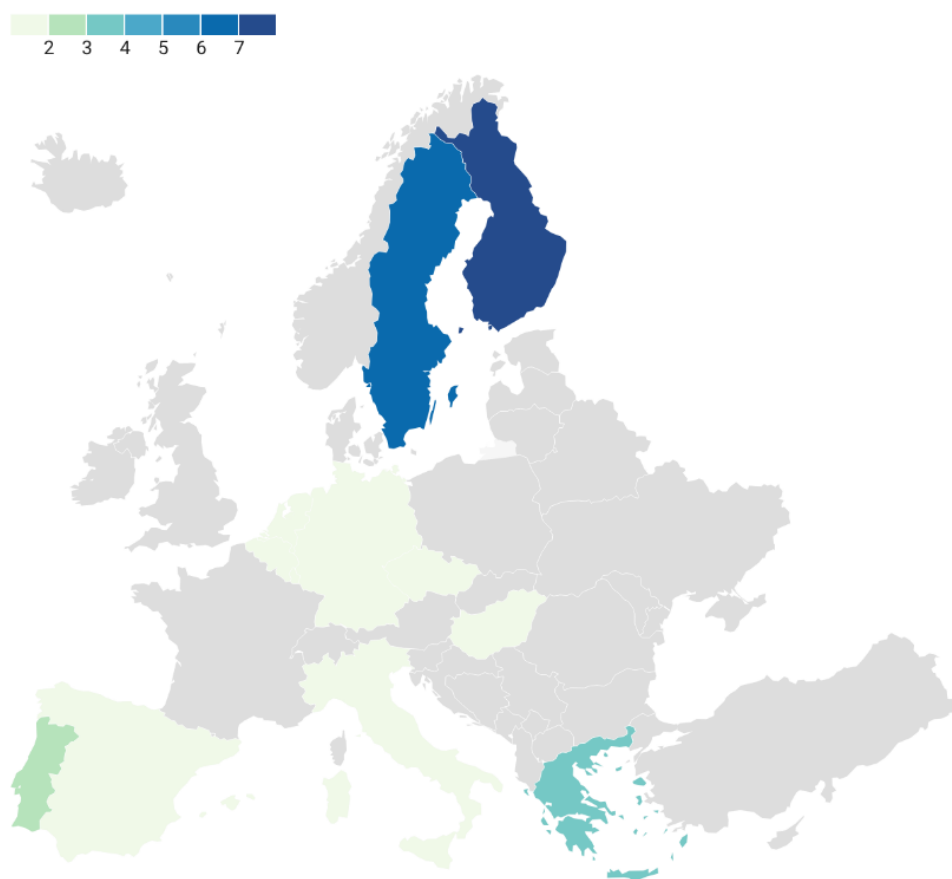


Figure 12: Power System Operation organisations per country

4.3.2. Responders' Use of Space Weather Services

Among the 27 organisations representing the power system operation sector, 7 respondents (26%) reported that they currently use space weather services. This group includes both electricity transmission operators and the single respondent from the nuclear energy domain, indicating that interest in space weather monitoring is not limited to transmission networks alone.

Among the 7 organisations in the power system operation sector that currently use space weather services, two (29%) reported using measurements and nowcasts. Their usage focuses on operationally actionable geomagnetic monitoring, including nowcasts and alerts of dB/dt at specific locations and products supporting GIC situational awareness such as power system network maps showing GICs, GIC risk index modelling, and geoelectric field variation monitoring in the vicinity of specific ground infrastructures. This indicates a targeted approach to real-time assessment of geomagnetic conditions and their potential impacts on transmission networks.

All but one organisation (6/7; 86%) reported using forecast services, making this the most consistently adopted service category within the power system operation sector. Forecast usage is strongly centred on alerts ahead of local conditions potentially leading to severe GIC levels, cited by all six forecast users (100%). In addition, two organisations (33%) reported more detailed, grid-relevant forecast products, including forecast dB/dt levels at specific locations and power system network maps showing (predicted) GICs. One of these also referenced broader contextual forecasts such as a global outlook of geomagnetic activity and transient and recurrent IMF Bz features, indicating a more comprehensive approach that combines localised warning thresholds with wider-scale drivers of geomagnetic disturbance.

Two organisations (2/7; 29%) indicated the use of post-event analysis services. Reported uses include data and tools to support power grid operators in post-event analysis and a table of modelled past GIC values and peaks for the users' network. While uptake is lower than for forecasts, it is comparable to measurements & nowcasts in this sector.

Additionally, three organisations (3/7; 43%) reported using other kinds of space weather services beyond the main categories. One referred to receiving space weather forecast warnings/alarms for GICs (G3–G5), another reported drawing on external sources such as the UK Met Office and public websites (e.g. spaceweather.se, spaceweather.com), and a third highlighted an escalation pathway via direct phone contact with a national space weather expert for urgent questions.

