Draft for Public Review

Earth Science in Action for Tomorrow's World

Earth Observation Science Strategy 2040

→ THE EUROPEAN SPACE AGENCY

Foreword

Figure 1. *Simonetta Cheli, Director of ESA Earth Observation Programmes*

At this pivotal moment in time, humanity finds itself at a crossroads. Climate change, environment biodiversity loss and extreme events impact all inhabitants of our planet, some to disproportionately greater degree, resulting in profound societal challenges. As a space agency it is our responsibility to apply the Earth observing tools at our disposal to inform and decide along which road to travel. The choice will ultimately determine the route to a more sustainable future, and aid transformation towards a more resilient society.

ESA's new Earth Observation (EO) Science Strategy provides a basis for implementation choices built on a solid scientific foundation. Today Earth is more closely scrutinised and monitored by satellites than at any other time in our history. ESA has taken a leadership role by pioneering Earth Explorer research satellites with new observing capabilities, conceiving, developing, and implementing the Copernicus Sentinel series of satellites in conjunction with the European Union, and by developing European weather satellites in conjunction with EUMETSAT. The ESA-developed Earth observing infrastructure, together with national and international partner missions, and a rapidly growing commercial fleet, enables more timely, more detailed, more frequent, and more widespread coverage than ever before with information products which span the needs of public, governmental and private users, supporting scientific enquiry, important public policy objectives and commercial endeavours.

At a time when ESA Strategy *Space2040*[1] seeks to further stimulate and strengthen these developments and lift Europe's space ambitions, our Earth Action embodies and embraces the activities which propel us towards a greener future, and the use of space data to mitigate climate change and enhance the quality of life.

[1] Space2040 - ESA's vision for the European space sector by 2040

Vision

Vision Statement

To craft world-class Earth Observation capabilities and information products for informed decisions and actions that best respond to today's challenges of understanding and sustainably managing our Earth environment.

The ESA Earth Observation strategic vision focuses on the steps we can take to address the environment, the climate crisis, and its societal and economic impacts. Scientific knowledge and understanding gained from new satellite technologies and the growing volumes of data provides the basis for decision-making and action, and for preparing a better tomorrow.

Prologue

Scientific advances in Earth system and climate research based on EO satellite technology have exponentially increased in the last years thanks to the wide variety of novel high-quality EO missions and datasets, as well as to the continuous provision of long-term data records providing fundamental evidence of climate change and its impacts worldwide.

Despite this progress, many observation and knowledge gaps remain and require urgent scientific action:

- Climate change impacts are no longer a future threat but a present-day reality in which the everyday effects of global warming and human pressures on the environment are more evident, frequent and intense across the globe;
- The rate of change in our planet, driven by climate change and human pressures, is accelerating leading the Earth system into new regimes and patterns in global cycles of water, carbon and energy, with more frequent and intense extremes at regional and local scales, for which abrupt irreversible changes can no longer be excluded. This poses new challenges for the scientific community;
- There is a vital need to enhance our capacity to observe and characterise these new regimes in a holistic manner, advancing the fundamental scientific understanding of the underlying processes, their drivers and impacts on the Earth system, society and ecosystems, and enhancing our predictive capacity to define effective responses and adaptation measures;
- A need exists to better incorporate human activities as an integral part of the Earth system, through the capacity to observe, characterise, predict and manage the impacts of human interventions upon the Earth system from global to local scales, posing major challenges for our observing system and modelling capacities that would require to address unprecedented scales in space and time;
- Feedbacks and interactions between nature, ecosystems and socioeconomics can no longer be ignored, requiring dedicated observing capabilities, and renovated interdisciplinary scientific efforts to advance how we assess and predict the evolution of ecosystems.

As a response to these needs, the Earth Observation Science Strategy 2040 outlines ESA's science vision, presenting priorities and accompanying approaches that reflect and directly respond to these scientific and societal challenges. It identifies the areas of science that ESA needs to respond to along the full value chain: from innovative missions through excellent science to societal benefits and applications. The strategy supports a range of programmatic actions including research and development of new techniques to extract information from existing data, early phase mission concept science, and international collaboration to name a few.

A science-driven approach lies at the heart of the ESA's Earth Observation Programme as it provides the basis to increase the collective understanding our evolving planet and the development of actionable information in tackling serious global environmental issues and the resulting challenges.

"First-class science is absolutely essential for the promotion of European interests and leadership, as it imparts a strong strategic drive to its technological and industrial system"[2]

The renewed science strategy builds on five inter-connected pillars:

- Advance our capacity to deliver high quality observations of our planet and its changes, providing a synoptic view of its complex processes;
- Address the critical scientific challenges and knowledge gaps that today limit our understanding of the Earth system and its interactions and feedbacks;
- Develop our capability to simulate, predict and forecast the dynamic evolution of the Earth and its climate system at scales in space and time compatible with societal needs;
- Timely and effective transfer of scientific knowledge, data and capacity into societal benefits, informed decision making, contributions to national and international policies and more generally supporting actions and green solutions that enable sustainable development for our society and economies;
- Ensure effective end-to-end approach to science establishing a continuous feedback loop between the latest scientific advances and definition of the next generation of observing systems.

At the heart of the renewed EO science strategy are a selected number of science questions which encapsulate pressing Earth system science issues and critical knowledge gaps in which satellite Earth Observation technology can provide a unique contribution, either leveraging existing or near-future EO data sources or by developing new capabilities.

The renewed EO science strategy responds directly to the urgent need to ensure the benefits from investment in EO science are translated into societal and policy benefits. These benefits come through a range of means, including the increasing need and ability to manage and protect our environment, anticipate and respond to extreme weather events and natural or human-induced disasters, through a better understanding of the dominant multidisciplinary interactive processes within the Earth system; and through the spin-off benefits where science-grade qualified data can be employed in operational environmental monitoring to support policy implementation and the sustainable management of Earth resources. The new EO strategy responds by explicitly linking and ranking the priority science questions in terms of societal benefits and policy needs and documenting the nature of these links.

The Earth system is complex and interconnected, comprising of the intertwining of the geosphere, atmosphere, hydrosphere, and biosphere. Despite our ever-advancing scientific knowledge, there are still significant gaps in our understanding of this intricate system and addressing these gaps is critical to respond to the challenges of the changing Earth environment and its climate and chart out courses of action.

The renewed EO science strategy - and the portfolio of priority science questions underpinning it - respond to these knowledge gaps over a range of timescales. These include delivering new knowledge and reducing critical knowledge gaps in the short term (typically from 2026-2031) by leveraging data and new information provided by existing missions and by satellite missions launched

[2] *"Uplifting ESA Science Funding" - European Space Sciences Committee, Seville, 6 November 2023.*

during this time frame. Addressing these gaps will also require a longer-term (towards 2040) investment in new, exciting, and ambitious EO missions. These missions allow us to explore, discover and develop new insights into our planet and provide venues to develop fit-for-purpose environmental and climate information from space which is currently unavailable, but of absolute importance to advance our understanding. Commercial space associated with fast development cycles offer a complementary and economically interesting path for rapidly developing additional EO capacity within domains where sensing technology and the application context are already mature.

The ESA EO science strategy provides a longer-term vision up to 2040 in line with the overall ESA Strategy *Space2040*. The strategy also serves the definition of ESA activities in a shorter time frame responding to the accelerating pace of science, discovery and applications and the pressing need to develop capabilities leading to actionable information for a sustainable Earth environment. The priorities and strategies are intended to focus attention on those areas where ESA's EO programmes can have the greatest impact.

The Earth Observation Science Strategy 2040 is based on four areas of action:

- Frontier Science and Discovery: a strong foundation
- From Science to Benefits: meeting society's needs
- Reducing critical knowledge gaps: taking action now
- Filling critical observation gaps: preparing for tomorrow today

Table of Contents

Foreword 1

Vision 2

Prologue 2

Strategic Science Priorities 6

Strategy Timescales & Timeframe 9

Strategic Areas of Action 9

- A1 Frontier Science and Discovery: a strong foundation 9
- A2 From Science to Benefits: meeting society's needs 10
- A3 Reducing Critical Knowledge Gaps: taking immediate action 12
- A4 Filling Critical Observation Gaps: preparing for tomorrow starts today 14

Enablers of Earth Action 15

- Building Partnerships and Cooperation 15
- Fostering a Community Approach to Science 15
- Building strong STEM Education, training and outreach 16
- Exploring EO science links with Commercial Space 16
- Harnessing Open Science through Digital Innovation 16

Assessing Progress 18

Appendix 1: The 22 Science Questions and their Relevance to International Treaties, Agreements and Conventions 19

Appendix 2: Science Questions & Relevance to National Policies 24

Appendix 3: Policy and benefits categories 27

Appendix 4: International Agreements and Treaties and areas impacted by EO science 28

Strategic Science Priorities

As part of a broad horizon scan, the ESA EO Science Strategy Foundation Study, combined with user consultation, enabled to establish and consolidate a set of new cross-cutting scientific questions as the foundation of the new Science Strategy.

