SPACE GENERATION ADVISORY COUNCIL

Saving Our Future on Earth Through Our Presence in Space

Recommendations from the Young Generations on the Role of Space for Climate Action

Official SGAC Policy Position

Approved by the Executive Committee on October 30th, 2022

SPACE GENERATION ADVISORY COUNCIL

Developed by the **SGAC Space for Climate Action Policy Division** under the **Space Generation Advocacy and Policy Platform (SGAPP)**

Sahba El-Shawa
Co-lead/Editor

Giulia Bordacchini
Co-lead

Jordan Stone

Giulia Costella

Milica Milosev

Lisa Lacroix

Ivan Fino

In support of the United Nations Programme on Space Applications
c/o European Space Policy Institute (ESPI), Schwarzenbergplatz 6, Vienna A-1030, AUSTRIA,
sgapp@spacegeneration.org, + 41 1718111830

Abstract

With increased awareness of environmental sustainability and how it affects our daily lives, we are seeing a much greater emphasis placed on sustainable practices and mitigating climate change. Space technologies, as well as the culture surrounding them, have influenced societal views of environmentalism, leading to a widespread belief in the necessity of sustainable development. Not only does this include Earth Observation satellites that allow us to monitor our changing planet, but also spin-off technologies that can be leveraged to address the climate crisis, by adapting and improving the quality of life on Earth. Space exploration, and the advancement of knowledge that comes with it, has far-reaching effects into many aspects of our global fight against climate change.

In September 2021, the Secretary General of the United Nations released "Our Common Agenda" outlining the priorities to be tackled during the next 5 years. Climate action and youth engagement are at the top of this list. As members of the younger generations in the Space Generation Advisory Council (SGAC) in support of the United Nations Programme on Space Applications, we believe that the space community should be at the forefront of the fight against climate change. To take action in this critical area, the Space Generation Advocacy and Policy Platform (SGAPP) established a policy working group on Space for Climate Action. Over the course of 2022, this specialised policy division has worked to develop an SGAC policy report outlining the views and proposals of the space generation on how space could, and should, contribute to climate action.

The purpose of this report is to share the main findings and conclusions of the research undertaken by the Space for Climate Action Policy Division, which cover the following topics: Environmental Impacts of Space, Space Law and Policy Development, Space Technology and Earth Observation Data Applications, Education and Outreach for Climate Action, Ethical and Political Considerations, as well as Green Economy, Finance, and New Space. The recommendations target various stakeholders spanning Scientific Community and Academia, Governments and Policy Makers, and Commercial Industries.

This report was approved by the Executive Committee of the SGAC as the official policy position of the organisation in October 2022. As such, it will be disseminated across various platforms with subsequent work from SGAPP in its implementation during the upcoming advocacy stage, in order to enable the adoption of these recommendations.

Table of Contents

Acronyms

COPUOS	Committee for the Peaceful Uses of Outer Space
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
GCOS	Global Climate Observing System
GHG	Greenhouse Gas
GIS	Geographical Information System
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite Systems
LCA	Life Cycle Assessment
NASA	National Aeronautics and Space Administration
OE	Overview Effect
SDG	Sustainable Development Goal
SGAC	Space Generation Advisory Council
SGAPP	Space Generation Advocacy and Policy Platform
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNOOSA	United Nations Office for Outer Space Affairs
WMO	World Meteorological organisation

1. Introduction

Space technologies have revolutionised our lives in countless ways. From the microchips in our phones, to global navigation systems, and our understanding of Earth's climate - space has developed knowledge and advanced technology to unimagined heights over the past 30 years. In 2004, the United Nations Framework Convention on Climate Change (UNFCCC) established the Implementation Plan for the Global Climate Observing System (GCOS), highlighting the importance of satellite data in obtaining systematic observations.[1] Of the 54 Essential Climate Variables (ECVs) identified, satellite data can help address approximately 60% of the variables.[2] Satellites enable us to monitor Earth's atmosphere, oceans, and surface temperatures at very high spatial and temporal resolutions. This data has allowed us to enhance our models and predictions of climate change, assess the effectiveness of our mitigation and adaptation solutions, and predict the impacts of our current trajectory.

Knowledge advancements from space exploration have widespread and profound impacts on our society. Increased awareness of the importance of environmental sustainability and its impacts on daily life are driving a revolution of sustainable practices that can mitigate climate change. The space community are now key players in achieving the UN's Sustainable Development Goals (SDGs). This is clearly evidenced by the remarkable value of Earth observation satellite systems, spin-off tech from space technology, and the green movements inspired by the fresh perspectives that outer space grants. In fact, the UN Space2030 Agenda was created for this very reason, showing that space is a driver for sustainable development.[3]

While countries around the world are aiming to reduce their emissions, it is clear that we are not meeting targets fast enough. As a result, vulnerable populations are suffering. In the coming years, we will see the adverse effects of the climate crisis continue to rise, and we need to be prepared. Space infrastructure can ease the burden with early warning systems that can detect natural disasters before they occur and alert those in danger. 2030 is coming up fast. We need all sectors, governments, organisations, and individuals to commit to achieving the SDGs. The lives of people and ecosystems around the world are affected by what we do with the knowledge we have. Our goal in developing the Space Generation

[1] World Meteorological organisation (WMO), https://public.wmo.int/en (accessed date 30.06.22)
[2] European Space Agency (ESA), https://climate.esa.int/en/evidence/what-are-ecvs/ (accessed 15.06.22)
[3] United Nations, The "Space2030" Agenda: space as a driver of sustainable development, General Assembly 76th session, 25 October 2021 https://www.unoosa.org/oosa/oosadoc/data/resolutions/2021/general_assembly_76th_session/ares763.html (accessed 06.06.22)

Advisory Council's official policy position is to maximise the applications and synergies between space exploration and sustainable development here on Earth.