In terms of user priorities (n=7), power system operators placed the highest value on information clarity (3.86/5) and information accuracy (3.86/5). These were followed by information accessibility (3.43/5) and timeliness of updates (3.43/5), with user interface quality rated at 3.00/5. Lower average importance was assigned to more advanced features, including 24/7 expert support (2.86/5), customisation and personalisation (2.57/5), data enrichment and analysis (2.43/5), and API standardisation and cataloguing (2.29/5).

Regarding service satisfaction (n=7), scores remain broadly aligned with the prioritisation pattern, with strongest satisfaction reported for core informational attributes. The highest average satisfaction ratings were for information accuracy (3.43/5) and information clarity (3.43/5), followed by information accessibility (3.14/5) and timeliness of updates (3.00/5). Satisfaction with user interface quality was moderate (2.57/5). Lower ratings were given to customisation and personalisation (2.14/5), data enrichment and analysis (2.00/5), and API standardisation and cataloguing (2.00/5), with 24/7 expert support slightly higher but still modest (2.57/5). Overall, this suggests that while baseline information delivery is viewed relatively positively, there is more limited satisfaction with advanced or value-added capabilities.

Among the 20 organisations not currently using space weather services, 5 (25%) indicated plans to adopt them in the future. All five prospective adopters (100%) expressed interest in forecast services, underscoring the central role of forward-looking situational awareness in driving initial uptake. Two organisations (2/5; 40%) also indicated interest in measurements and nowcasts, suggesting a smaller but tangible demand for near real-time monitoring alongside forecasts. No respondents in this prospective group expressed interest in post-event analysis, indicating that retrospective capabilities are not yet a priority for first-time adopters in this sector.

The remaining 11 organisations that do not plan to adopt services at this stage cited low perceived relevance (64%) and limited expertise (36%) most frequently, followed by low priority (36%) and limited resources (27%). Multiple constraints were often reported together (45% cited two or more barriers), indicating a combination of capability gaps and limited perceived operational need.

4.3.3. Responders' Knowledge of Space Weather Risks and Services

Respondents in the power system operation sector reported an average self-assessed understanding of space weather risks of 3.11 out of 5, suggesting a moderate level of awareness across the sector. This average indicates that while some organisations possess a foundational understanding of space weather and its implications, there is still room for further capacity-building and targeted knowledge development.

A significant majority—20 out of 27 organisations (74%)—expressed interest in receiving more information on space weather risks. The preferred formats varied, but email was by far the most frequently selected channel (16 mentions). Online seminars and websites followed at a similar level (7 mentions each). Offline seminars were mentioned 3 times, while training sessions were cited once, indicating that interactive formats are valued by a smaller subset compared to lightweight digital delivery.

Interest in learning more about space weather services was also high, with 16 out of 27 organisations (59%) indicating a desire for further information. Again, email was the most commonly cited channel (13 mentions), followed by websites and

online seminars (6 mentions each). Offline seminars were mentioned 3 times, and one respondent indicated interest in formal training sessions.

These results underscore a general willingness among power system operators to engage further with the topic of space weather, particularly through accessible and flexible communication channels.

4.3.4. Responders' Experienced Disruptions

Out of 27 respondents in the power system operation sector, 19 provided information on whether their organisation had experienced disruptions related to space environment conditions. Among these, 2 organisations (11%) confirmed having experienced such disruptions, while the remaining 17 reported no known impacts.

However, this relatively low percentage requires careful interpretation. Of the 27 respondents, 13⁴ are Distribution System Operators (DSOs), who are responsible for the maintenance and operation of medium- and low-voltage local electricity networks. Unlike Transmission System Operators (TSOs), who manage high-voltage grid infrastructure for national and cross-border electricity transmission, DSOs are naturally less exposed to space weather impacts due to the smaller, more localised nature of their networks. When excluding the 13 DSO respondents, we find that two out of the remaining 10 organisations (20%) with available information—a more representative subset of actors exposed to space weather effects—reported having experienced such disruptions.

The two organisations that reported disruptions represent different profiles in both frequency and severity of impact. One organisation, a TSO based in a high-latitude country, reported that disruptions occur regularly—at least once a year, and characterised the impact as significant, meaning that the effects required substantial corrective measures. In contrast, the second organisation—operating in the nuclear energy domain—reported that disruptions occur only rarely, and noted no measurable impact from the events.

These findings suggest that, while the overall incidence of disruption across the sector is currently limited, the associated risk is not negligible and merits ongoing attention.

