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Role of the Copernicus satellite programme in building the resilience of European supply chains: results of a Delphi study

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ABSTRACT
The paper aims to analyse the challenges European supply chains face in the context of satellite communications (specifically, in the Copernicus programme) amidst geopolitical and pandemic disruptions. It focuses on identifying factors and barriers and recommended solutions to enhance resilience in these supply chains. The study employs a comprehensive approach, incorporating Delphi surveys, a literature review, and the STEEPED analysis. Experts from the satellite communications field participated in the Delphi survey, and the study scrutinised the impact of Delphi theses on various stages of supply chains. STEEPED analysis was used to identify factors enhancing the resilience of European supply chains in satellite communications. An analysis of their validity and uncertainty was also carried out. The research highlights the factors influencing supply chain resilience within satellite communications, emphasising the importance of coping with uncertainty, shocks, and disruptions. The study presents valuable recommendations to strengthen supply chain resilience amid infrastructural and geopolitical challenges. This research enriches insights into building resilience strategies for European supply chains operating within intricate and uncertain environments. By analysing the role of the Copernicus programme and Earth observation data, the paper contributes to the theoretical framework, providing essential knowledge for managing supply chains in a dynamic and complex environment. The study's recommendations offer practical guidance for EU institutions overseeing the Copernicus programme and its users. By effectively leveraging Copernicus and Earth observation data, stakeholders can enhance their analysis methods. These insights enable practical actions to be taken, ensuring the continuity and stability of European supply chains amidst challenging global scenarios.

KEY WORDS
Copernicus satellite programme, Delphi studies, uncertainty, resilience, supply chains, Europe

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Introduction

The resilience and stability of supply chains across crucial sectors, including satellite communications, are currently under threat. Recent disruptions, such as climate disasters, the COVID-19 pandemic and the Russian-Ukrainian war, have significantly hindered the flow of goods and materials (Orlando et al., 2022; Jagtap et al., 2022; Kaňovská & Vlčková, 2022). To navigate unpredictable market conditions, it is imperative to enhance the movement of goods, services, information, and capital within and beyond the European Union.

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The results presented here are part of a study in which the authors of this article took an active part, carried out for the European Parliament in 2022/2023, entitled "A preparedness plan for Europe: Addressing food, energy and technological security". This article focuses on satellite communications, particularly its European component in the form of the Copernicus programme.

The Copernicus programme plays a pivotal role by providing access to real-time data collected by Earth observation satellites and in-situ (non-space) observations. It offers essential information services that facilitate better supply chain monitoring and management. Satellite imagery and remote sensing data are employed to scrutinise various aspects, including environmental conditions, transport routes, infrastructure, inventory levels, geolocalisation of goods flow, carbon footprints, and risk and resilience planning in supply chain management (Kasmaeeyazdi et al., 2021; Kuhlmann et al., 2019; Alzate et al., 2022).

The study aimed to identify factors and obstacles, proposing coordinated solutions to enhance the resilience of European satellite communications. Additionally, it sought to offer substantial recommendations to the European Parliament, specifically focusing on enhancing the Copernicus satellite programme capabilities to address disruptions in supply chains.

The study employed a literature review and the Delphi methodology to achieve these objectives. Experts from relevant fields evaluated specific theses through the Delphi questionnaire. The STEEPED analysis pinpointed factors that could potentially boost the resilience of European supply chains in satellite connectivity.

In the realm of satellite communications, experts highlighted two primary policy (strategic) options: (1) supporting the decisions of the EU institutions managing the Copernicus programme and (2) supporting end-users (non-experts) and intermediate users – experts in the field of Copernicus data analysis and Earth observation.

The literature review section summarises previous research on satellite communications technology, focusing on the European Copernicus programme. The section on research methods elucidates the Delphi method and STEEPED analysis as the primary research approaches. The section on research results outlines the Delphi theses, factors, barriers to supply chain resilience, and strategic options. Next, the discussion of the results assesses opportunities and threats linked to strategic options and identifies potential areas for development based on trends and strategic documents. Lastly, the section on conclusions synthesises the findings and suggests avenues for further analysis, offering a comprehensive perspective on fortifying supply chains in satellite communications.

1. Literature review

The advancement in satellite communication technology has rendered satellite observations crucial for understanding Earth phenomena, especially in environmental and socio-economic contexts (Zhao et al., 2022). Supply chain management has significantly benefited from these satellite observations.