Twenty-two Scientific Questions (CSQs) have been defined to guide Earth Observation Programmes (See Table 1). By contrast to the science domain-focused "*Challenges of the Living Planet Programme*" at the heart of ESA's previous EO science strategy, these new cross-cutting questions have been prioritised and selected out of a broader set of 57 "Candidate Science Questions" (CSQs), based on their relevance and importance in addressing gaps, and in terms of their direct relevance to societal benefits and policy domains (see Appendices 1, 2). Following guidance provided from user community feedback, the priority in the selection of the final list of key questions is: "where are the benefits to society inhibited by lack of scientific understanding of Earth system processes"; and "where is understanding/discovery of Earth system processes inhibited by innovation and lack of appropriate spaceborne data".

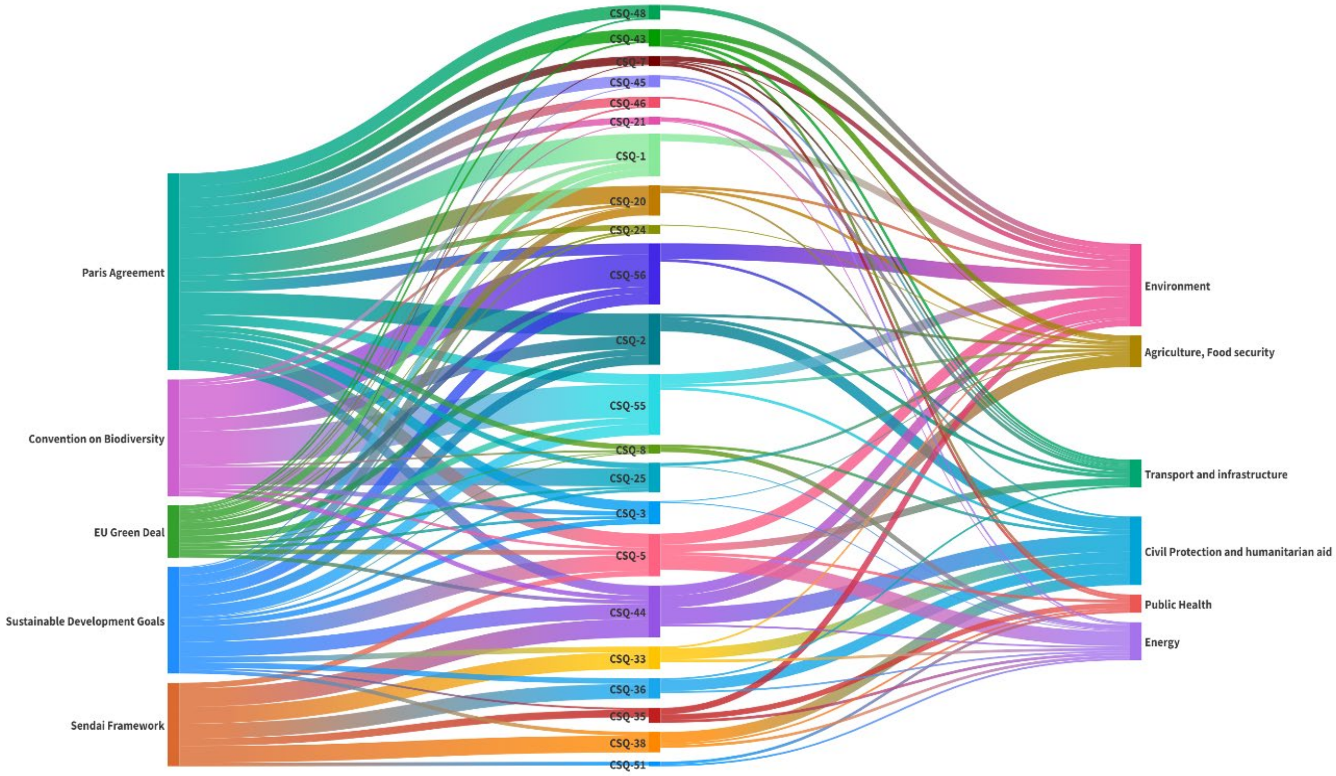

Figure 2. *Traceability between each of the Candidate Science Questions (CSQs) in the centre and International Agreements/ Treaties on the left, and socio-economically relevant application domains on the right.*

The resulting 22 Candidate Scientific Questions (CSQs) encapsulate a series of pressing Earth system science issues that can be addressed by Earth observation (in combination with other data sets) – either by using existing capabilities and soon to be launched missions, or from future missions with capabilities yet to be developed. Based on the relative weighting between filling observation or knowledge gaps, development of new technology, or the timescale of scientific returns, the science questions are priorities and selected to yield direct short-term policy or socio-economically relevant benefits, or to target longer-term fundamental, high impact scientific advances.

Each of the CSQs summarised in Table 1 and outlined in greater detail in Appendices 1 and 2 are identified by a brief descriptive text, and explicitly linked to International Treaties, Agreements and Conventions as well as National policy, whilst Appendix 3 identifies the benefit categories.

Table 1. *Short titles of the 22 priority Science Questions to guide implementation actions within the EO Programmes. A full description of each is found in Appendix 1, and the accompanying Benefits identified in Appendix 3.*

CSQ-**01** Global carbon cycle	CSQ-**02** Land biosphere responses	CSQ-**03** Ocean carbon cycle	CSQ-**05** Coastal sea level
CSQ-**07** Coastal process mediation	CSQ-**08** Coastal carbon cycle	CSQ-**20** Ice mass balance	CSQ-**21** Sea ice themodynamics
CSQ-**24** Polar climate relationship	CSQ-**25** Polar Ecosystem Impacts	CSQ-**33** Solid Earth deformation	CSQ-**35** Erosional Processes
CSQ-**36** Seismic deformation processes	CSQ-**38** Earth's crust dynamics	CSQ-**43** Coupled cycles	CSQ-**44** Water cycle
CSQ-**45** Climate sensitivity	CSQ-**46** Earth energy imbalance	CSQ-**48** Planetary heat exchange	CSQ-**51** Coupled lithosphere-atmosphere-ionosphere
CSQ-**55** State of land ecosystems	CSQ-**56** Ecosystems transition		

Each CSQ is accompanied by documentation containing the following elements:

- Knowledge Advancement Objectives (KAOs): these are specific objectives by which progress towards resolving the scientific question can be measured;
- Geophysical Observables: the primary geophysical variables needed to advance the science question. These are divided into priority observations and supporting observations, and where possible linked via reference numbers to CEOS[3]/OSCAR[4] database requirements;
- Measurement Specifications: the observation requirements for datasets providing the geophysical observables;
- Other Data sets, Methods, Tools, and Models: beyond spaceborne observations, other items may be needed to address the science questions. These could include non-EO data sets, new retrieval algorithms, new data-model assimilation techniques, calibration/validation facilities etc.