As we accelerate our plans to go back to the Moon and beyond, it is more important than ever to clarify the driving force behind our exploration. We must pay particular attention to how space activities impact our lives on Earth - whether positively or negatively - and ensure that we continue to go to space for peaceful purposes and for the benefit of all humankind.

Scope and Limitations

In addition to the specialised research areas explored in this paper, the research team concentrated on collecting and analysing priorities and actions of two major global space agencies throughout this paper: NASA and ESA. Their collaborative approach was used to shed light on best practices that are increasingly being used for a wide spectrum of global concerns, including climate change. However, this is a limitation of the paper, as other agencies and organisations within the space sector around the world are involved in this field. An important element of this transdisciplinary effort is an attempt to include the highest number of international stakeholders by collecting their activities, projects, and initiatives to embrace the vast number of approaches potentially leading to new collaborations (or strengthening existing ones) supporting the cause. Therefore, future work will build upon the existing recommendations in order to guide their implementation in various countries and regions, based on their existing capabilities and national priorities.

Climate Change and Sustainability

It is essential to first understand what the terms of *climate change* and *sustainability* actually represent. Our Earth is surrounded by an atmosphere, a very thin but extremely active layer of gas. The atmosphere captures approximately 77% of the Sun's ultraviolet radiation and emits it in all directions, some of it to the planet's surface. This pushes up the balance between incoming and outgoing energy and increases the temperature, thus causing a natural and extremely important effect, the greenhouse effect. Thanks to it, the Earth's average temperature has a current value of 13.9 degrees above zero.[4] This is a decisive detail: at twenty degrees below zero, as on the Moon which has no atmosphere, there would

[4] T. Sharp, V. Stein, What is the average temperature on Earth?, 25 February 2022, https://www.space.com/17816-earth-temperature.html (accessed 06.06.22.)

be no liquid water on the planet, only ice. Therefore, oceans, rivers, life as we know it, owe their possibility of existence to the greenhouse effect.

However, the greenhouse effect is also causing the climate crisis due to an increase in gases responsible for the effect, primarily carbon dioxide (CO_2). "The annual rate of increase in atmospheric carbon dioxide over the past 60 years is about 100 times faster than previous natural increases, such as those that occurred at the end of the last ice age 11,000-17,000 years ago."[5] According to the Intergovernmental Panel on Climate Change (IPCC) latest report, there is no doubt that human influence has caused the warming of the atmosphere, ocean and land (Table 1).[6]

Table 1: Main ways humans have influenced the climate crisis

Driver	Description
Electricity	Reliance on fossil fuels to generate electricity.
Transportation	Reliance on fossil fuels to power transportation.
Heat	Heat is mostly produced by businesses and homes, by burning fossil fuels and handling waste.
Deforestation	Since 1990, forests have shrunk globally by approximately 200 million acres.[7]
Agriculture and livestock farming	Greenhouse gas emissions from agriculture mainly come from livestock such as cows, agricultural soils, and rice production.

In particular, it is very likely that humans are the main drivers of the global retreat of glaciers and decrease in Arctic sea ice.[8] But glacier retreat is not the only negative effect of climate change, since the entire biosphere has been affected, with climate zones shifting toward the poles in both hemispheres. Moreover, the chance of compound extreme events has increased: we are witnessing more heatwaves and droughts on a global scale and

[5] Lindsey, Rebecca. "Climate Change: Atmospheric Carbon Dioxide," 2022. Accessed July 11, 2022. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.

[6] H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (Eds.), IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2022. In Press.

[7] FAO. "The State of the World's Forests 2020." Www.Fao.Org. Accessed July 11, 2022. http://www.fao.org/state-of-forests/en/.

[8] V. Masson-Delmott., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (Eds.), IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2021. In press

compound flooding in some locations. Another effect is the decrease in land monsoon precipitation, attributed by IPCC to human-caused Northern Hemisphere aerosol emissions. The list below summarises some of the direct effects of climate change on Earth:

- Increase in the temperature of the planet
- Localised increases or decreases in precipitation
- Increase in the frequency and intensity of extreme weather events
- Increase in the risk of desertification
- Decrease in glaciers and perennial snows
- Sea level rise
- Loss of biodiversity
- Spread of diseases
- Problems in food production

In order to tackle these major effects, every country needs to design and implement sustainable strategies that prevent, adapt or mitigate the rise of environmental migrants, ecological changes and socio-economic impacts.

The definition of sustainability is very clear - meeting our own needs without compromising the ability of future generations to meet their own needs. The concept of sustainability is a relatively new idea, but the movement as a whole has roots in social justice, conservationism, internationalism and other past movements with rich histories. In 1983, the United Nations tapped former Norwegian prime minister Gro Harlem Brundtland to run the new World Commission on Environment and Development. After decades of effort to raise living standards through industrialization, many countries were still dealing with extreme poverty. It seemed that economic development at the cost of ecological health and social equity did not lead to long-lasting prosperity. It was clear that the world needed to find a way to harmonise ecology with prosperity. After four years, the “Brundtland Commission” released its final report “Our Common Future”.[9] In this report, the Commission successfully unified environmentalism with social and economic concerns on the world’s development agenda and defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

[9] G.H. Brundtland, Our Common Future: Report of the World Commission on Environment and Development, UN-Document A/42/427, Geneva, 1987, http://www.un-documents.net/ocf-ov.htm (accessed 11.07.22.)