Supply chain management involves the synchronisation and enhancement of tasks connected to manufacturing, sourcing, processing, and dissemination of products and services. It encompasses strategising and implementing diverse procedures like procurement, production, logistics, and customer service to ensure seamless product flow from suppliers to end customers (Ryciuk, 2020; Lee et al., 2020; Małys, 2023; Sodhi et al., 2021; Talwar et al., 2021). Supply chains play a crucial role in managing European Union economies (Zehendner et al., 2021; Handfield et al., 2020).

Globalisation and outsourcing have enlarged and complicated supply chains, making them susceptible to disruptions, such as climatic (e.g., heatwaves, hurricanes, and floods) and anthropogenic disasters (e.g., economic recession, political turmoil, port outages, poor communication, and human error). In the current global market, managing disruptions is vital to ensuring companies' long-term survival (Bui et al., 2021). These disruptions affect organisations, industries, and entire economies, necessitating resilient business models and supply chains (Shashi et al., 2020). Supply chain resilience refers to a supply chain's ability to recover, adapt, or transform in the face of disruptive events (Wieland et al., 2021).

To enhance preparedness, risk mitigation, and responsiveness, supply chain resilience management employs various technologies, including artificial intelligence, Internet of Things, predictive maintenance systems, and blockchain technology (Modgil et al., 2021; Kopanaki, 2022; Li et al., 2022; Gu et al., 2021; Leończuk, 2021; Ejdys & Szpilko, 2023). Satellite technologies, like earth observation satellites, satellite-based weather monitoring, and satellite communication, are also integral in building supply chain resilience. They offer valuable data for monitoring, communication, identification, and tracking, enabling proactive planning, risk mitigation, and swift responses. Despite its significance, limited studies explore building supply chain resilience using satellite technology (Sengupta et al., 2022; Mirtsch et al., 2023; Gupta et al., 2022; Golan et al., 2021; Undseth & Jolly, 2022).

This article investigates the Copernicus programme's role in enhancing the EU's supply chain resilience. The Copernicus programme, which was initiated in 1998, is a pivotal satellite initiative supporting Europe's social, environmental, and economic endeavours. Leveraging Earth Observation satellites (Sentinels) and in situ (non-space) observations, Copernicus provides unrestricted access to real-time data collection. It offers essential information services crucial for socio-economic monitoring, global security management, and environmental stewardship (Apicella et al., 2022). Copernicus aids in understanding climate change impacts and improving resource management and has diverse applications across sectors (Kasmaeeyazdi et al., 2021). Copernicus has led to applications supporting digital farming practices and crop monitoring in agriculture (Meier et al., 2020; Wolanin et al., 2019). It also monitors extractive activities and ensures compliance in European and foreign supply chains (Kasmaeeyazdi et al., 2021).

Copernicus data and services play a significant role in various supply chain aspects, including remote sensing, environmental monitoring, tracking, sustainability, risk assessment, and resilience (Schiavon et al., 2021; Pollard et al., 2018). This article specifically focuses on managing supply chain resilience within the European Union, emphasising the vital role of the Copernicus programme. Europe faced the initial brunt of the COVID-19 pandemic and the consequences of the Russian-Ukrainian war, severely impacting the European supply chain (Orlando, 2022).

The growing prominence of satellite imaging across industries is anticipated to significantly shape societies and economies. Projections suggest exponential market growth, from USD 350 billion to USD 2.7 trillion in the next three decades. Harnessing Copernicus data within the EU industry could create new market segments driven by value-added services (Kasmaeeyazdi et al., 2021).

It is crucial to analyse the services and capabilities of the Copernicus programme amidst current challenges. Concerns arise due to satellite malfunctions, unrepairable in space, and crises stemming from recent environmental, social, and geopolitical events (Aladayleh et al., 2023; Jagtap et al., 2022). These unprecedented impacts highlight the need to explore the potential of the Copernicus satellite technology in addressing systemic and economic threats that directly impact supply chain resilience. This necessitates comprehensive and timely analysis.

2. Research methods

The study utilised the Delphi method to gather expert perspectives on the future of the Copernicus programme. The Delphi method involves a few rounds (usually two) of questionnaires sent to a panel of experts to forecast developments in uncertain situations where traditional analytical techniques are unsuitable. It is used when reliable data is limited or external factors strongly influence the predicted phenomena (Kononiuk et al., 2021; Grzybowska & Tubis, 2022; Korzeb et al., 2024).