[3] CEOS Database: https://database.eohandbook.com/database/instrumenttable.aspx
[4] WMO OSCAR Database: WMO OSCAR | Observing Systems Capability Analysis and Review Tool - Home

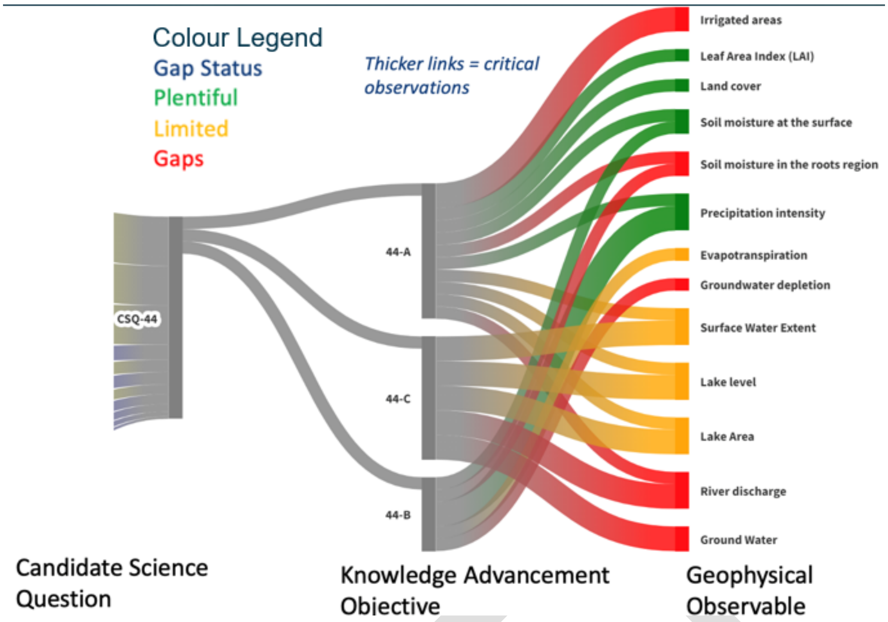

Figure 3. *Example of traceability between a selected priority Science Question CSQ 44 "Water Cycle", its specific Knowledge Advancement Objectives, and the required geophysical observable parameters to and address the question. More critical observations are indicated by thicker links, and gaps in observations are indicated in red. The gap status colours indicate sensor availability in relation to the number of operational or approved satellites listed in the identified databases[3,4].*

The portfolio of 22 Candidate Scientific Questions provides a solid basis to guide the implementation the EO Programmes in the four different action areas of the strategy. Characterising the CSQs in terms of its potential contribution to these areas enables for instance one to identify and distinguish science questions with a direct and traceable contribution to policies and societal benefits, or those where we expect significant advances in our understanding and reduce knowledge gaps on a five to six years' time scale. The result of the characterisation of the CSQs for all four strategy action areas is provided below. This figure provides a coherent and traceable basis for setting priorities and implementing programmatic activities in each action area.

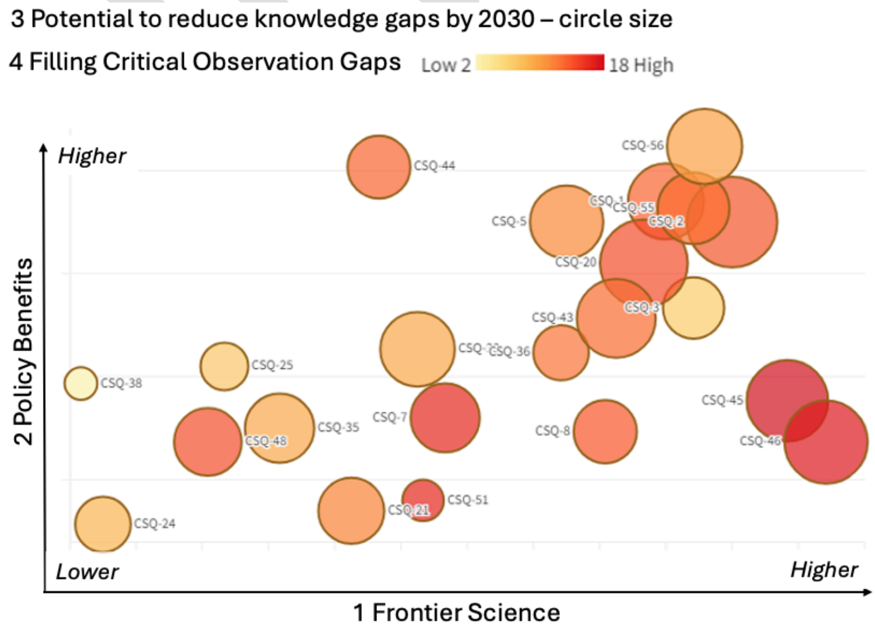

Figure 4. *Example framework for characterising the CSQs in terms of the four areas of action of the EO science strategy 2040.*

Strategy Timescales & Timeframe

The 2021 Independent Science Review of ESA's EO programme recommended that the time horizon for the Science strategy should be revisited and shortened, with a suggested review and revision every six years by comparison to previous decadal updates. Whilst the present scientific Living Planet Challenges not yet addressed or fulfilled should not be forgotten, this timescale acknowledges the accelerating pace of science, discovery and applications development and emphasises the need for more frequent reflection on scientific progress.

The Strategy timescale and timeframe have important implications for EO programme implementation, and for the rates of progress of different programme elements. Exploitation of ongoing missions and available data using new methods or novel approaches can be used to progress on addressing the priority science questions on the shortest timescale within one or two three-year programme cycles. Similarly, smaller and more expeditious missions (such as Scouts) can be implemented within a shorter timeframe to deliver new observations and scientific progress. By contrast, the development lifecycle of ambitious flagship (Earth Explorer) research missions providing fundamentally new types of observations may take a decade between idea and launch, yielding scientific results only after 10-15 years. Consequently, technology development for more complex future missions must be guided by priorities and an architectural vision with (at least) decadal foresight, such that such missions providing critical new capabilities to address some of the most challenging science questions, or persistent monitoring, become feasible. Hence the new portfolio of science questions reflects activities that contribute over a range of timescales, some delivering impact and benefits in the short term, and others supporting long-term strategic goals.

The anchoring of new (Earth Explorer type) missions remains a key focus of the science strategy, as the Earth Observation envelope programme has delivered significant success, scientific progress and impact through this mechanism. But the science strategy is also recognised to support a range of other actions including R&D on new techniques to extract information from existing data, early phase mission concept science, and international collaboration amongst others. The SQs therefore include objectives that require a range of different programmatic actions to enable scientific progress, including new mission concepts, specific R&D to enable maturation of the science and technology, research on algorithms, retrievals and data assimilation.

In recognition of these elements, the present Science Strategy reflects a short-term element spanning two three-year programme segments, and a time horizon extending to 2040, corresponding to the ESA Strategy *Space2040*.

Strategic Areas of Action

A1 Frontier Science and Discovery: a strong foundation

Frontier science refers to pursuit of discoveries and ideas that have not yet been supported by scientific evidence with new observations, methods or models. Stimulating excellence in novel, discovery or transformational science is a core strategic objective for ESA, serving as the foundation for all areas of action and impact. Frontier science and discovery plays a critical role across programmes in shaping and inspiring discoveries, catalysing technological advancements, developing workforce talents, industrial competencies and competitiveness, and infrastructure assets.

Strategic Objective 1: *To pursue excellent, innovative, inspirational and impactful frontier science as a primary driver of innovation in Earth observation programmes and activities.*

Benefits of frontier science-driven EO programme include:

1. **Enhanced understanding of the Earth and its environment:** The scientific method combined with ambitious transformational science provides a tool for advancing our understanding of the Earth's system and anthropogenically induced interactions and changes. This knowledge is vital for making informed decisions, developing sustainable policies, and mitigating the challenges posed by environmental changes.
2. **Economic Growth, Innovation and Prosperity**: The advancements in technology, industry, and organisation enabled by frontier science lead to a wealth of tangible benefits. Commercial applications, job creation, overall prosperity and valuable technical, programmatic and commercial capabilities are direct outcomes of scientific innovation, fostering economic growth, societal well-being, and enhanced resilience to future global developments.
3. **Securit**y: Scientific insights gained from research underpin essential security capabilities. By bolstering EO science, we enhance our ability to develop advanced technologies, skills and capabilities that safeguard European citizens and European geopolitical interests.
4. **Risk Mitigatio**n **and Preparedness**: Many challenges and threats, such as natural disasters and climatic and environmental change, can be better anticipated, understood, and fed into concrete actions when building on the outcomes of frontier science.
5. **Prestige:** New scientific discoveries made possible through discovery Earth Observation captivate the public imagination, showcasing Europe's capabilities and fostering a sense of collective pride. These achievements also generate credibility and respect from global partners - and competitors.
6. **Inspiration and Education**: EO science has the unique power to inspire and engage people across age groups and backgrounds. It enables and supports informing the public and the building of capacity and human capital to address the future environmental challenges.

Frontier science is also best addressed by harnessing scientific knowledge, technical resources, and know-how at European level through ESA and hence remains a pillar of the new EO science strategy.

The Candidate Science Questions underpinning the new EO Science Strategy provide both the justification and the means to prioritise and guide frontier science across ESA's future EO programmes. By defining and documenting pressing Earth system science issues, identifying related geophysical information required and identifying supporting tools and models, the CSQs provide a unique framework to guide the development of ambitious new satellite missions and support highly innovative science with current and near-future EO missions.