Looking at the previous definitions we can understand that sustainability is a societal goal with three pillars: environmental, economic and social.[10]

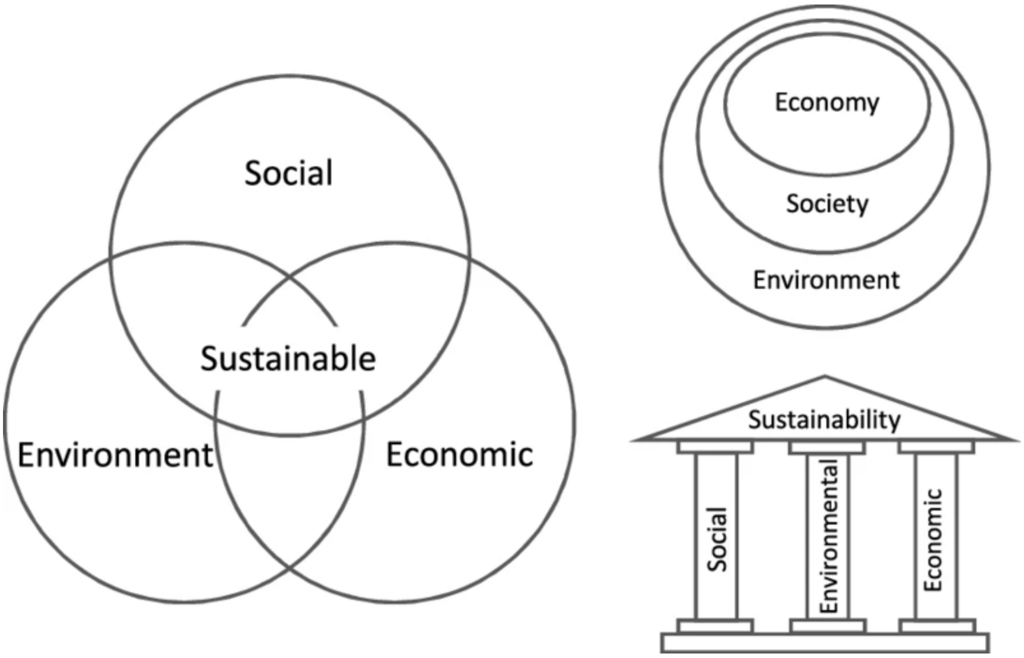


Figure 1. Left, typical representation of sustainability as three intersecting circles. Right, alternative depictions: literal 'pillars' and a concentric circles approach.

Environmental sustainability: Ecological integrity is maintained, all of earth's environmental systems are kept in balance while natural resources within them are consumed by humans at a rate where they are able to replenish themselves.

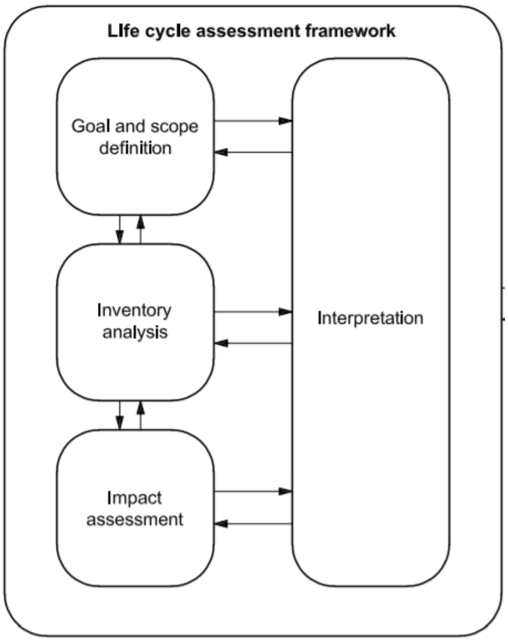
Economic sustainability: Human communities across the globe are able to maintain their independence and have access to the resources that they require, financial and other, to meet their needs. Economic systems are intact and activities are available to everyone, such as secure sources of livelihood.

Social sustainability: Universal human rights and basic necessities are attainable by all people, who have access to enough resources in order to keep their families and communities healthy and secure. Healthy communities have just leaders who ensure personal, labour and cultural rights are respected and all people are protected from discrimination.

[10] Purvis, B., Mao, Y. & Robinson, D. Three pillars of sustainability: in search of conceptual origins. Sustain Sci 14, 681–695 (2019). https://doi.org/10.1007/s11625-018-0627-5

Environmental Impacts of Space Activities

Although this report focuses on the ways in which space can benefit climate action and sustainability on Earth, it is important to also account for the environmental impacts caused by space activities. One initiative that is pioneering this area of research is the European Space Agency's Clean Space office.[11] Since its inception in 2012, the EcoDesign branch of CleanSpace has been leading its field of expertise by quantifying the impacts to various environmental indicators using the ISO standardised methodology of Life Cycle Assessment (LCA). The objective of EcoDesign is to reduce the environmental impacts of the space sector by developing green technologies and applying LCA to space mission design. ESA also supports the development of environmental reporting guidelines in the European space industry, which is led by the European Commission.