Questionnaires were sent to over 20,000 researchers who were identified through keyword searches in the Web of Science database. The Delphi survey included over 150 experts from different fields like food, energy, transport, and satellite communications. The experts had varying backgrounds in terms of education, age, gender, sector, and country. In the first round, 153 experts participated, decreasing to 117 in the subsequent round. The smaller number of experts in the second round of Delphi surveys is, unfortunately, a standard drawback of the method (Schmalz et al., 2021). The goal of the research was to evaluate specific theses, factors, and barriers related to the Copernicus programme.

The research methodology consisted of five stages: (1) the development of the preliminary version of the questionnaire; (2) the first round of the Delphi research; (3) the development of the results of the first round; (4) the second round of the Delphi research; and (5) the development of key policy (strategic) options.

The initial research involved statistical analysis, report reviews, and expert interviews exploring the potential of satellite technology, especially Copernicus, for addressing crises in humanitarian, agricultural, and economic domains, such as supply chain disruptions. The research team developed preliminary questionnaires, refining them based on interview insights.

Sixteen theses were formulated, with three specifically related to satellite communications: T1. The market for free applications utilising Copernicus data will experience rapid growth, leading to an expansion in independent satellite data analysis by end-users; T2. Copernicus data, when subjected to multidimensional analysis, will facilitate environmentally conscious supply chain management through the provision of secure transportation, eco-friendly transportation options, and meteorological forecasts for transportation purposes; T3. During times of socio-political crises such as wars, migration, and economic downturns, the significance of Copernicus data analytics will rise, offering opportunities for optimising supply chains. For each area, the researchers also prepared specific enabling factors and barriers affecting the theses.

In the second phase, supply chain experts, academics, government representatives, and politicians were invited to participate in the initial Delphi survey evaluating the theses.

The third phase involved sharing the comprehensive initial survey results with the experts through Computer Assisted Web Interviewing. The same group completed the second questionnaire.

In the fourth stage, the second survey results were compiled, with certain variables presented as indicators to simplify the analysis. Relevance indices were calculated to determine the strategic importance of each thesis using the following formula (Kononiuk et al., 2021), accounting for very high to very low rankings:

$$I_s = \frac{100n_{VH} + 75n_H + 50n_A + 25n_L + 0n_{VL} + 0H_s}{n - n_{HS}} \quad (1)$$

where n is the number of responses;
VH — very high, H — high, A — average, L — low, VL — very low, HS — hard to say.

Similarly, indicators were identified for enabling factors (IE) and barriers (IB) to implement the theses, revealing key drivers and obstacles.

The fifth step of the methodology was to use the study results to develop strategic options for building an ecosystem in the EU that is able to cope with disruption, increasing supply chain resilience.

The study identified factors through STEEPED analysis that could potentially enhance the supply chain resilience of European satellite communications. Their importance and uncertainty were analysed on a seven-point scale using the School of Intuitive Logic for Scenario Construction (Walton et al., 2019). The STEEPED provides a multidisciplinary perspective encompassing societal, technological, economic, environmental, political/legal, ethical, and demographic viewpoints, extending the STEEP trend analysis checklist (Szpilko, 2020).

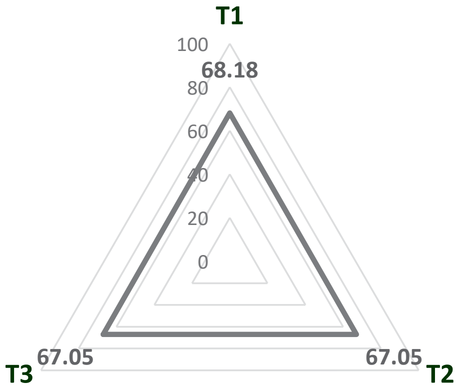
3. Research results

Three theses concerning Copernicus satellite communication received high relevance ratings based on indicators (Figure 1). Experts recognised the potential to empower end-users, promote sustainability, and enhance supply chain adaptive capacity during disruption, explaining the high ratings.

The factors enabling implementation of the theses differed slightly (Figure 2). For T1, "Increasing scope and quality of end-user education" was most important, potentially increasing independence from external providers and enabling faster, more flexible responses during disruptions. For T2, "Widespread promotion of the Copernicus programme" was key to facilitating informed decisions and sustainable supply chains. For T3, "Mutual and effective collaboration between key stakeholders of the Copernicus programme" was critical since successful optimisation relies on coordination between supply chain actors and Copernicus stakeholders.