A2 From Science to Benefits: meeting society's needs

There is an ever growing need to ensure investments in EO science are transferred into benefits to society. These benefits come through the increasing capability to manage and protect our environment through a better understanding of the dominant multidisciplinary interactive processes within the Earth system; and through the spin-off benefits where data designed for science can be employed in operational environmental monitoring and evidence-based policy implementation or be incorporated in local resource management.

Strategic Objective 2: *To develop scientific knowledge and capacity to deliver high-quality validated, trusted, actionable information products relevant to national, international and global policy frameworks.*

The science questions pursued in the new strategy include many with a clear link to policy and societal benefits which can be delivered by improving our understanding and associated green solutions development. In assessing links to policy benefits, the new EO science strategy considers four different aspects:

1. **Inform**: EO science informs policy debates through provision of knowledge, understanding and evidence. Examples include the provision of climate records and enhanced Earth System models which quantify and explain the "how" and "why" our Earth's climate and environment are changing;
2. **Assist**: EO science assists and supports society in addressing current and future challenges in areas such as responding to environmental issues and reducing the loss of life. Examples benefits include improved weather forecasting, air quality warning, natural resources management, and responding to geohazards including warning systems and emergency response;
3. **Comply**: EO science provides the basis for the future definition and enforcement of policy outcomes/ legislation. Examples of this benefit include Measurement, Reporting and Verification (MRV) systems used for carbon accounting, Montreal treaty support, and Policing Marine Protected Areas;
4. **Evaluate:** EO science supports assessment of the outcomes of policy decisions. An example of this benefit is the unique role of EO in monitoring the trends in greenhouse gas (GHG) emissions worldwide.

These four criteria quantify the **relevance** to the policy domain for all priority science questions tabled in the strategy. A question is deemed relevant if it provides knowledge, data, or tools to 'inform' policy and policy options, 'assist' policy delivery, ensure 'compliance' with regulations and 'evaluation' of the impact and efficacy of any enacted policy response. Relevance is assessed with respect to the main international treaties and agreements (e.g. Paris Agreement, Convention on Biodiversity, UN Sustainable Development Goals, Sendai Framework on Disaster Risk Reduction, and EU Green Deal), or to national policy domains (Energy, Environment, Transport and infrastructure, Civil Protection and Humanitarian Assistance, and Public Health).

In addition to relevance, the strength and uniqueness of the link between each science question and the policy area is of great importance in connecting science to policy and defining priority strategic goals. In preparing the present strategy, a full assessment was carried out and summarised in the Appendix. Illustrated in Policy-Science Question scores and heat map illustrations (see below) the strength of the contribution to each policy domain is summarised - going from very low (white colour) for science questions where the contribution to policies is lacking or very limited, to very high (dark red) for science questions where there is a unique, strong connection between the science question and the international policy. As an example, Science Question 01 ("What anthropogenic and natural processes are driving the global carbon cycle?") is coloured in dark red as the knowledge developed through science investigations will directly *inform* Article 4 and 5 of the Paris Agreement as well as support the Enhanced Transparency Framework and Global Stocktake.

The relevance of the priority science questions to policies/societal benefits provides a sound and transparent basis to guide and prioritise future ESA EO science activities. An important subset of the priority science questions is characterised by strong to very strong contributions to national and international policies. Addressing these questions within future ESA EO programmes will therefore greatly enhance Strategic Areas of Action.

CSQ	Policy				
	Paris Agreement	Convention on Biodiversity	Sustainable Development Goals	EU Green Deal	Sendai Framework
CSQ-01	26	4	8	8	0
CSQ-02	24	14	10	7	0
CSQ-03	11	5	6	3	0
CSQ-05	15	3	17	5	10
CSQ-07	9	0	1	0	0
CSQ-08	6	2	1	1	0
CSQ-20	19	3	9	1	1
CSQ-21	7	0	0	1	0
CSQ-24	6	0	2	2	0
CSQ-25	6	19	3	3	0
CSQ-33	0	0	6	0	18
CSQ-35	0	0	2	0	8
CSQ-36	0	0	6	0	16
CSQ-38	0	0	4	0	18
CSQ-43	13	0	0	2	0
CSQ-44	16	5	16	4	20
CSQ-45	12	0	0	1	0
CSQ-46	10	0	0	2	0
CSQ-48	14	0	0	2	0
CSQ-51	0	0	0	0	4
CSQ-55	11	36	12	7	0
CSQ-56	12	35	12	7	0

Figure 5. *Relative strength of the contribution of each CSQ to major international policies and agreements. The numerical scores for each CSQ and policy area provide a quantitative measure of the directness and are computed based on a methodology developed by the EO Science Strategy Foundation Study.*

Addressing science questions and advancing our understanding of the Earth System will benefit interdisciplinary data science. It will enable and provide an expanding basis for connecting scientists from different sectors, EO specialists, climate scientists, ecosystem scientists, social and economic scientists to jointly undertake far-reaching interdisciplinary research and to provide the quantitative basis for a scientific response to the urgent societal needs underpinning the European and global environmental and development agendas.

Strategic Objective 3: *To advance interdisciplinary science, fostering the integration of socio-economic data and EO in interdisciplinary research.*

A3 Reducing Critical Knowledge Gaps: taking immediate action

The increasing number of scientific, operational and commercial satellites that will be launched in the coming years both in Europe and worldwide is certain to offer an unprecedented opportunity to radically improve our capacity to holistically observe and understand the Earth system, opening the door to novel discoveries and scientific breakthroughs with significant impacts in society. This will require the pursuit of multi-mission synergic opportunities offered by the wide variety of sensors and ensuring these developments and products are qualified by a sound characterisation of error and uncertainties. In addition, Earth Action and progress towards a green and resilient future relies strongly on scientific understanding and innovation coupled with Earth system modelling to most effectively leverage the full benefits from satellite data.

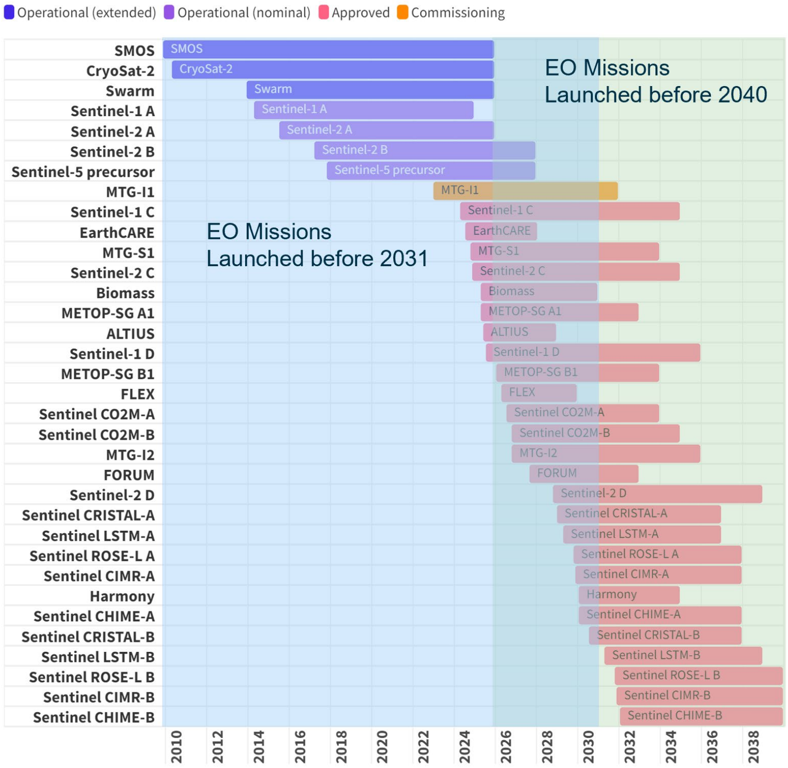

Figure 6. *ESA research and operational missions during the strategy timeframe. Missions to be launched or operational during the coming years (2026-2031) and in the longer term (up to 2040) are identified. Note: this data is extracted from the CEOS database and all dates for launch/EOL dates are subject to change.*

Building on this expanding spaceborne infrastructure and the information provided by existing and planned missions (Figure 6), specified CSQs for which demonstrable progress can be made in the six-year time frame up to 2031 will be addressed through ESA's EO programmes. Benefits in addressing the Earth system knowledge gaps expressed by the CSQs should include:

- Increased expertise and capacity in the European upstream and downstream sectors with respect to the new instruments and their exploitation for scientific and pre-operational purposes;
- Consolidated scientific basis for key algorithms, ensuring that user specified information can be generated effectively and credibly with the new data becoming available;
- Improved, robust and fit-for-purpose Digital Twin Earth (DTE) components that build on the increased knowledge and scientific capacity developed through ESA programmes. DTE acts as digital replicas of Earth system components, enhancing our understand of the past, monitor the present state of the planet, assess its changes, and simulate its potential evolution under different (*what-if*) scenarios at scales compatible with decision-making;
- Increased users' and stakeholders' readiness to rapidly uptake derived information products within the science and applications community.