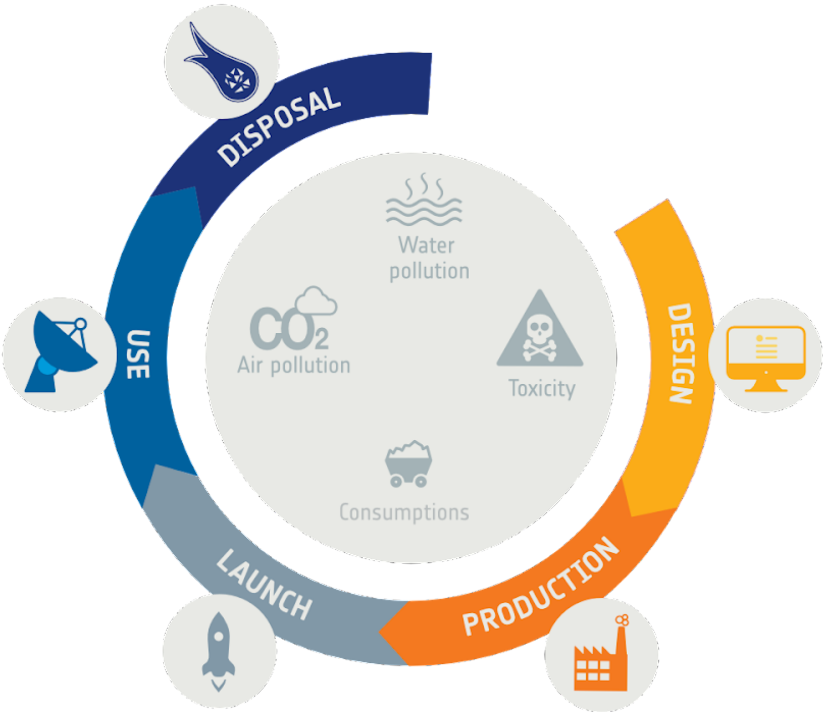


The LCA methodology was originally developed from energy analysis in the 1970s, but has since become all-encompassing and what is called "cradle-to-grave" i.e. taking into account the entire life cycle of a system, including resource requirements, emissions, and generated waste. Increasingly, LCA has become one of the core elements of environmental policy around the world.[12] LCA was standardised between 1990 and 2000, driven by the Society of Environmental Toxicology and Chemistry (SETAC) as well as the International organisation for Standardization (ISO). The two main ISO standards covering LCA are ISO 14040 and ISO 14044, outlining its principles, framework, requirements, and guidelines

As space is a very unique sector, some adaptations were needed in order to apply LCA to space. The life cycle of a space mission follows specific stages which require special considerations. ESA has pioneered the analysis and reduction of environmental impacts within the space sector, and this methodology was captured in an ESA LCA Handbook, which

[11] El-Shawa, S., 2020. Clean Space: Assessing, Mitigating, and Remediating the Environmental Impacts of Space Activities (ISU internship report). Illkirch-Graffenstaden (France) : International Space University, 2020.
[12] J.B. Guinée, R. Heijungs, G. Huppes, A. Zamagni, P. Masoni, R. Buonamici, T. Ekvall, and T. Rydberg, Life Cycle Assessment: Past, Present, and Future, Environ. Sci. Technol. (2011) 45, 1, 90–96.

was published in 2017. Dedicated studies were also performed which resulted in space-specific LCA datasets which were compiled in an ESA LCA Database (DB).



Previous LCA studies at ESA have examined both spacecraft and launchers, and identified the environmental impact in terms of various environmental indicators. In the past years, ESA has also included environmental requirements in projects such as Copernicus, Ariane 6, and Galileo. These projects and other technology developments at ESA are leading to multiple LCA datasets, making the database a fundamental tool for the space sector to comply with those requirements. The goal of the ESA LCA DB and handbook is to harmonise information from a variety of sources in the space sector and host them in a centralized place, in order to make them available to all European stakeholders and facilitate future LCA studies.

When assessing the environmental impacts of a space mission or project, a wide variety of indicators are considered. These indicators are driven by different types of impacts, and depending on the indicators chosen, the models can vary greatly. The following tables show an overview of some of the impact indicators considered in a comprehensive LCA.

Table 2 - Environmental impact indicators in ESA LCA handbook

Abbreviation	Impact Category	Unit	Source/LCIA method
GWP	Global Warming potential (100 years)	kg CO2 eq	IPCC
ODEPL	Ozone Depletion	kg CFC-11 eq	ODPs of WMO, 1999
HTOXc	Human toxicity (cancer and non-cancer)	CTUh	USEtox
HTOXnc			
FWTOX	Freshwater ecotoxicity	CTUe	
MWTOX	Marine aquatic ecotoxicity	kg 1,4-DB eq	CML2002
ADEPLf	Fossil resources depletion	MJ	
ADEPLm	Mineral resources depletion	kg Sb eq	
MDEPL	Metal resources depletion	kg Fe eq	ReCiPe
PCHEM	Photochemical ozone formation	kg NMVOC eq	
PMAT	Particulate matter formation	kg PM10 eq	
FWEUT	Freshwater eutrophication	kg P eq	
MWEUT	Marine eutrophication	kg N eq	
IORAD	Ionizing radiation	kg U235 eq	
ACID	Air acidification	kg SO2 eq	CML2002

Table 3 - Flow indicators in ESA LCA handbook

Abbreviation	Impact Category	Unit	Source/LCIA method
WDEPL	Gross water consumption	m3	Ecoinvent
PRENE	Primary energy consumption	MJ	
Ad hoc indicators	Mass disposed in ocean	kg	Calculated from primary data to approximate impacts of launchers
	Mass left in space		
	Al2O3 emissions to air		

The aforementioned indicators are used by ESA Clean Space and its contractors for LCA analysis. It is essential to harmonise these indicators, particularly to perform comparisons on different models. Note that the space debris indicator is under development, and as such it is not yet included in the ESA handbook methodology or LCA assessments.