Figure 3 shows the barrier indicators for each thesis. The main barrier for T1 was the "High level of uncertainty in data from citizen measurement networks", requiring improved reliability, stakeholder trust, collaboration, standardisation, and uncertainty management methodologies. For Thesis 2 and 3, "Low competences of end users of the Copernicus programme" was the top barrier, hindering data assessment, emergency decision-making, and environmentally friendly optimisation. Overcoming this, requires enhanced educational capacity through training, workshops, and knowledge sharing.

Experts identified the greatest theses impact on "Improving reliability, frequency, and flexibility of supply" (Figure 4). This suggests that Copernicus data analysis helps optimise operations in the supply chain by minimising environmental impact and mitigating socio-economic disruption delays and uncertainties.



T1. *The market for free applications utilizing Copernicus data will experience rapid growth, leading to an expansion in independent satellite data analysis by end-users*

T2. *Copernicus data, when subjected to multidimensional analysis, will facilitate environmentally conscious supply chain management through the provision of secure transportation, eco-friendly transportation options, and meteorological forecasts for transportation purposes*

T3. *During times of socio-political crises such as wars, migration, and economic downturns, the significance of Copernicus data analytics will rise, offering opportunities for optimizing supply chains.*

Fig. 1. Values of relevance indicators for theses on satellite communications

Source: (Ejdys et al., 2023).

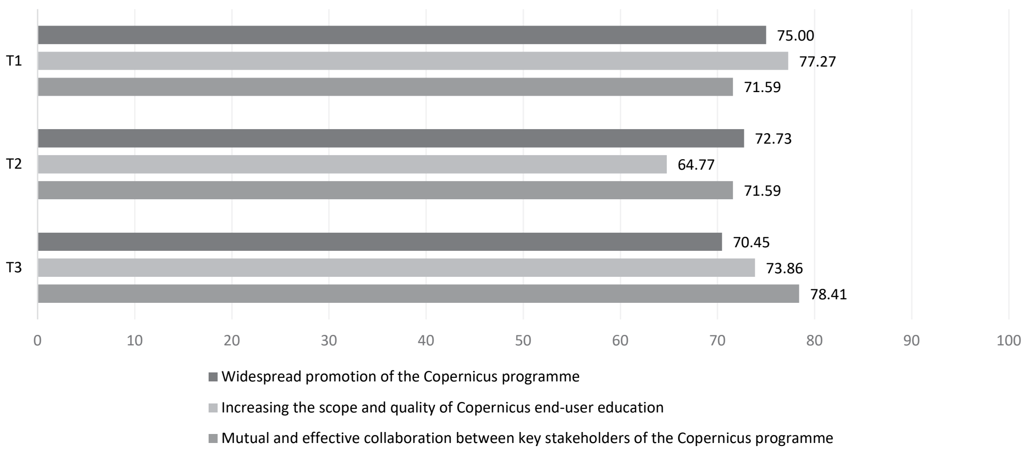


Fig. 2. Values of indicators relating to the drivers of the Delphi thesis

Source: (Ejdys et al., 2023).

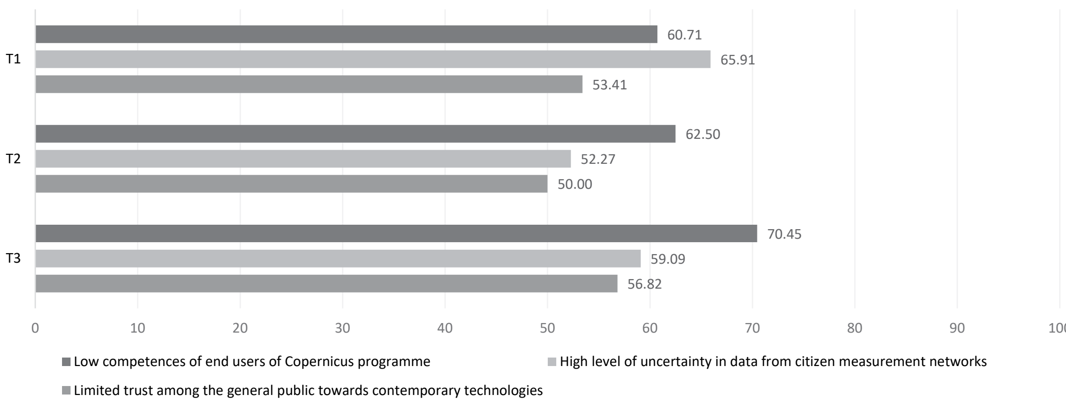


Fig. 3. Values of indicators relating to barriers to the Delphi theses

Source: (Ejdys et al., 2023).