Strategic Objective 4: *To ensure the EO science community takes full advantage of the opportunities offered by the existing (including archived and long-heritage data) and new missions that will be launched in the timeframe 2026-2031 to advance our understanding of the Earth System and maximise scientific return.*

Addressing the big-ticket science questions front of us will require major institutional collaborations and the coordination of science programmes across the European research landscape. With the landmark joint Earth System Science initiative with the EC Research and Innovation Directorate (DG-RTD) and the cooperation agreement with the Directorate General for Climate Action (DG-CLIMA), ESA and EC are seizing the opportunity to harness combined expertise and resources to bring about transformative change in Earth and climate science.

***Strategic Objective 5**: To maximise the combined impact of the ESA, national and EU investments by reciprocal reinforcement and alignment of research priorities to foster research and innovation and the use of EO data to support the green transition and climate action.*

By embracing New Space approaches, having a shorter development lifecycle of only a few years, smaller (Scout-like) research missions are designed to target specific science and policy questions and address knowledge gaps on a shorter timescale. Complementing ESA's larger (Earth Explorer) research missions, such missions are developed to contribute to Earth science and practical applications, while retaining the potential to be eventually scaled up to larger monitoring missions.

Strategic Objective 6: To demonstrate the value of more agile small research satellites as a means of filling critical observation gaps and delivering short-term answers to critical science questions.

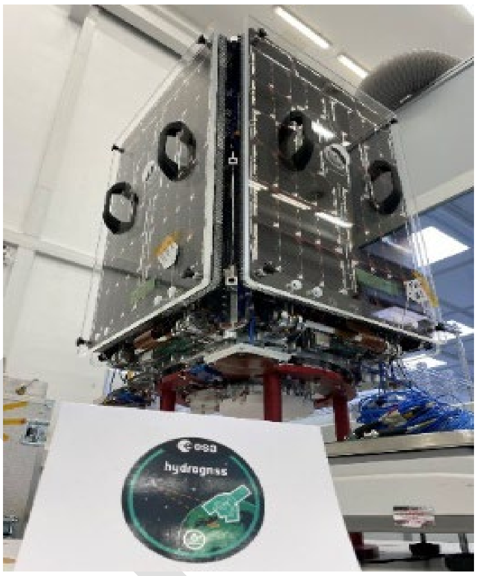

***Figure 7.** Agile development of SmallSat missions such as the HydroGNSS Scout pioneers new capabilities to fill critical observation gaps.*

A4 Filling Critical Observation Gaps: preparing for tomorrow starts today

Deep technology development is required to fill crucial information gaps discussed in the present document. This includes the study and pre-development of novel and improved spaceborne observation capabilities. Certain (especially the mission centric) components require a longer-term vision of up to a decade or more.

In addition to addressing the technological needs, future missions require sustained scientific efforts to define, explore and further develop the science context and preparation of the missions - and also to secure the engagement of the user community. Such sustained science efforts bring many benefits including increased scientific understanding and framing of the mission purpose and potential, innovation in terms of new approaches to data use and uptake, exploration of the value and science impact of new measurements and experiments and improved guidance to the mission development ensuring that each mission is fit-for-purpose and provides maximum science return.

Bold, fit for purpose, game-changing European research missions have consistently delivered unprecedented knowledge about the Earth System.

The CSQs with highest relevance to critical observation gaps provide the scientific justification and framework guiding the preparation of long-term investments in EO missions. These science questions serve a compass, guiding the development of future technologies and developing expanded Earth Observation capabilities.

Furthermore, it remains necessary to establish a blueprint by which to build and maintain the optimal European EO reference architecture. This should include the persistent backbone of gold-standard reference missions, particularly for securing the extension of fundamental climate data records, and for supply of sustained datasets as the basis for the operational services, upon which to deliver EO based solutions. Equally, the reference architecture relies on a system-of-systems framework that considers all components of the observing system in relation to the synergetic potential and specific observation needs. Components can be seen as missions (e.g. operational satellites, reference missions, scientific missions, commercial missions), as data and operations management, access, ground segment, technical/industrial components, modelling and decision-support or authentication and certification components.

Strategic Objective 7*: To develop and implement an architectural blueprint for an EO system-of-systems for guiding long-term ESA research and technology preparation, mission implementation and operation of a coherent and sustainable space based EO ecosystem.*

Within the long-term vision expressed by the architectural blueprint the steps needed to prepare the future transition of observations from research to operations must be foreseen and prepared. Robust technology development is recognised on the one hand a necessary prerequisite to make the transition, whilst bi-directional feedback must be established between the R&D activities and operational service providers to prepare the way.

ESA holds a unique position with its overall overview of the full mission life cycle.

Enablers of Earth Action

Building Partnerships and Cooperation

Strategic partnerships and cooperative initiatives are widely recognised to be essential when engaging actors within and beyond the space sector, especially when coordinated efforts between science, business, governments, international organisations, and citizens alike are needed. This holds particularly when addressing planetary emergencies and the need to change human behaviour.

Strategic Objective 8: *Promote and strengthen international collaboration with partner space agencies (EUMETSAT, NASA, JAXA), key space actors, and space faring nations (such as ISRO, CONAE, INPE), expanding ESA and European capacity to address the priority science questions and actively engage in Earth science action.*

In Earth Action, cross-sector partnerships with key public and private stakeholders are essential to bridge demand and offer leading to adoption and ultimately enabling impactful decision-making and actions informed by EO. Recent landmark initiatives between ESA and the European Commission, such as with DG-CLIMA, DG-RTD, DG-CNECT and DG-INTPA enhance our joint capabilities to better understand and address the impacts of climate change and to respond to the European Green Deal - even at global scale. Strategic partnerships ESA established with major mandated international policy makers and International Financial Institutions leverage financial resources and political processes to scale scientifically proven EO solutions across countries and mainstream it into a wide range of socio-economic sectors. ESA EO will therefore continue to reinforce and build cooperation with key European partners such as EUMETSAT, ECMWF and European Commission (AGRI, CLIMA, CNCT, DEFIS, INTPA, JRC, RTD, ENV), as well as with international space agency actors, UN organisations (e.g. FAO, UNEP, UNESCO, WMO) and International Financial institutions (e.g. ADB, WB, IMF).

Fostering a Community Approach to Science

Adopting a community and collaborative approach to science through the ESA Science Clusters aims at jointly addressing the major science challenges in a coordinated manner. The goal is to bring teams and projects together with different expertise, data and resources in a synergistic manner.

The approach shall be supported by a broad participation and direct engagement of the scientific community in ESA activities, through dedicated mechanisms, such as the new Earth System Science Hub as the centre for scientific collaboration, networking and open cooperative research with world-class scientists in Member States and worldwide.

As part of this strategy ESA will foster a strong and coordinated approach to science contributing to an effective European research area through a close coordination and alignment of scientific priorities with Horizon Europe through the ESA-EC Earth-System Science Initiative and other major national science funding programmes and institutions as well as promoting joint scientific actions with partner space agencies.

Strategic Objective 9: *Foster a community approach to science though dedicated mechanisms (e.g., ESA Science Clusters, Earth System Science Hub), promoting a continuous dialogue and wide participation of the scientific community to ESA activities at both European and international level, maximising synergies across teams and disciplines and ensuring a collective scientific contribution to address the Science Questions of this Strategy.*

Building strong STEM Education, training and outreach

STEM education and training programmes need to be reinforced to prepare the next generation of scientists and ESA EO practitioners and to engage early career scientists in EO research and in ESA Earth Action activities.

Strategic Objective 10: *Dedicate appropriate level of support to the preparation of the next generation of European EO scientists through dedicated EO training and education activities.*

ESA should maximise the outreach and dissemination of EO science results not only towards the scientific community (e.g., by advanced open science tools), but mainly towards the general public, policy makers, non-space experts and stakeholders, and especially towards the young generation through advanced immersive visualisation capabilities, interactive dashboards, and novel communication means.