Another consideration is the environmental impact of spacecraft testing. This is not currently considered by ESA Clean Space, and generally overlooked in the industry. Due to the requirement for comprehensive testing of spacecraft and , due to the large cost and time investments involved in developing these projects, it is unlikely that the tests themselves would be reduced. However, by considering the consumption and impacts involved in the different types of testing, we can develop more efficient ways of testing spacecraft. Following a review of the European Cooperation for Space Standardization (ECSS) testing requirements for spacecraft in ECSS-E-ST-10-03C, the typical tests performed and the factors which may influence their impacts were identified.[13] The main factors believed to influence these impacts are energy consumption and material consumption. Additionally, it is important to take into account the models which are created for testing purposes, but are not flown. A general summary of the tests and models identified, as well as some additional considerations can be found in the following table.

Table 4 - Summary of spacecraft testing, models, and additional considerations

Type of Testing	Spacecraft Models	Additional Considerations
Environment (Thermal, Humidity, Pressure) including Vacuum testing and cycling	Engineering model	Duration, energy consumption, and material consumption of different tests
Acceleration (steady state) and static load	Structural-thermal model	Labor required during and after testing (including number of workers and visual inspection)
Sinusoidal and random vibration	Qualification model	Payload-specific tests
Acoustic noise, microvibration, and audible noise (for crewed elements)	Proto-flight model	The number of times tests are repeated on different models
Shock and strain (mechanical)	Flight-spare model	Required infrastructure such as cleanrooms and facilities

[13] ECSS-E-ST-10-03C Space engineering: Testing. ESA-ESTEC Requirements & Standards Division, Noordwijk, 2012. http://everyspec.com/ESA/download.php?spec=ECSS-E-ST-10-03C.048162.pdf (accessed 20.06.22)

Solar flux and infrared flux	Flight model	Facility conditions (e.g. specific temperature and humidity)
Leakage		Transportation of equipment and staff during testing
Electromagnetic Compatibility (EMC)		Different testing requirements depending on component TRL
Electrostatic Discharge (ESD)		Waste treatment and recycling, or hazardous wastes

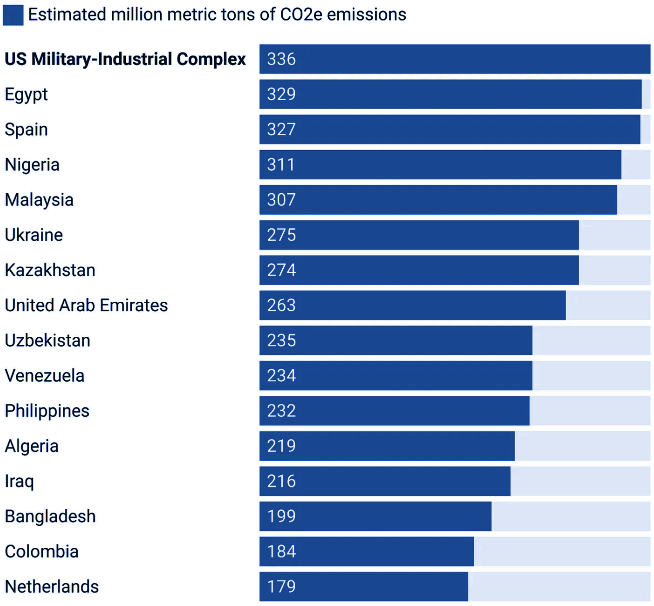
With regards to the impacts of launchers, pollution from rocket fuel is typically the first issue people consider. However, it is not necessarily the largest source of environmental impacts. Namely, the materials used in structure production have the highest impact on mineral resources depletion. Conversely, global warming potential is mainly caused by these material production facilities, which produce the largest greenhouse gas emissions. Other impact categories such as air acidification or water use relate to the industrial consumption and manufacturing processes. Finally, the impacts of solid rocket motors relate directly to the propellant burn, which causes an impact on global warming potential and ozone depletion.

In addition to launcher LCAs, ESA studies have been carried out on the atmospheric impact of the launch event itself on ozone depletion. These propellant burning studies have shown that impacts on ozone depletion are due to the alumina (Al_2O_3) particles which remain in the atmosphere after the launch event. An ongoing area of research is aiming to characterise the impact of these particles and relate them to factors such as particle or engine size, propellant type, and launch trajectory. Further work is required in this area.

Finally, it is worth noting that regardless of all these impacts caused by space projects and missions, the largest environmental impact by far stems from the "defence" sector of the space and defence industry. In 2018, the United States military industrial complex (MIC) produced more carbon emissions than entire countries.[14] Amongst the 196 countries the World Bank ranked by greenhouse gas emissions in 2018, the US MIC came in at

[14] N.C. Crawford, Pentagon fuel use, climate change, and the costs of war, Watson Institute, Brown University, 2019.

25th-highest, polluting more than 171 countries (see following figure).[15] As more wars and military bases are funded, this impact only increases. The MIC includes major aerospace entities, such as Boeing, Lockheed Martin, and Raytheon to name a few. The implications of this sector of activity within the "space and defence" industry are far larger than what is typically considered in the environmental impacts discussion. To significantly reduce the space sector's contributions to environmental detriment, a necessary and important step is decoupling aerospace exploration activities from military activities.