In the case of the Netherlands, the national power grid is relatively compact, and the conductive nature of the soil further mitigates the direct risks associated with space weather events. As such, the likelihood of significant local impacts is considered low. However, owing to the high degree of interconnection between the Dutch grid and the wider European power network, the Netherlands remains indirectly exposed to space weather-related risks that may have broader continental consequences.

This scenario is similarly applicable to many smaller European countries, which, despite their limited direct vulnerability, remain at risk due to their integration within the continental infrastructure. As a next step, it would be prudent to initiate a Europe-wide exercise or structured opportunity for exchange, enabling the sharing of expertise and the joint evaluation of potential continent-level impacts and risks associated with space weather.

4.3.5. Responders' Preparedness Levels

Out of 27 organisations in the power system operation sector, 8 (30%) reported that they currently include space weather in their risk or impact assessments. Two had conducted assessments within the past year and plan to update them within the next two years. Three others completed their assessments over five years ago, with one planning to update within five years

⁴ In Section 3 (sectoral analysis), Creos Luxembourg S.A. is counted under TSOs only (despite its dual TSO/DSO role) to avoid double counting across subcategories. In addition, EPV Alueverkko Oy is included in the broader organisational mapping (Section 4) based on its functional role in the power system ecosystem, but it is excluded from the sectoral analysis because it did not self-identify “Power System Operation” as its primary sector in the survey. As a result, the mapping in Section 4 captures a wider set of relevant actors and yields a higher number of DSOs (15) than the sectoral analysis (13).

and the two others without a defined timeline. The remaining two carried out assessments within the past five years, but neither has scheduled an update.

These organisations cited key risks such as transformer damage, power outages, signal blackouts, and vulnerabilities to information networks. Despite recognising these risks, only two—including the nuclear operator—reported having implemented mitigation measures, including “measures in the electricity grid”.

Among the 19 organisations that do not currently include space weather in their risk assessments, the most frequently cited barriers were low relevance (53%) and low priority (37%), followed by limited resources (26%) and limited expertise (26%). Several respondents cited multiple constraints in combination (37%), indicating both capacity limitations and perceived lack of operational need.

Identically, eight out of 27 organisations (30%) reported having an emergency response framework in place for extreme space weather events. These were predominantly described as in-house emergency plans (all eight), with one respondent also referencing alignment with a national emergency plan. Among the remaining 19 organisations without a framework, three indicated plans to develop one—two by 2026 and one by 2028.

As with risk assessments, the reasons for not having emergency frameworks largely mirrored earlier findings. The most frequently cited barriers were low relevance (44%) and limited expertise (38%), followed by limited resources (31%) and low priority (19%), often in combination. One respondent also indicated uncertainty, noting they did not know whether a space-weather-specific framework existed within their organisation.

When asked to rate their level of preparedness to respond to an extreme space weather event (on a scale from 1 to 5), the average score across the sector was 2.52, indicating a generally low to moderate level of operational readiness.

Regarding institutional awareness, 14 of the 27 organisations (52%) stated they would know who to contact in the event of a space weather-related issue. The organisations named include national meteorological/space weather agencies (e.g. KNMI, FMI, SMHI, IRF, SIDC, DLR, MSB), grid operators (e.g. Svenska kraftnät and DSOs such as Köyliön-Säskylän Sähkö Oy and Kymenlaakson Sähköverkko Oy), and broader coordination bodies such as ESA, the Portuguese Space Agency, and ENTSO-E.

Finally, 9 of the 27 organisations (33%) expressed interest in a follow-up meeting to discuss their space weather information needs and to learn more about ESA’s service offerings.

4.4. Other

4.4.1. Responders’ Profiles

The “Other Sectors” category comprises 17 responses from organisations that did not select one of the previously analysed sectors of spacecraft operations, communications/PNT, or power system operations. These respondents span a wide set of operational domains, illustrating the breadth of potential space-weather relevance beyond the programme’s core sectors.

Reported activity areas include military operations, aviation (civil and business), satellite test systems, research and academia, civil protection/civil defence, and space downstream and mission operations. Additional domains include Earth observation, IT/ICT, healthcare, road and traffic infrastructure management, and electricity transmission, as well as public bodies/ministries (including one respondent indicating “none” as a primary domain).

Geographically, Austria is the most represented country in this group (6 responses), followed by Finland (2). Germany, Italy, and Spain each contribute 2 responses, while Slovakia, Greece, and Hungary each contribute 1. This distribution reinforces that

engagement with space weather is extending well beyond the three priority sectors selected for Phase 2, and supports consideration of a broader sectoral scope in future activities.