Strategic Objective 11: *Maximise the outreach and communications of ESA EO scientific results toward the general public, policy makers and specially towards the younger generations.*

Exploring EO science links with Commercial Space

Commercial space missions represent a new and relatively unexplored source of data to support advances in our understanding of the Earth system. Hybrid public and commercial constellations have the potential to enhance both the temporal and spatial resolution, and integrating the data from commercial and institutional missions can enable more comprehensive and integrated analysis in response to the strategic science questions. The CSQs provide a useful reference to further explore the potential of commercial space missions not only by providing the scientific objectives and context, but also by specifying the geophysical information needs to address the questions. Requirements such as observation type, role and suitability of data products and commercial data provision, in addressing the science questions, need to be quantified and the feasibility of integrating scientific data quality metrics in a commercial solution needs to determined. This would allow the benefits of integrating available or future commercial EO data and services into the EO data ecosystem to be realised.

Strategic Objective 12*: To explore the complementary capabilities of commercial space as a new vehicle to accelerate and address science priorities.*

Harnessing Open Science through Digital Innovation

FAIR (Findability, Accessibility, Interoperability, and Reusability) foundational principles, together with Open Science and Open Innovation, provide a significant opportunity to collectively contribute and harness the power of cutting-edge digital technologies in delivering validated, trusted and actionable information. Working with diverse remote sensing data and research data management platforms throughout the "measure-understand-predict-decide-action cycle" is crucial to be able to effectively address the priority science questions. To this end, modern, powerful, and agile open infrastructures have become essential enablers for scientific research and applications supporting a wide range of sectors.

Building such solutions with a long-term perspective, supported by capacity building and wide and open education on FAIR and Open Earth Science, fosters institutional and scientific collaboration and promotes a scientific process that is both equitable and inclusive. Open as well as federated approaches to the enabling technologies and practices leads to infrastructures that are both are inherently more accessible, as well as resilient, sustainable and safe. However, they rely on interoperability, evolving standards and most importantly community participation. In fact, much of the essential underlying open-source supporting EO industry today relies on voluntary effort.

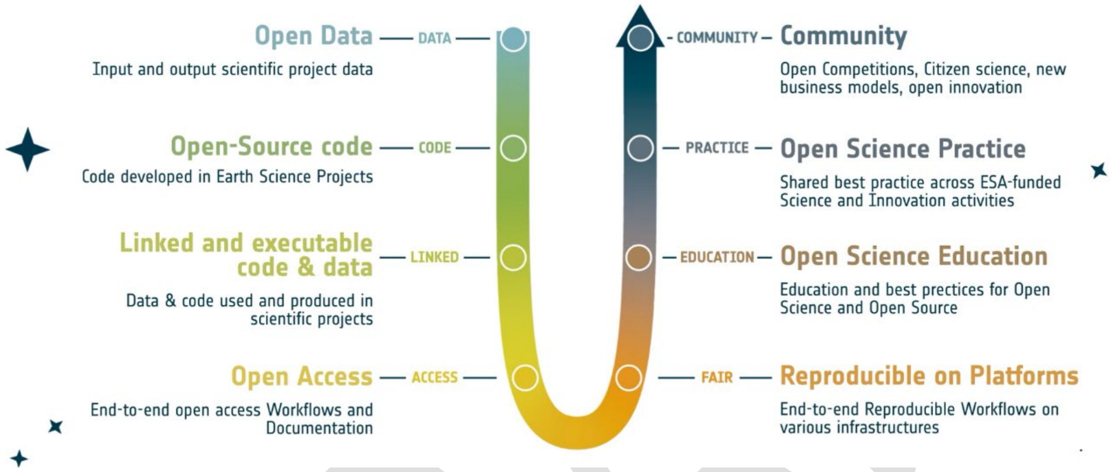

Figure 8. *Application of Open Science principles to stimulate and accelerate scientific progress and Open Innovation.*

The long-term sustainability of the open innovation ecosystem depends on the institutional support to grow capability, competitiveness and to educate. Supporting the evolution and growth of this ecosystem is therefore not just desirable but a necessity. Open innovation fosters a networked approach to the innovation process, maximising knowledge exchange, resource optimisation, cost reduction and sustainability. It also promises to maximise stakeholder engagement when combined with user-centric approaches, accelerating value creation and improving transparency and trust. A strong engagement is necessary through up-to-date policies, enabling technology, and inclusive partnerships. Such an approach will foster research data discoveries and for the resulting information to be FAIR and open to the maximum extent possible and/or as closed as necessary, while maintaining high standards of security and privacy.

Strategic Objective 13*: To foster the development of a culture of openness in EO science, applications and industry, and of a sustainable open innovation ecosystem.*

The multiplication of data sources from satellites, Unmanned Aerial Vehicle (UAV) or High-Altitude Pseudo Satellites (HAPS), combined with Internet of Things (IoT) holds the potential to reshape Earth Observation, offering new opportunities for science and entrepreneurship. Artificial Intelligence (AI), and Deep Learning have already demonstrated their value in maximising multidisciplinary exploitation of the growing big data resource. Strengthening and integrating evolving AI capabilities within ESA and the European data pipeline is therefore paramount to maximise the benefits of EO investments.

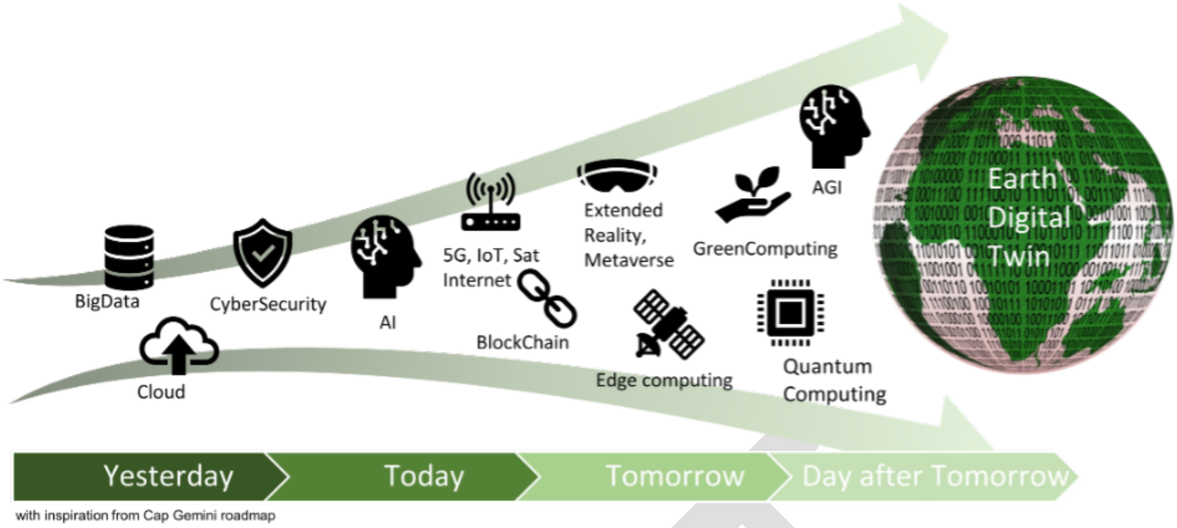

Figure 9. *Harnessing digital innovation and the enabling tools to develop an improved scientific understanding and representation of the Earth system as input to the Digital Twin framework.*

The combination of EO, societal data and IoT with the AI evolution and the availability of vast computational power, offered by hybrid High Performance Computing (HPC) – Quantum Computing (QC), offers immense opportunities to advance and improve Earth system modelling, revolutionising resource and hazard management and stimulate the EO downstream sector.

In terms of societal benefits, the evolution of EO cloud-based ecosystems promise more versatile capabilities that foster uptake and fuel EO-based science and lead towards operational value-adding on-demand services. This has the potential of lowering the adoption barrier for EO driven solutions by new users, including key decision makers.

Strategic Objective 14*: To develop and enhance European capabilities for harnessing digital innovation, particularly AI, to maximise the exploitation of EO data for scientific and socio-economic benefits.*

Assessing Progress

The ESA EO Science Strategy 2040 outlines a set of cross-cutting priority science questions which together with the identified strategic objectives can be employed as a framework for prioritising EO programme implementation.

Future programme implementation actions, such as the selection of EO missions, can be indexed or referenced to the Science Questions, such that scientific progress and output of the Programme can be tracked and assessed in relation to the degree to which the observation gaps and knowledge advancement objectives have been addressed or fulfilled, and/or in terms of the impact and short-term benefits.
Assessment of progress can be structured in along the lines of the four key areas of strategic action which have been defined, and in terms of the distribution of progress and achievements of activities addressing the selected priority Science Questions.