Country greenhouse gases for 2018 via World Bank. Military, military industry output for 2018, 2017 via Neta Crawford, "Pentagon Fuel Use..." (2019), Costs of War project.
Chart: Stephen Semler (@stephensemler) • Created with Datawrapper

Recommendations

- harmonisation of environmental impact assessments across space agencies and private institutions
- Development of a space debris indicator and characterising the environmental impact of spacecraft demise
- Characterising the environmental impact of rocket launches and propellant burn in the atmosphere
- Streamlining environmental impact assessment into the requirements of ongoing space missions, as well as future projects
- Decoupling defence and space, in order to reduce militarization as well as the significant detrimental social and environmental impacts associated with it

[15] The World Bank, Total greenhouse gas emissions (kt of CO2 equivalent), Climate Watch 2020, GHG Emissions, World Resources Institute, Washington, DC, 2020, https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE?most_recent_value_desc=true (accessed 03.06.22.)

2. Policy and Law

Environmental conservation and space exploration are more similar and interlinked than what may initially be assumed. This section provides an overview and traces the interconnections between the current international legal regimes in space and environmental law. From a space sector perspective, we aim to better address environmental impacts by providing an overview of the current international legal scenario to reveal potential improvements and identify the best practices. Furthermore, it aims to suggest applications, intertwined with all the recommendations that will follow in the upcoming sections, which could progress environmental protection and strengthen the knowledge on the potentiality of space technologies and application for mitigation, prevention, and early warning purposes, including management of natural disasters.

A variety of non-binding guidelines, policies, regulations, and norm-setting strategies used in international environmental management are permitting the generation of these recommendations. Like many other sectors of anthropological activities, the space one is steadily working to accommodate both economic interests and environmental protection in line with the principle of sustainable development. This section's primary objective is to increase awareness of the necessity for extensive environmental efforts to be directed toward integrated national and worldwide industrial and societal acts and processes.

Space Law

The term Space Law is most commonly associated with the rules, principles, and standards of international law found in the five international treaties and five sets of principles governing outer space developed by the United Nations. In addition to these international treaties, many countries have national laws that govern space-related activities. Space law addresses a wide range of issues, including the preservation of the space and Earth environments, liability for damage caused by space objects, dispute resolution, astronaut rescue, the sharing of information about potential dangers in outer space, the use of space-related technologies, and international cooperation. A number of fundamental principles guide space activities, including the concept of space as the province of all humanity, the freedom of all states to explore and use outer space without discrimination, and the principle of non-appropriation of outer space (UNOOSA). The Committee on the

Peaceful Uses of Outer Space (COPUOS)[16] is the forum for international space law development where five international treaties and five sets of principles on space-related activities have been concluded:

- Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space[17]
- Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space[18]
- Convention on International Liability for Damage caused by Space Objects[19]
- Convention on Registration of Objects Launched into Outer Space[20]
- Agreement Governing the Activities of States on the Moon and Other Celestial Bodies[21]

For writing convenience, it will be used as the informal name of each of the Treaties, respectively: Outer Space Treaty of 1967, Rescue Agreement of 1968, Space Liability Convention of 1972, Registration Convention of 1975, and Moon Treaty of 1979.

Furthermore, the United Nations oversaw the drafting, formulation and adoption of five General Assembly resolutions, Declaration of Legal Principles included:

- Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, adopted on 13 December 1963 - resolution 1962.
- Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting, adopted on 10 December 1982 - resolution 37/92.
- Principles Relating to Remote Sensing of the Earth from Outer Space, adopted on 3 December 1986 - resolution 41/65.

[16] Space Law Treaties and Principles. UNOOSA. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html
[17] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, entered into force Oct. 10, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205
[18] Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, entered into force Dec. 3rd, 1968, 672 UNTS 119
[19] Convention on International Liability for Damage Caused by Space Objects entered into force Oct. 9, 1973, 24 U.S.T. 2389, 961 U.N.T.S. 187
[20] Convention on Registration of Objects Launched into Outer Space, entered into force Sep. 15, 1976, 28 U.S.T. 695, 1023 U.N.T.S. 15
[21] Agreement Governing the Activities of States on the Moon and Other Celestial Bodies entered into force July 11, 1984, 1363 UNTS 3

- Principles Relevant to the Use of Nuclear Power Sources in Outer Space, adopted on 14 December 1992 - resolution 47/68.
- Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries, adopted on 13 December 1996 - resolution 51/122.

These five treaties address issues such as non-appropriation of outer space by any one country, arms control, freedom of exploration, liability for damage caused by space objects, the safety and rescue of spacecraft and astronauts, the prevention of harmful interference with space activities and the environment, notification and registration of space activities, scientific investigation and exploitation of natural resources in outer space, and the settlement of disputes (UNOOSA). All space exploration and human spaceflight, planetary sciences, and commercial uses of space, including the global telecommunications industry and the use of space technologies such as position, navigation, and timing (PNT), occur against the backdrop of the Outer Space Treaty's general regulatory framework.

In outer space, protection entails safeguarding of both the space and Earth environment, as defined in the Outer Space Treaty, negotiated at the United Nations and in force since 1967, has been ratified by over 100 countries. It is the most important and foundational source of space law. The treaty governs all humankind's activities in outer space, including activities on other celestial bodies and many activities on Earth related to outer space. The Outer Space Treaty is regarded as the cornerstone of international space law conventions, or what may be termed the *Magna Charta*. From 1967 to 1979, five (5) Treaties were stipulated and, in the decades since the Moon Agreement, there have been few hard law instruments in space governance. All the progresses have been made in the form of customary international law and non-binding instruments, so called soft law.