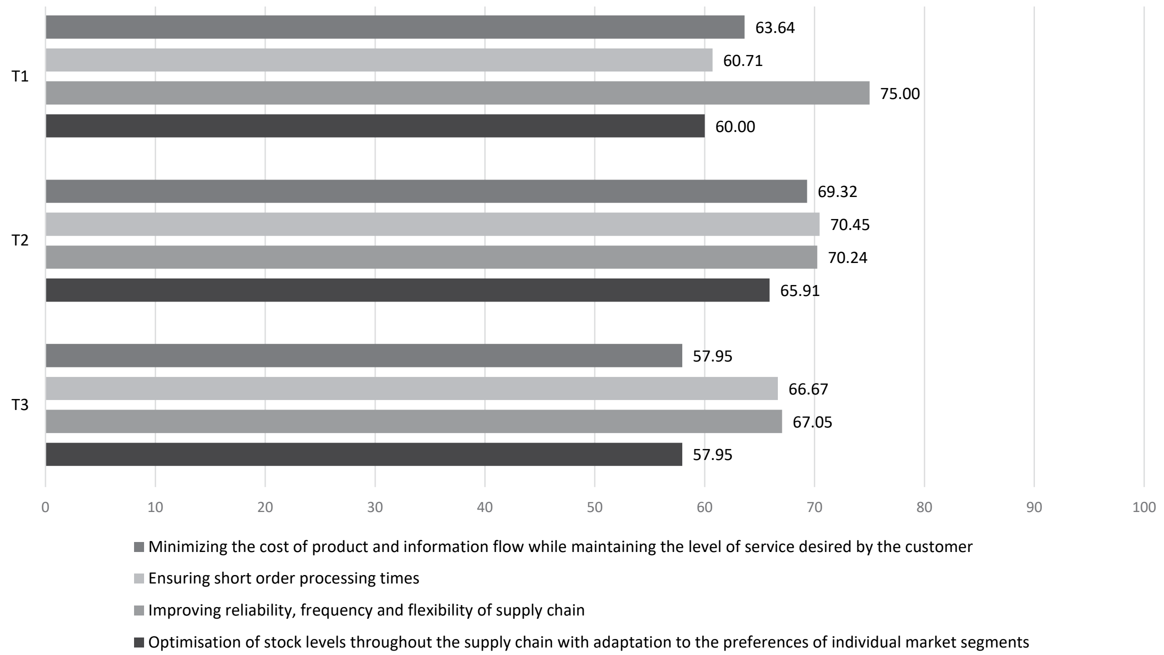


Fig. 4. Values of theses strength indicators for supply chain functions

Source: (Ejdys et al., 2023).

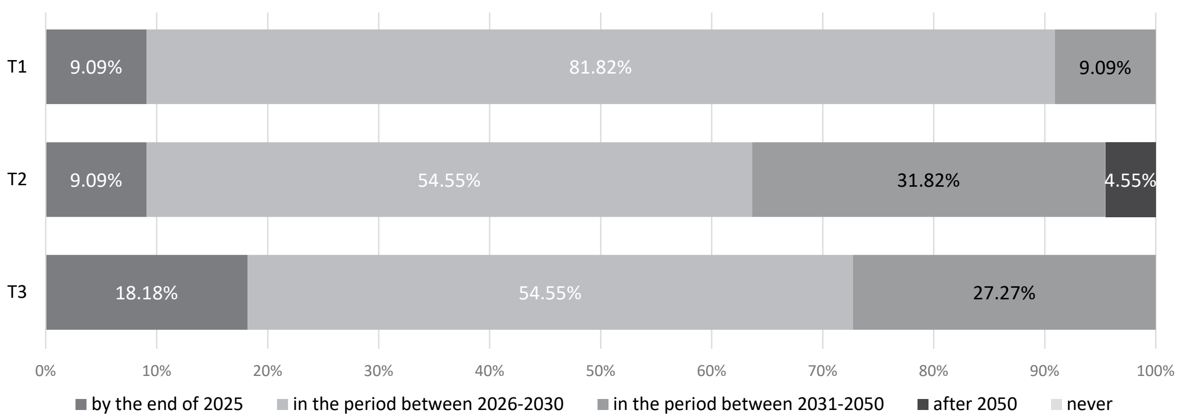


Fig. 5. Time perspective for the implementation of the individual theses

Source: (Ejdys et al., 2023).

Figure 5 shows the time horizon assessments for each thesis. Importantly, none of the theses were considered impossible. Experts recognised that even uncertain, distant theses could potentially materialise in various future possibilities.