4.4.2. Responders' Use of Space Weather Services

Out of the 17 organisations classified under “other sectors”, 6 respondents (35%) indicated that they currently use space weather services. Within this user subset (n=6), measurements & nowcasts are most prevalent (83%), followed by forecasts (67%) and post-event analysis (50%). One respondent additionally referenced specified near real-time monitoring for operational applications. Reported information sources span both institutional and internal channels, including NOAA SWPC, ESA services (e.g. portal/modelling outputs), INAF, Aeronautica Militare, and ESA/NASA, illustrating heterogeneous usage patterns across operational and analytical contexts.

When asked to rate the importance of operational space weather service features (n=6), respondents gave the highest priority to information accuracy (4.83/5), followed by information clarity (4.50/5) and timeliness of updates (4.50/5), alongside user interface quality (4.33/5) and information accessibility (4.33/5). Lower average scores were assigned to data enrichment and analysis (3.17/5) and API standardisation and cataloguing (3.00/5), with customisation/personalisation (2.83 /5) and 24/7 expert support (2.83/5) rated lowest overall. Several respondents also highlighted additional priorities not captured in the standard list, notably technical documentation for data and models, improved advance warning/lead time, and confidentiality requirements (each rated 5 by the respective respondent).

Perceived areas of satisfaction broadly mirror the pattern seen in priorities, with strongest scores attached to core usability and access. Respondents reported the highest satisfaction for information accessibility (4.33/5), followed by user interface quality (4.00/5) and information clarity and timeliness of updates (3.83/5 each). Information accuracy was rated lower (3.17/5). The lowest satisfaction scores were assigned to customisation and personalisation (2.50/5), data enrichment and analysis (2.33/5), and 24/7 expert support (2.33/5), with API standardisation and cataloguing also relatively low (2.83/5). Qualitative comments further point to needs around better differentiation of data sources (including leveraging new missions/orbits) and real-time monitoring of radiation effects on space electronics.

Among the 11 organisations not currently using space weather services, 5 (45%) expressed plans to adopt them in the future. Intended uptake is concentrated on forecasts (100%) and measurements & nowcasts (60%), while post-event analysis was cited by 1/5 (20%). The remaining 6 organisations cited a mix of barriers to adoption. The most frequent were low perceived relevance (50%), followed by limited expertise (33%), low priority (33%), and limited resources (17%). A third of respondents (33%) listed multiple (two) combined constraints.

4.4.3. Responders' Knowledge of Space Weather Risks and Services

Respondents from the other sectors reported an average self-assessed understanding of space weather risks of 3.24 out of 5, reflecting a moderate level of awareness. This suggests that while many have some familiarity with the concept and potential impacts of space weather, there remains substantial scope for increasing sector-specific knowledge and operational relevance.

A very large majority—16 out of 17 organisations (94%)—expressed interest in receiving more information about space weather risks. Preferred delivery channels (multiple selections allowed) were led by email (56%), followed by website resources (38%) and online seminars (32%). There was also substantial interest in more structured formats, with offline seminars (32%) and training sessions (25%). This suggests a clear preference for accessible digital dissemination, complemented by a strong appetite for interactive and capacity-building formats.

Similarly, 15 out of 17 organisations (88%) indicated they would like more information about space weather services. Preferred channels (multiple selections allowed) were again led by email (53%), followed by websites (47%) and online seminars (40%). Offline seminars were requested 5 times (33%), and training opportunities 5 times (33%), closely mirroring preferences

expressed for risk-related information and indicating a continued appetite for both digital dissemination and structured engagement formats.

These responses point to a broad and active interest across diverse sectors in improving understanding and service awareness, particularly via flexible and accessible formats.

4.4.4. Responders' Experienced Disruptions

Among the 17 organisations in the other sectors group, 9 [53%] provided information regarding their experience with disruptions caused by space environment conditions. None of these ten [0%] organisations reported having experienced any disruptions, and accordingly, no impact or disruption frequency was noted.

4.4.5. Responders' Preparedness Levels

Among the 17 organisations in this group, 3 [18%] reported that they include space weather in their risk or impact assessments. Of these, two assessments were conducted within the past year [67%], while one was conducted within the past five years [33%]. Looking ahead, two organisations plan to revisit their assessment within the next two years [67%], and one within the next five years [33%].

Reported risks include radio signal interference (e.g. ionospheric effects and solar radio bursts), radiation effects, and orbit determination issues. All three organisations [100%] also reported having implemented mitigation measures, including radiation-hardened component testing (RHA), and awareness training/internal procedures.