On this basis, it is proposed that the ideal time horizon for periodically revisiting progress assessments corresponds to the six-year timescale required to measure substantive scientific progress. This matches with the timespan of durability of the priority science questions and strategic priorities and defines the interval at which the content of the Strategy should optimally be revisited and reevaluated.

Appendix 1: *The 22 Science Questions and their Relevance to International Treaties, Agreements and Conventions*

(ID) Science Question		Paris Agreement	Convention on Biodiversity	Sustainable Development Goals	Sendai Framework	EU Green Deal
SQ1 CSQ1	**What anthropogenic and natural processes are driving the global carbon cycle?**	Major contribution to informing Art. 4 Mitigation and evaluating policy responses; Major contribution to Art. 5 on maintaining sinks and reservoirs, both terrestrial and ocean; Other contribution to Enhanced Transparency Framework and Global Stocktake	Informs Arts 6/7/8/9 pm measures, monitoring, in-situ conservation and ex-situ conservation	Major contribution to SDG 12 Climate Action	N/A	Contributes to policy goals Net Zero by 2050 and Clean, Affordable Energy
SQ2 CSQ2	**How has the land biosphere responded to human activity and climate change?**	Major contribution to informing Art 4 policy on climate state; Major contribution to Art. 5 on maintaining land/biosphere sinks and reservoirs; Potential to assist adaptation policy and Global Stocktake	Major contribution to Art 9 Ex-situ conservation; Inform/evaluate contribution to Arts 6, 7, 8, 11 and 13; Needed to assess impact of financing measures	Major contribution to SDG15 Life on Land; Informs policy goal on SDG12 Climate action	N/A	Contributes to Net Zero by 2050; Strong contribution to Ecosystems and Biodiversity policy
SQ3 CSQ3	**How has the ocean carbon cycle responded to**	Relevance to Art 4 Mitigation, reporting on climate state; Informs	Some relevance to Art 6 on measures for conservation; Some	Relevance to SDG12 Climate action and SDG13 Life below water	N/A	Some relevance to Net Zero by 2050

	anthropogenic CO2 and climate change?	Art 5 on ocean sink status and potential to assist policy delivery	relevance to Art 7 on identification and monitoring;			
SQ4 CSQ5	**What processes drive changes sea level in the coastal ocean?**	Some relevance to Art 4 on climate state and Art 5 ocean sinks; Strong contribution to Art 7 on adaptation and Art 8 Minimise loss and damage	Some relevance to Art 6/7/13 incl. impacts on conservation measures for coastal habitats	Strong relevance to SDG11 Sustainable cities and costal population/ development; Relevance to SDG12/13/14 pertaining to climate action, life on land and life under water;	Informing Priorities 1/2/3/4 for coastal risk assessment and adaptation policies; Informs financing of prevention measures	Informs urgency of Net Zero by 2050
SQ5 CSQ7	**How do coastal processes mediate exchanges between land, atmosphere and the open ocean ?**	Relevance to Arts 4/5/7/8	N/A	Some relevance to SDG13 Life below Water	N/A	N/A
SQ6 CSQ8	**How are coastal areas contributing to the global carbon cycle, and how are they responding to climate change and human pressures?**	Medium relevance to Art 4 mitigation; Some contribution to Art 5 maintaining ocean sink	Art 7/13 some relevance to Identification/ Monitoring and Public education	Some relevance to SDG13 Life below water	N/A	Indirect relevance to Net Zero policy
SQ7 CSQ20	**What are the key drivers for the mass balance change of the ice sheet, the ice shelves and the glaciers?**	Strong contribution to informing Art 4 Mitigation; Strong relevance to Art 7/8 on adaptation and minimising loss and damage; Strong public relevance	Art7 Identification and monitoring of Arctic habitat	Relevance to SDG12/13/15 Climate action and life on land/under the ocean	Indirect relevance to understanding disaster risk via to sea level	Informs Net Zero policy
SQ8 CSQ21	**What are the dominant physical processes that drive**	Informs Art 4 Mitigation on climate state and sensitivity; Indirect	N/A	N/A	N/A	Indirect relevance to Net Zero policy

	the sea ice thermo-dynamic state and variability	contribution to Art 5/& on adaptation, loss and damage				
SQ9) CSQ24	**Determine the relationship between changes in Polar regions and global climate variability**	Relevance to Art 4/5 on mitigation and maintaining sinks/reservoirs	N/A	Link to SDG12 Climate action	N/A	Indirect relevance to Net Zero policy
SQ10) CSQ25	**How does the cryosphere impact on Polar ecosystems, and how is the changing climate altering these feedbacks?**	Informs Art 4 mitigation policy; Some relevance to Art 5 and 7	Strong relevance across all CBD Articles; Strong role for public education and awareness	Relevance to SDG14 Life on Land	N/A	Relevance to Ecosystems and biodiversity policy
SQ11) CSQ33	**How does the solid Earth deform under present and past ice loads and what does it tell us about its rheology?**	N/A	N/A	Relevance to SDG11 Sustainable cities and SDG14 Life on Land	Strong relevance to all Sendai Priorities	N/A
SQ12) CSQ35	**Can we quantify erosional processes of drainage basins and the resulting sediments discharge to the oceans?**	N/A	N/A	Some relevance to SDG14 Life on Land	Good relevance to all Sendai Priorities	N/A
SQ13) CSQ36	**Can we observe, model and forecast the deformation processes during the seismic cycle at plate boundaries, from pre- to post-seismic phases and during the inter- seismic phase ?**	N/A	N/A	Relevance to SDG11 Sustainable Cities and SDG14 Life on Land	Strong relevance across all Sendai priorities	N/A

SQ14) CSQ38	**How does Earth's crust evolve in interaction with internal geodynamic processes, and how does this reshape the Earth's surface over the long-term?**	N/A	N/A	Relevance to SDG11 Sustainable Cities and SDG14 Life on Land	Strong relevance across all Sendai priorities	N/A
SQ15) CSQ43	**What are the main coupling determinants between Earth's energy, water and carbon cycles?**	Very strong relevance for Art 4 Mitigation	N/A	N/A	N/A	Relevance to Net Zero by 2050
SQ16) CSQ44	**How important are anthropogenic influences on the water cycle, and how accurately can we predict them?**	Strong relevance to Art 4 Mitigation; Contributes to Art 7/8 on adaptation and minimising loss and damage	Useful input to all Article of CBD	Informs SDG6 on clean water and sanitation; Strong input to SDG11/12/13 due to impact on life and society	Very strong contribution to all Sendai priorities due to the high % of hydro-met losses	Links with Net Zero policy and Ecosystems/ Biodiversity policy
SQ17) CSQ45	**How can we improve uncertainties for climate sensitivity while improving estimates of the internal flow of energy within the climate system?**	Very strong relevance to Art4 on climate state and sensitivity	N/A	N/A	N/A	Indirect link to Net Zero policy
SQ18) CSQ46	**How does the Earth energy imbalance and Earth heat inventory change over time and why?**	Very strong relevance to Art4 on climate state and sensitivity	N/A	N/A	N/A	Indirect link to Net Zero policy
SQ19) CSQ48	**How can we improve the monitoring and understanding of**	Very strong relevance to Art4 on climate state and sensitivity	N/A	N/A	N/A	Indirect link to Net Zero policy

	planetary heat exchange at regional scale?					
SQ20) CSQ51	**What are the mechanisms that couple the lithosphere, atmosphere and ionosphere, and can they be modelled and monitored with adequate to support hazard risk management ?**	N/A	N/A	N/A	Informs all Sendai Priorities	N/A
SQ21) CSQ55	**What are local patterns of ecosystem structure composition and functions worldwide?**	Informs most Articles of the Paris Agreement	Strong relevance across all Articles of the CBD	Strong link to SDG14 Life on land; Relevance to SDG12 Climate action	N/A	Strong relevance to Ecosystems and Biodiversity policy
SQ22) CSQ56	Ecosystems transition	Informs most Articles of the Paris Agreement	Strong relevance across all Articles of the CBD	Strong link to SDG14 Life on land; Relevance to SDG12 Climate action	N/A	Strong relevance to Ecosystems and Biodiversity policy