The study identified 14 factors through STEEPED analysis (Table 1). Experts rated the importance and uncertainty of these factors on a seven-point scale (Figure 6). Factors with the highest importance and uncertainty in the STEEPED context were environmental and political (Figure 7). Managing these requires monitoring, adapting to changing standards, and collaborating with stakeholders for long-term supply chain resilience and sustainability. For example, factor P1 suggests anticipating and mitigating geopolitical uncertainty risks, continuous monitoring, scenario planning, and adapting strategies. Environmental or political disruptions in one region can cascade across the entire supply chain. Copernicus-enabled supply chain resilience relies on identifying vulnerabilities and addressing them across stages and locations for stability.

The Delphi survey included an open-ended question on possible actions to build EU satellite com-

Tab. 1. STEEPED factors that can foster the resilience of supply chains in the area of satellite communications in the European Union

STEEPED index	Name of the factor
Societal1 **S1**	• Standard of living and safety of individuals in society
Societal2 **S2**	• Public confidence in contemporary technologies
Technological1 **Th1**	• Advancement in Artificial Intelligence
Technological2 **Th2**	• Progress in Internet of Things systems
Economic1 **Ec1**	• Proficiency of end-users utilising Copernicus data and services
Economic2 **Ec2**	• Collaboration among key stakeholders involved in the Copernicus programme
Environmental1 **En1**	• The extent of climate neutrality and biodiversity preservation
Environmental2 **En2**	• Utilisation of natural resources through modern digital technologies, such as measurement, control, monitoring, and reporting
Politycal1 **P1**	• The stability of geopolitical conditions
Politycal2 **P2**	• The effectiveness of legislation regarding cybersecurity and digital data use
Ethical1 **Et1**	• Willingness to embrace technological innovations that enhance quality of life, including reducing environmental pollution
Ethical2 **Et2**	• The involvement and contribution of civil society
Demographic1 **D1**	• Challenges posed by aging population
Demographic2 **D2**	• The scale of international migration

Source: (Ejdys et al., 2023).

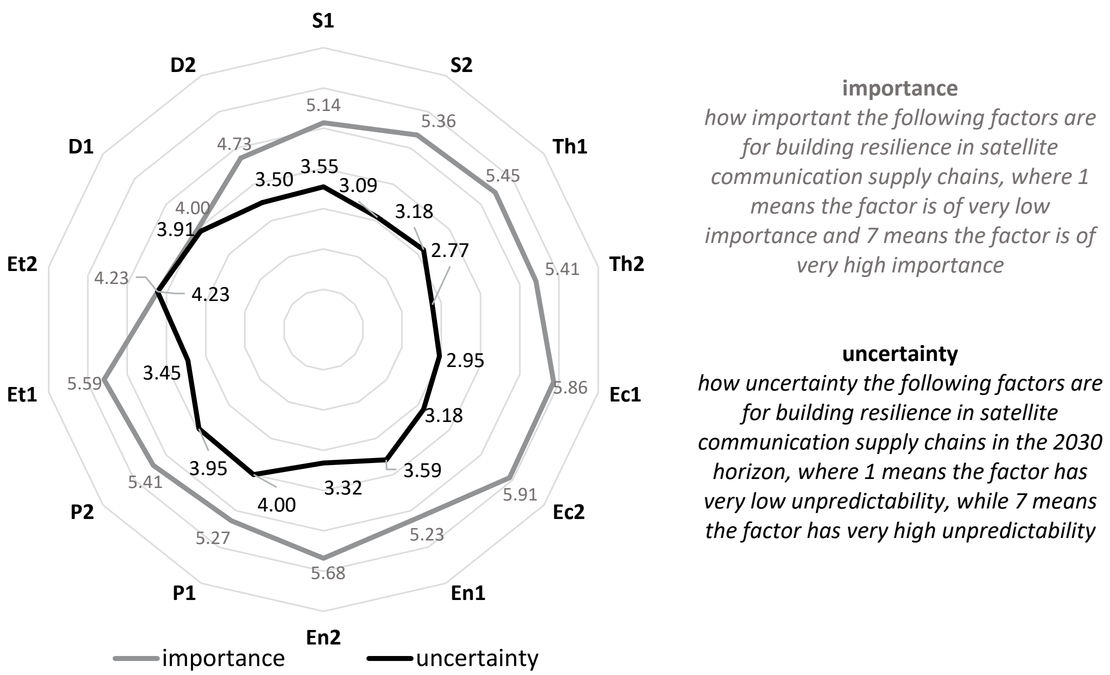


Fig. 6. Seven-point-scale rating of the importance and uncertainty of the following factors for building resilience in satellite communication supply chains

Source: (Ejdys et al., 2023).

munications supply chain resilience. Experts suggested ensuring secure, autonomous, accessible communication services; better critical technology supply chain control; open Copernicus data; synchronising Copernicus with relevant EU programmes like Horizon Europe and Digital Europe; and bridging the gap between satellite data and decision-making.