To address scientific concerns that spacecraft missions to the Moon and other celestial worlds would jeopardise future scientific exploration, the International Council of Scientific Unions (ICSU) formed an ad hoc Committee on Contamination by Extraterrestrial Exploration (CETEX) in 1958. Not even a year later, this mandate was moved to the newly formed Body on Space Research (COSPAR), which was deemed to be the proper site to continue CETEX's work as an interdisciplinary scientific committee of the ICSU, today the International Council for Science. The COSPAR Planetary Protection Policy represents one of the most prominent examples of soft law in space governance. By the international space community, it is considered an accomplishment of technocratic governance on a global scale and shall be read both as regulatory and soft law and instrument.

Arctic and Remote Sensing

By analysing the fundamental principles of space law, we assist in a double projection of the protection pillar, hence resulting in a key principle for both Environmental and Space Law. Despite the protection occurring over two distinct environments - the space environment and the terrestrial one - the focus of both industries and international communities is undeniably sharing analogue needs. These requirements ask for technically compatible mitigation and preventative measures.

The international coordination of mitigation and prevention measures across the Arctic region is an excellent example of technically compatible efforts. Remote sensing and derived data are used to protect the Arctic, a crucial geographic region with strategic value for both space and environmental law.

The Arctic climate is created by Earth's orbital mechanics, specifically the planet's tilt, which results in the absence of sunlight in winter and 24-hour sunlight in summer. Satellite communications, surveillance, navigation, search and rescue, weather forecasting, sea-ice monitoring, fishing, prospecting, and environmental research are all critical in the Arctic. Many of the remote-sensing satellites, which are used for everything from intelligence gathering to disaster relief, are placed in polar orbits that converge over the Arctic. As an outcome, the region's largest commercial ground station is located on the Norwegian archipelago of Svalbard. [22]

There are two predominant standpoints on remote sensing that relates to its use for the Arctic and for climate change overall. The first one concerns illicit remote sensing conducted without the prior consent of the surveyed state. This view is held by developing states that do not partake in space activities, consequently not developing space technologies; in particular, some governments of developing countries have argued that sovereignty includes the ability to collect data from their territories. A second point of view is known as the 'open skies' doctrine, which allows the dissemination of remotely sensed data to all interested parties, including states, individuals and organisations, on a non-discriminatory basis. Under the open skies' doctrine, the prior consent of the country being surveyed is not required.

[22] M. Byers, Arctic Security and Outer Space, Scandinavian Journal of Military Studies, 2020.

At the international level, an intermediate position has emerged: the UN Principles Relating to Remote Sensing of Earth from Outer Space[23] include the legal framework governing remote sensing operations. As they cover "sensing of the Earth's surface from space (...) for the purpose of improving natural resource management, land use, and environmental preservation," the Principles are primarily focused on achieving sustainable development goals. Principle 1 states that remote sensing activities must be carried out for the good of, and in the interests of, all States, with a focus on the needs of developing nations, and in the context of tackling climate change as a global challenge, this represents another essential link with Environmental Law.

The global partnership-based approach to sustainable development elaborates on this special focus, on the needs of the States most impacted by environmental concerns. The Principles, likewise, highlight the crucial share that international cooperation plays, which is known as a "procedural super principle" in both international Environmental Law and International Space Law. Indeed, the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement both promote cooperation in the sharing of information linked to climate change.

Space Policy

The decisive drivers of developments in green technologies are space policies and new and traditional funding schemes, including governmental financial support. Space policy can be defined as the political process of developing and implementing a State's, or else an association of states', public policy regarding spaceflight and the uses of outer space for both civilian, scientific and commercial, and military purposes.[24] Space policy intersects with science policy because national space programs frequently conduct or fund space science research, as well as defence policy for applications such as spy satellites and anti-satellite weapons. Government regulation of third-party activities such as commercial communications satellites and private spaceflight is also included. Additionally, it includes the development and implementation of space law, and space advocacy organisations, such as the Space Generation Advisory Council, exist to help.

As run through in the previous paragraph, the international treaties, such as the 1967 Outer Space Treaty (OST), seek to maximise peaceful uses of space while limiting militarization.

[23] United Nations A/RES/41/65, 3 December 1986.
[24] Goldman, Nathan C., Space Policy: An Introduction. Ames, IA: Iowa State University Press, 1992.

While the OST is the cornerstone in the regulation of activities in outer space, the emergence of new issues that were not contemplated at the time of its creation all strain the treaty's coherence and continuing adequacy and may necessitate the need for new governance frameworks. The United Nations, which has emphasised how space infrastructures and technologies represent a key factor for the achievement of each of the 17 SDGs, part of the UN 2030 Agenda adopted back in 2015, has repeatedly affirmed the close relationship between space and the environment. In 2018, following a broad international process under the auspices of COPUOS, the Committee adopted a set of 21 non-binding UN COPUOS Guidelines for the Long-Term Sustainability of Outer Space Activities, COPUOS LTS Guidelines. The key feature of the Guidelines is its implementation from the perspectives of government, industry, and civil society. The journey that led to their adoption provided a clear understanding that a follow-up LTS working group was needed. The recently formed working group with a five-year mandate continues the work in support of space and terrestrial environments.

Over the past two years, the UN has negotiated the Space Agenda 2030 through the UN Committee on the Peaceful Uses of Outer Space (COPUOS). It considers space as a driver for sustainable development and can be appraised as the world's first data-driven approach to global growth and development, highlighting the critical role that space technology plays in endorsing sustainable development. In this regard, it is necessary that all parties within the space ecosystem shall continue to investigate how to closely collaborate towards grasping the full potential of space for sustainable development.