Appendix 2: Science Questions & Relevance to National Policies

Science Question		**Energy**	**Environment**	**Agriculture, Food security**	**Transport & infrastructure**	**Civil Protection & humanitarian aid**	**Public Health**
SQ1 CSQ1	Global carbon cycle	Informs Net Zero transition and emission reduction policy	N/A	N/A	N/A	N/A	N/A
SQ2 CSQ2	Land biosphere responses	N/A	Strong relevance to Nature and Biodiversity policy; Relevance to Soil and Land policy; Some impact on urban environment	Farm to fork emissions; Increased production	N/A	N/A	Habitat change linked with vector borne disease risk;
SQ3 CSQ3	Ocean carbon cycle	Informs Net Zero transition	N/A	Sustainable fisheries	N/A	N/A	N/A
SQ4 CSQ5	Coastal sea level	Informs energy transition; Transition risk to renewable assets; Informs Energy security	Informs marine and costal environment policy; Impact on Urban environment policy (risk)	N/A	Informs risk to land transport; Informs maritime transport infrastructure and other infrastructure categories (e.g., ports)	Strong relevance to understanding disaster risk; Contributes to enhanced risk preparedness and increase risk resilience	N/A
SQ5 CSQ7	Coastal process mediation	Informs and assists coastal renewable sources (tide, wind)	Informs marine and costal environment policy	Informs sustainable fisheries	N/A	Informs risk understanding, preparedness and resilience	N/A
SQ6 CSQ8	Coastal carbon cycle	Informs and assists coastal renewable sources (tide, wind)	Informs marine and costal environment policy	Informs food security, sustainable	N/A	N/A	N/A

					fisheries and increased production			
SQ7 CSQ20	Ice mass balance	Informs and assists coastal renewable sources (tide, wind)	N/A	N/A	Impacts on maritime transport; Inform risk to supporting infrastructure	Informs risk understanding and preparedness, esp to maritime communities	N/A
SQ8 CSQ21	Sea ice themodynamics	Informs renewable energy transition	N/A	N/A	N/A	N/A	N/A
SQ9 CSQ24	Polar climate relationship	Informs energy transition	N/A	N/A	N/A	N/A	N/A
SQ10 CSQ25	Polar ecosystem impacts	Informs energy transition	Informs Nature and Biodiversity policy	N/A	N/A	N/A	N/A
SQ11 CSQ33	Solid Earth deformation	Informs transition risk, risk to assets	Relevance to urban environment policy	N/A	Informs risk to land transport and supporting infrastructure	Strong contribution to risk understanding, preparedness and resilience	N/A
SQ12 CSQ35	Erosional processes	Informs transition risk, risk to assets	Relevance to urban environment policy; Good link to Soil and land policy	N/A	Informs risk to land transport and supporting infrastructure	Some contribution to risk understanding, preparedness and resilience	N/A
SQ13 CSQ36	Seismic deformation processes	Informs transition risk, risk to assets	Relevance to urban environment policy	N/A	Informs risk to land transport and supporting infrastructure	Strong contribution to risk understanding, preparedness and resilience	N/A
SQ14 CSQ38	Earth's crust dynamics	Informs transition risk, risk to assets	Relevance to urban environment policy	N/A	Informs risk to land transport and supporting infrastructure	Strong contribution to risk understanding, preparedness and resilience	N/A
SQ15 CSQ43	Coupled cycles	Net Zero transition; Informs emission reduction strategy	Relevant to Marine & coastal environment; Relevance to Water	Informs farm to fork emissions, food security and increased production	Informs risk to land, maritime and air transport	N/A	Improved understanding of vector borne, respiratory and

			policy and Soil and land policy				temperature related health risks
SQ16 CSQ44	Water cycle	Informs renewable energy transition; Informs transition risk, risk to assets	Relevant to Marine & coastal environment; Strong relevance to Water policy and Soil and land policy	Strong input to food security and increased production; Support to understanding farm to fork emissions	Risk of inundation to all forms of transport and supporting infrastructure	Improved weather and flood risk models improve risk understanding, preparedness and resilience	Strong contribution to improved understanding of water borne, health risks
SQ17 CSQ45	Climate sensitivity	Net Zero transition; Informs emission reduction strategy	Informs water policy	N/A	N/A	N/A	N/A
SQ18 CSQ46	Earth energy imbalance	Net Zero transition; Informs emission reduction strategy	N/A	N/A	N/A	N/A	N/A
SQ19 CSQ48	Planetary heat exchange	Net Zero transition; Informs emission reduction strategy	N/A	Informs food security and sustainable fisheries policy	N/A	N/A	Links with respiratory and temperature related health risks
SQ20 CSQ51	Coupled litho-,atmo-,iono-sphere	N/A	N/A	N/A	Impacts on air transportation	Some contribution to risk understanding, preparedness and resilience	N/A
SQ21 CSQ55	State of land ecosystems	N/A	Strong contribution to Nature and Biodiversity policy; Contribution to soil and land policy	Informs increased production and food security policy	N/A	N/A	Range of links ecosystem function and pest and pathogen disease risk
SQ22 CSQ56	Ecosystems transition	N/A	Strong contribution to Nature and Biodiversity policy; Contribution to soil and land policy; Informs marine and coastal policy	Informs increased production and food security policy	N/A	N/A	Range of links ecosystem function and pest and pathogen disease risk

Appendix 3: *Policy and benefits categories*

Policy / benefit domain	**Components**	**Major international treaties/ agreements**	**Relevant international bodies/agencies**	**UN SDGs**	**EU DGs and EAs**
Energy and climate action	- Energy policy - Climate mitigation - Climate adaptation - Climate finance	UNFCCC Paris Agreement REDD	IPCC IEA TCFD WB/IADB/ADB/IMF	7 Affordable and clean energy 13 Climate action 15 Life on land	ENER CLIMA CINEA
Environment	- Nature and biodiversity - Air quality and ozone - Water quality - Forestry - Coastal & marine environment	CBD Ramsar Convention Montreal Protocol	UNEP IPBES TNFD	6 Clean water and sanitation 13 Climate action 14 Life below water 15 Life on land	ENV
Agriculture, fisheries and food security	- Food production - Food supply chain - International commodities - Fisheries	Common Agriculture Policy	UN FAO UN WFP IFAD IMO	2 Zero hunger 13 Climate action	AGRI MARE (Fisheries)
Transport and infrastructure	- Air/maritime/land transport - Smart cities and urban - Regional development	SOLAS, MARPOL	IMO ICAO IBRD WB/IADB/ADB/IMF	13 Climate action 14 Life below water 11 Sustainable cities and communities	MOVE MARE (Maritime transport) REGIO
Civil protection and humanitarian aid	- Disaster risk reduction/resilience - Emergency response - International humanitarian response	Sendai Framework	UN HCR UN OCHA UN DP ICRC/IFRC	15 Life on land	ECHO
Public health	- Health - Social wellbeing - Disease risk - Accident and emergency		WHO UN DP	3 Good health and well being 15 Life on land	SANTE HERA

Appendix 4: *International Agreements and Treaties and areas impacted by EO Science*

Treaty/Agreement	**Policy goals/objectives**
Paris Agreement (following Heggelin et al)	Article 4. Mitigation (incl Climate state and Climate sensitivity) Article 5 Maintaining sinks and reservoirs (incl land/biosphere and ocean) Article 7 Adaptation Article 8 Minimizing loss and damage Article 12 Public engagement Article 13 Enhanced Transparency Framework Article 14 Global Stocktake
Convention on Biodiversity (CBD)	Article 6. General Measures for Conservation and Sustainable Use Article 7. Identification and Monitoring Article 8. In-situ Conservation Article 9. Ex-situ Conservation Article 11. Incentive Measures Article 13. Public Education and Awareness
UN Sustainable Development Goals (SDGs)	SDG1 No poverty SDG2 Zero hunger SDG3 Good health & wellbeing SDG4 Quality education SDG5 Gender equality SDG6 Clean water, sanitation SDG7 Affordable, clean energy SDG8 Work & economic growth SDG9 Industry, innovation SDG10 Reduced inequalities SDG11 Sustainable cities SDG12 Climate action SDG13 Life below water SDG14 Life on land
Sendai Framework on Disaster Risk Reduction	Priority 1: Understanding disaster risk Priority 2: Strengthening disaster risk governance to manage disaster risk Priority 3: Investing in disaster risk reduction for resilience Priority 4: Enhancing disaster preparedness for effective response
EU Green Deal	Net Zero by 2050 (incl Climate Law) Clean, affordable, secure energy Circular economy Energy efficiency Zero pollution Ecosystems and biodiversity (incl EU Taxonomy) Farm to fork' sustainable food system Sustainable mobility