Each option has proposed strategic actions to enhance the effectiveness of the Copernicus programme. Strategic Option 1 focuses on supporting relevant EU management institutions. Key actions include optimising European supply chains by prioritising the Copernicus satellite programme as a vital Earth observation resource. This prioritisation is

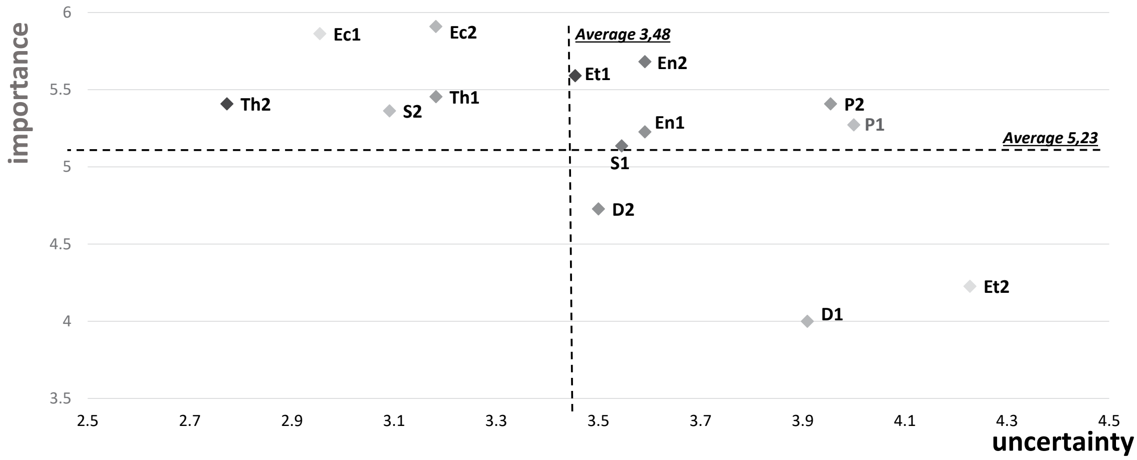


Fig. 7. Importance and uncertainty of STEEPED factors

Source: (Ejdys et al., 2023).

critical for EU policy formulation and European Data Spaces, aligning with relevant EU framework programmes. Promoting supply chain management within EU countries, especially semiconductor manufacturers and Copernicus data providers, is also crucial. Legislation ensuring economic independence from non-EU technologies must be enacted. Bridging the gap between Copernicus data and decision-making necessitates establishing a transparent control mechanism for raw material purchases and critical technology-related supply chains. Measures to safeguard satellites from hostile hacking attacks are imperative, ensuring full EU control and operation, along with the development of new satellites enabling direct servicing and repair in space.

Strategic Option 2 focuses on supporting Copernicus users. Creating incentives like concessions, grants, and support forms is vital to encourage Copernicus data and service usage, particularly in building resilient supply chains. It is essential to use case studies to identify effective and ineffective practices in building resilient supply chains. These lessons should be shared openly, contextualising them within specific crisis impacts for supply chain optimisation. Collaboration with the Copernicus User Dissemination Framework Partnership Agreement (FPCUP) consortium for projects enhancing supply chain resilience is valuable. A promotional campaign is necessary to emphasise the advantages of using Copernicus' free data for supply chain strengthening. Educational efforts should focus on acquiring interdisciplinary competencies for effectively analysing Copernicus-derived data. These strategic actions empower stakeholders to make informed decisions, reinforcing supply chain operations against disruptions and ensuring resilience and sustainability.

4. Discussion of the results

The authors identified opportunities and threats related to the strategic options, considering current trends and megatrends. Strategic Option 1, which supports EU institutions managing Copernicus, includes opportunities like providing citizens and businesses secure Copernicus-based information, systems, services and applications, especially for cybersecurity (Kaur & Ramkumar, 2022). Precise monitoring enabling accurate agricultural and environmental management combined with the Internet of Things development (Doshi et al., 2019) is another opportunity. Strengthening EU education systems through improved multidimensional data analysis competencies is also an opportunity, although with risks like training costs, technology expenses, prohibiting existing agricultural practices based on new geospatial data, and a shortage of data science teaching staff.