Among the 14 organisations not currently conducting space-weather risk or impact assessments, the most commonly cited barriers were limited expertise [36%] and low relevance [36%], followed by limited resources [29%] and low priority [14%]. Multiple constraints were often reported together [29% cited combined resource/expertise or resource/relevance limitations]. A small number of respondents pointed to unawareness [1/14; 7%], ongoing exploratory work (e.g., correlation/risk analysis) [1/14; 7%], or noted that inclusion is under consideration, including prior technical conferences on the topic [1/14; 7%].

Emergency response frameworks are in place in 3 organisations. Two reported an in-house emergency response plan, while two referenced a national emergency response plan (including one organisation that reported both in-house and national arrangements). None of the remaining organisations reported concrete plans to develop an emergency framework. The most frequently cited barriers were limited expertise [36%] and low relevance [36%], followed by low priority [21%] and limited resources [21%]. In addition, uncertainty/lack of visibility ("don't know" / "not accessible to me") was mentioned by 3/14 respondents [21%], and unawareness by 1/14 [7%].

Average preparedness across the group is 2.53 out of 5, indicating low to moderate readiness. Only 6 organisations [35%] reported knowing whom to contact, citing in-house experts and bodies such as BMK (crisis management), the Austrian/ESA Space Weather Offices, and Observatori de l'Ebre.

Finally, 7 out of 17 organisations [41%] expressed willingness to engage in a follow-up meeting to discuss their needs and learn more about ESA's space weather services.

5. MAPPING ANALYSIS

Mapping scope and method.

The mapping exercises presented in Section 4 are limited to organisations identified through the Phase 2 survey process (i.e., organisations that submitted at least one response). To reflect the multi-role nature of operational stakeholders, the mapping is based on reported activities and functions rather than on the single sector tick-box selected in the questionnaire. Consequently, an organisation may be mapped under multiple functional categories and, where relevant, may appear in more than one sectoral ecosystem (e.g., a spacecraft operator that also provides communication services). The mapping therefore complements—rather than reproduces—the sectoral analysis by capturing cross-cutting roles within the survey-identified stakeholder set.

Power System Operation

To complement the analytical insights from survey responses, a structural mapping of organisations in the Power System Operation domain was conducted to categorise stakeholders by functional role across six thematic categories: Energy Supply Chain, Grid Infrastructure & Innovation, Regulatory & Governance Framework, Financial & Advisory Actors, Advocacy & Collaboration, and End-User Focus.

In total, 28 unique organisations were identified as relevant to the power system domain. Given that some actors span multiple roles, the mapping captures 33 entries across sub-categories. Notably, Creos Luxembourg S.A. is represented as both a TSO and a DSO, while Fortum spans generation, trading, and several innovation-related roles.

The breakdown by sub-category is as follows:

- 15 entities were mapped as Distribution System Operators (DSOs). These organisations are responsible for the operation and maintenance of medium- and low-voltage electricity networks that supply power to residential and industrial users. Examples include Caruna Oy, Kymenlaakson Sähköverkko Oy, GENAB (Göteborg Energi Nät AB), Helen Electricity Network Ltd., Skellefteå Kraft Elnät AB, E-Redes, EDP Redes España, and Vattenfall Eldistribution.
- 10 entities were classified as Transmission System Operators (TSOs), which manage high-voltage grid infrastructure and are critical to national and cross-border electricity transmission. Notable examples include Svenska kraftnät (Sweden), TenneT NL TSO bv (Netherlands), TenneT TSO GmbH (Germany), REN (Portugal), Elia (Belgium), Terna SpA (Italy), MAVIR (Hungary), Independent Power Transmission Operator (Greece), and ČEPS, a.s. (Czech Republic). Creos Luxembourg S.A. (Luxembourg) is also mapped as a TSO due to its dual transmission and distribution role, and EPV Alueverkko Oy (Finland) is included as a regional transmission grid operator.
- 4 organisations were identified as Power Generators, including Forsmarks Kraftgrupp AB (nuclear), Fortum (hydro, nuclear, and thermal), Public Power Corporation (thermal and hydro), and PPC (thermal and hydro).
- 1 entity was listed under Energy Traders, representing market-facing activity such as electricity buying and selling.
- 0 entities were currently mapped under Electricity Market Operators, though these actors play a structural role in balancing markets and may warrant inclusion in future updates.

Within the Grid Infrastructure & Innovation category, the mapping captured emerging diversification:

- 1 Energy Developer, reflecting involvement in project planning and next-generation energy systems.
- 1 Technology Provider, indicating support for grid modernisation or operational tools.
- 1 Energy Storage Player, reflecting early integration of flexibility and backup solutions in grid operations.
- 0 Emerging Actors, though this space may evolve with the growing role of digital and decentralised technologies.

Notably, no entries were recorded under the Regulatory & Governance, Financial & Advisory, Advocacy & Collaboration, or Consumers categories— except for one entity classified under Prosumers, reflecting indirect support for decentralised energy production (e.g. through service offerings by integrated actors such as Fortum).

This mapping reveals that the current power system engagement in the Demonstrator is heavily concentrated in the operational core—with DSOs and TSOs accounting for 25 out of 33 mapped entries (76%)—with limited representation from enabling institutions, end-users, or the financial and regulatory ecosystem. As the initiative matures, broadening engagement to include these underrepresented categories will be essential for developing a holistic and resilient European space weather response infrastructure.

Communications and / or PNT

To complement the analytical insights from survey responses, a structural mapping of key organisations in the Communications and/or Positioning, Navigation and Timing (PNT) sector was undertaken. The objective was to categorise stakeholders according to their functional roles within the broader communications and satellite-based navigation ecosystem. The classification follows the six thematic categories used across the Demonstrator: Communication & Navigation Supply Chain, Ground Control Segment, Regulatory & Governance Framework, Financial & Advisory Actors, Advocacy & Collaboration, and End-User Focus.

In total, 37 unique organisations were mapped as relevant to the Communications and/or PNT domain. However, due to the multi-role nature of several actors, the mapping registers 46 entries across different sub-categories. For example, GMV appears across both communications-facing and PNT-facing activities; IGASPIN and Spacearth Technology can be positioned both as components-oriented actors and GNSS system integrators; and HISDESAT and Sateliot span both satellite operations and service provision.

The breakdown by sub-category is as follows:

Communication & Navigation Supply Chain

- Components Manufacturers (2): Organisations producing hardware or technical components relevant to communications/PNT value chains (e.g. IGASPIN GmbH, Spacearth Technology).
- GNSS System Integrators (4): Actors integrating GNSS/PNT capabilities into usable systems and services (e.g. GMV (PNT side), Thales Edisoft Portugal, S.A., alongside IGASPIN and Spacearth Technology where integration capability is explicit).
- Spacecraft Subsystems Manufacturers (0): No organisations were explicitly mapped here under the current evidence base and scope.
- Spacecraft Manufacturers (4): Organisations responsible for full satellite platforms (e.g. ReOrbit Oy, OHB LuxSpace, GomSpace Luxembourg, Tyvak International SRL).
- Satellite Operators (4): Organisations managing on-orbit assets (e.g. SES, Hellas Sat, HISDESAT, Sateliot).
- Communication Services Providers (9): Organisations delivering communications services to users (e.g. NOS Comunicações SA, MEO, NOVA, O2 Slovakia, Deutsche Telekom IT Solutions Slovakia, NAV Portugal E.P.E., plus GMV (communication side) and operator-service providers such as HISDESAT and Sateliot).
- GNSS Services Providers (3): Service-level PNT actors (e.g. Bundesamt für Kartographie und Geodäsie, Landesamt für Geoinformation und Landesvermessung Niedersachsen, GMV (PNT side)).

Ground Control Segment

- Ground Station Equipment Providers (0): Not represented.
- Ground Stations Networks (2): Infrastructure and network operators supporting uplink/downlink and TT&C functions (e.g. Telespazio S.p.A., Italian Space Agency – Sardinian National Base).
- Telecommunications Ports (0): Not represented.

- Mission Control Centers (MCC) (2): Mission operations / control functions (e.g. Telespazio S.p.A., GMV [communication side]).

Regulatory & Governance Framework

- Regulatory Bodies (0): No explicit entries.
- Policy-Making Institutions (3): Public-sector entities with institutional mandate relevant to PNT/space security governance (e.g. Bundesamt für Kartographie und Geodäsie, Landesamt für Geoinformation und Landesvermessung Niedersachsen, Space Security Centre of the Spanish National Institute for Aerospace Technology).
- Standardisation Bodies (0) and Other Intergovernmental Organisations (0): No explicit entries.

Financial & Advisory Actors

- Consultancy Firms (6): Research and advisory actors supporting operational, technical, or systems-level work (e.g. JOANNEUM RESEARCH, TU Wien, AVT-Airborne Sensing Austria GmbH, INECO, Budapest University of Technology and Economics, Technical University of Kosice – Faculty of Aeronautics).
- Insurance & Risk Management (0) and Investment & Funding Bodies (0): Not represented.

Advocacy & Collaboration

- Industry Alliances and Trade Associations (2): (e.g. Vereinigung Cockpit, Distretto Tecnologico Aerospaziale scarl).
- Lobbying Groups (0): Not represented.

End-User Focus

- Aviation operators (civil/business) (3): TAP Air Portugal, NetJets – Transportes Aéreos, SA, and one respondent listed as Airline.
- Government / defence users (2): DEU Space Command and Ejército del Aire y del Espacio.