For Strategic Option 2, which supports Copernicus users, opportunities include increasing accessibility for citizens to secure Copernicus-based systems, services and applications. Recognising the growing importance of citizen scientists (Roche et al., 2020) and empowering end-users to predict natural phenomena and rationalise agricultural production are also opportunities, as is promoting scientific and business cooperation to advance Copernicus. However, threats include potential digital exclusion of groups like the Silver Generation (Butt & Draheim, 2021), ensuring cybersecurity of Copernicus-based information, systems and applications potentially incurring costs, uncontrolled in-situ facilities causing environmental interference, and users making decisions based on falsified data from hacking (Lukin & Haselberger, 2020). Concerns have also been raised about unfavourable crop regulation changes negatively impacting farmers.

Promoting Copernicus and its data in economic sectors can ensure a reliable resource supply. An example is the RawMatCop project, securing mineral supply. Implementing Copernicus EU-wide enhances digital capabilities, aiding workforce preparation for digital transformation (Kasmaeeyazdi et al., 2021).

Conclusions

Recent events in European socio-economics highlight the need to evaluate supply chain risks and resilience of Copernicus satellite communications. This study proposes two strategies to enhance resilience and mitigate disruptions. The first strategy supports EU institutions managing the Copernicus programme, while the second assists users and intermediaries associated with the programme.

The study used Delphi, a literature review, and the STEEPED analysis to examine theses on satellite communications. Experts expect rapid growth in the free apps market utilising Copernicus data, enabling end-users to independently analyse satellite data. They foresee satellite communications supply chains transforming into ecosystems that integrate value-added activities between 2026–2030.

Two enabling factors were identified: (1) enhancing Copernicus end-user education and (2) promoting mutual collaboration between key stakeholders. First, by enhancing Copernicus end-user education, individuals and organisations can acquire the necessary knowledge and skills to effectively utilise and analyse Copernicus data. This will contribute to the growth of the market for free applications based on Copernicus data, as pointed out in thesis T1. Second, mutual and effective collaboration among key stakeholders of Copernicus, including researchers, entrepreneurs, and politicians, can foster innovation, knowledge sharing, and coordinated efforts towards leveraging Copernicus data for supply chain optimisation, environmental management, and decision-making during crises. This collaboration aligns with the multidimensional analysis of Copernicus data mentioned in T2 and the importance of Copernicus data analytics during socio-political crises brought up in T3.

The study identified two key barriers: (1) low end-user competences hindering market growth and (2) high uncertainty in data from citizen measurement networks impacting multidimensional analysis. These barriers affect data reliability and limit potential uses of Copernicus data. For the T1, rapid app market growth depends on the end-user ability to effectively analyse and use the data. If end-users lack the necessary skills, independent analysis could be limited. For the T2, multidimensional analysis of Copernicus data is important for environmentally conscious supply chain management. However, high uncertainty in data from citizen measurement networks can introduce inaccuracies, potentially limiting analysis reliability and effectiveness. This could create challenges in using Copernicus data for secure, eco-friendly transportation and accurate forecasts. For the T3, during socio-political crises, the value of Copernicus data analytics in optimising supply chains increases. However, the low skills of end-users can restrict effective utilisation during complex, volatile situations. Additionally, high uncertainty in citizen measurement data can add further difficulties, potentially impacting analytics accuracy and reliability during crises.

The study also analysed the impact of the theses on supply chain functions, emphasising improvements in reliability, frequency, and flexibility of delivery. Additionally, based on STEEPED analysis, 14 factors were recognised, including civil society involvement, cybersecurity legislation, ageing population, and geopolitical stability. Among these factors, the stability of geopolitical conditions emerged as the most important and simultaneously the most uncertain aspect of the study.

Despite the potential domains for Copernicus programme activities, challenges arise from geographical dispersion, diverse user communities, and varying preferences (Taramelli et al., 2019). Managing different initiatives becomes difficult but poses a significant challenge requiring dedicated scientific efforts.

Moreover, technical issues identified by the Delphi study and the work of the European Innovation Council (European Innovation Council (EIC) Work

Programme 2023, 2023) include a growing number of dysfunctional satellites, limited in-space servicing capability, and EU's limitations in controlling and maintaining Copernicus infrastructure. These concerns necessitate the analysis of the strategic autonomy of EU space assets.

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