This mapping reveals a diverse and technically mature stakeholder landscape, with strong representation from spacecraft manufacturers, subsystem developers, and operational service providers. However, the regulatory, financial, and advocacy aspects of the Communications and/or PNT ecosystem remain underrepresented, suggesting that future engagement efforts may aim to strengthen linkages with governance, funding, and user-facing coordination bodies. Additionally, the presence of multiple multi-role actors (e.g. GomSpace, Telespazio) highlights the need for integrated service models and tailored space weather support across multiple stages of the value chain.

Spacecraft Operations

To complement the analytical insights from survey responses, a structural mapping of organisations linked to the Spacecraft Operations ecosystem was conducted. The objective was to categorise stakeholders according to their functional roles within the operational spacecraft domain, using the standard Demonstrator framework: Ground Control Segment, Services Providers, Regulatory & Governance Framework, Financial & Advisory Actors, Research & Academics, Advocacy & Collaboration, and User Segment.

In total, 42 unique organisations were mapped as relevant to this ecosystem. However, reflecting the multi-functional nature of several entities, the mapping records 49 subgroup entries across the different sub-categories. For instance, Telespazio S.p.A. is represented in both Ground Station Networks and Mission Control Centres (MCC), while GMV [spacecraft operation side] appears under MCC and SST Services Providers. DLR is also represented across operational and R&D roles.

The breakdown by sub-category is as follows:

Ground Control Segment

- Ground Station Equipment Providers (1): A limited number of respondents clearly fall into the role of ground segment equipment provision. Terma Technologies GmbH (AT) is mapped here as a representative supplier of ground station hardware/software capabilities.
- Ground Station Networks (2): Organisations operating ground-based communications infrastructure include Italian Space Agency – Sardinian National Base and Telespazio S.p.A.
- Mission Control Centres (MCC) (4): Entities responsible for commanding and monitoring missions include DLR (Department for Spaceflight Operations and Astronaut Training), Telespazio S.p.A., Serco Italia S.p.A., and GMV (spacecraft operation side). This reflects a core operational layer where space weather information can directly support day-to-day mission decision-making.

Services Providers

- Satellite Operators (7): Operators managing on-orbit assets include SES, Hellas Sat, HISDESAT Servicios Estratégicos S.A., Sateliot, Thales Edisoft Portugal, Geosat, and D-Orbit. This subgroup anchors the mapping in the organisations directly exposed to space weather impacts through spacecraft operations and service continuity.
- SST Services Providers (3): Organisations contributing to orbital safety and conjunction/risk monitoring include Neuraspace, GMV (spacecraft operation side), and the Space Security Centre of the Spanish National Institute for Aerospace Technology—highlighting the adjacency between spacecraft operations and space safety functions that are sensitive to space environment conditions.

Regulatory & Governance Framework

- Regulatory Bodies (0)
- Policy-Making Institutions (3): Public bodies with policy/coordination functions include Bundesministerium für Klimaschutz, Dipartimento di Protezione Civile – Roma, and the General Directorate of Civil Protection and Emergencies Spain.
- Standardisation Bodies (0)
- Other Organisations (2): Operationally relevant public technical stakeholders include AEMET and the Space Security Centre of the Spanish National Institute for Aerospace Technology (also mapped under SST due to its functional role).

Financial & Advisory Actors

- Spacecraft Operation Consultancy Firms (3): Advisory/engineering support functions are represented by On-Air Consulting & Solutions, INECO, and Planetek. While this remains a relatively small cluster, it indicates that some actors contribute through operational support, integration, and technical advisory capacity rather than direct mission control.
- 0 entities were identified under Insurance & Risk Management, Investment and Funding Bodies, or Business Incubators, suggesting an opportunity for future engagement with financial enablers and early-stage support actors.

Research & Academics

- Universities and Research Centers (8): Research and academic stakeholders include JOANNEUM RESEARCH, University of Vienna, TU Wien, Budapest University of Technology and Economics, Democritus University of Thrace, Technical University of Kosice (Faculty of Aeronautics), Austrian Academy of Sciences (Space Research Institute), and IST NanosatLab.
- Space Agencies' R&D Initiatives (1): DLR is also represented under agency R&D initiatives, reflecting its dual role in research and operational capability development.

Advocacy & Collaboration

- Industry Alliances and Trade Associations (2): Collaboration and representation bodies include Distretto Tecnologico Aerospaziale scarl and Vereinigung Cockpit (also mapped as a user-representative stakeholder due to its operational community relevance).
- Lobbying Group (0)

User Segment

- Consumers (13): Institutional and operational end-users include defence and aviation stakeholders (DEU Space Command, Ejército del Aire y del Espacio, an Airline, TAP Air Portugal, NetJets), operational public bodies (ASFINAG, Nav Portugal E.P.E., Dipartimento di Protezione Civile – Roma, General Directorate of Civil Protection and Emergencies Spain), and other institutional users (Bundesamt für Kartographie und Geodäsie, Landesamt für Geoinformation und Landesvermessung Niedersachsen, Oy Apotti Ab, Vereinigung Cockpit). Their presence reflects that space weather considerations in spacecraft operations frequently propagate downstream to operational users and safety-critical services.

Overall, the mapping shows that the spacecraft operations ecosystem represented here is strongest in core operational functions (MCCs), satellite operations, and adjacent SST services, while also featuring a meaningful perimeter of institutional users and public authorities. At the same time, the limited presence of dedicated equipment providers, and the relatively modest representation of financial/insurance and formal standards/regulatory bodies, suggests clear opportunities for broader stakeholder engagement if the intent is to scale space weather integration from operational use cases to system-wide preparedness and governance.

Overall mapping conclusion

Across the three priority domains, the mapped landscape is strongest where space weather information is most immediately actionable: operational cores (TSOs/DSOs; satellite operators; MCC/SST-adjacent functions) and major service providers. In contrast, enabling layers—regulators/standardisation bodies, insurance/risk transfer, investment/funding, and broader advocacy structures—are consistently underrepresented. This suggests that current engagement is well-suited to validating operational use cases, but scaling uptake and harmonisation will require deliberate outreach to governance and financing actors that can formalise requirements, standards, and long-term resourcing.

6. CONCLUSIONS

The Sectorial Phase of the Space Weather Demonstrator builds directly on the Arctic Phase, extending the scope from a geographically concentrated assessment of high-latitude vulnerabilities to a pan-European, sector-oriented view of operational readiness across critical infrastructure domains. While the Arctic Phase documented tangible space weather impacts in Finland and Norway—ranging from GNSS disruptions in agriculture and autonomous systems to satellite interference and radar anomalies—it also revealed the need for an increase in structured awareness and preparedness among many operators in these northern regions. These initial findings motivated a broader assessment with an extended geographic scope to evaluate awareness, service usage, and preparedness across Europe.

Across Phase 2, 94 organisations provided inputs, with responses concentrated in the three priority domains (power system operation, communications/PNT, and spacecraft operations). Overall uptake of space weather services remains limited (36% current users), despite generally moderate self-assessed understanding of space weather risks (mean 3.53/5) and strong

expressed demand for further information on both risks and available services (79% for each). A consistent pattern emerges across domains: stakeholders prioritise core service fundamentals—accuracy, clarity, accessibility, and timely updates—yet satisfaction with these fundamentals is only moderate (all under 4/5, except accessibility). This reinforces a clear opportunity, consistent with Phase 1 findings, to better tailor products and service delivery to operational decision-making: translating forecasts and nowcasts into user-relevant impact pathways, improving sector-specific interpretability (e.g., thresholds, decision triggers, lead times), and offering targeted delivery formats (dashboards, briefings, interfaces, and APIs) aligned with different mission and asset use cases. In parallel, institutional integration remains incomplete. Only 26% of respondents report incorporating space weather into risk or impact assessments, and 21% report having an emergency response framework for extreme space weather warnings, with preparedness levels averaging 2.6/5.

At the same time, Phase 2 indicates a clear opportunity to convert interest into action. A substantial share of non-users plan future adoption (40% of non-users), and over half of respondents (53%) expressed willingness to engage in follow-up discussions on operational needs and service expectations. Spacecraft operations stands out as the most engaged domain, combining higher service uptake, higher exposure, and stronger appetite for continued dialogue. In contrast, power system operation and communications/PNT show persistent gaps between awareness and formal preparedness, reinforcing the need for targeted onboarding, sector-specific framing of relevance, and clearer escalation pathways.

Taken together, the Arctic and Sectorial phases provide a consolidated picture of European space weather readiness: awareness is increasing and interest is high, but structured preparedness and operational integration lag behind. These findings directly support the continued development of the ESA Space Weather Service Network and the broader objective of a user-driven European operational space weather capability.

Next steps should therefore follow a dual approach: deepen engagement with high-exposure operational communities through follow-up activities (including the 50 follow-up requests received, and the resulting individual meetings and national workshops as part of the end of Phase 2, planned for completion before summer 2026), while preparing the basis for broader outreach to underrepresented enabling actors (governance, standardisation, and risk-management stakeholders) to formalise requirements, scale adoption, and sustain long-term resilience. On this basis, a final Phase 2 report could be targeted for PB-SSA in September 2026, alongside consideration of a subsequent Phase 3 to extend engagement and consolidate long-term implementation.