Open Space Policy benefitting Earth

If we consider non-binding international guidelines, national policies and regulations, the emphasis on the space asset is steadily increasing and it brings with it the need for a diverse set of policies. In fact, space is considered an enabler of new services and applications that might assist humanity in pursuing sustainability and in understanding and combating climate change. The European Commission, in collaboration with the European Space Agency and the European Environment Agency, launched the Copernicus Programme in 2014 as a follow-up to the previous Global Monitoring for Environment and Security (GMES). A civic, user-driven effort called Copernicus aims to create environmental information services based on EO data. The EU's concern for environmental challenges, for which the Union is also a party to various global environmental agreements, led to the decision to establish European space-based environmental monitoring services. Now, public and corporate organisations have at their disposal complete, open, and free access to Copernicus environmental data and information. EU Member States and the international community can rely on Copernicus services to implement their policies.

Copernicus services provide information in six areas: ocean, land, and atmosphere monitoring, emergency response, security, and climate change. Copernicus Data Hubs, which include the Open Access Hub, the Collaborative Data Hub, the International Access Hub, and the Copernicus Services Data Hub, are ESA web portals that make Sentinel data available to individuals and organisations worldwide.[25] Relating to the interconnectedness of policies, Copernicus makes many additional indirect contributions to the formulation of global policies that seek to address the ramifications of climate change, such as food security.[26]

Digital Twin Earth

We have arrived at a critical moment where all the policies generated by different legislative and regulatory bodies shall be interconnected in order to give a higher degree of efficacy, given the vastness of the challenge we are facing and the huge objective our society has set. With this environmental policy and technical initiative, space data provided an additional opportunity to generate a virtual representation that serves as a real-time replica of a physical object or process, hence called digital twin. It is made up of three parts: the physical item in real space, the digital twin in software form, and the data that connects the first two parts. The first time the term has been used was when NASA was trying to find a solution for repairing the damaged Apollo 13 spacecraft. It is thought to be one of the earliest examples of digital twin usage, thirty or so years before the term digital twin was officially coined.

The Digital Twin Earth[27] is a brilliant data forecast method with the objective to demonstrate the efficacy of the policy adopted to mitigate the impact of climate change implications. As part of the Green Deal and Digital Strategy, the European Commission launched Destination Earth (DestinE)[28] to help achieve the goals of the green and digital transitions. It attempts to create a highly realistic digital model of the Earth on a global scale in order to monitor and

[25] European Space Agency (ESA), Europe's Copernicus programme, https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Europe_s_Copernicus_programme (accessed 27.06.22)
[26] Copernicus, https://www.copernicus.eu/en (accessed 29.06.222)
[27] "Working towards a Digital Twin of Earth." European Space Agency, https://www.esa.int/Applications/Observing_the_Earth/Working_towards_a_Digital_Twin_of_Earth. Accessed 13 December 2022.
[28] European Commission, Destination Earth – new digital twin of the Earth will help tackle climate change and protect nature, European Commission - Press release, Brussels, 30 March 2022, https://ec.europa.eu/commission/presscorner/detail/en/IP_22_1977 (accessed 30.06.22)

predict the interaction of natural phenomena and human activities. For implementation purposes, the European Commission is supported by the European Space Agency (ESA), the European Centre for Medium-Range Weather Forecasts (ECMWF), and the European organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

Digital Twin Earth would demonstrate the future usefulness of already implemented rules and regulations by modelling the exact scenario using accurate satellite data and a historical run over of satellite data sets. Through DestinE, users will be able to access theme information, services, models, scenarios, simulations, forecasts, and visualisations. The underlying models and data will be evaluated on a continual basis in order to give credible and actionable scenario predictions.

The platform will initially serve government agencies before eventually opening up to a broader spectrum of scientific and industrial users, as well as the general public, with the intent to promote innovation and develop new applications and services. A fusion of real-time observations and high-resolution predictive modelling in thematic areas will soon allow all the actors of our society to validate the efficacy and consistency of environmental and adjacent sector policies adopted so far at international, national, or local level. By 2030, the global society will have at disposal a whole digital duplicate of the Earth.[29]

Shared Principles of Space and Environmental Law

At the international level, an intermediate position has emerged: the UN Principles Relating to Remote Sensing of Earth from Outer Space (A/RES/41/65, 3 December 1986) include the legal framework governing remote sensing operations. According to Principle I, remote sensing activities must be carried out in the best interests of all States and in order to meet the needs of developing countries. The focus on the needs of developing nations, in the context of a global challenge such as climate change, represents another key intersection with Environmental Law.

The principles of responsibility and solidarity toward future generations is another point in point. In the space environment, orbital congestion is posing the question of preserving the access and the exploitation of orbits for future space missions, hence urgently attempting to mitigate the space debris issue. On Earth, Principle 3 of the UN Declaration Rio de Janeiro,[30]

[29] European Commission, Destination Earth (DestinE), https://digital-strategy.ec.europa.eu/en/policies/destination-earth (accessed 12.06.22)
[30] United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992

approved in June 1992: “The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.”

Already 30 years ago, the UN stated that human development is considered as a temporal process that involves present and future generations, steadily intertwined one with the other. The problem of intergenerational equity is expressed also in the single Conventions, the Principle of responsibility toward future generations is often remarked. In the Bonn Convention of 1979, it is underlined that each generation possesses the resources for future generations, and they are responsible for the preservation of this inheritance, inviting to use lands with caution.

Accountability for Harmful Actions

At the international level, for more than a decade now, the imperative has been to steer global governance to facilitate the creation of policy and regulations to resist adverse environmental changes and human behaviours, which necessarily invite the taking of urgent action. The "polluter pays" and precautionary principles, as well as the "no harm" rule, can be employed to impute accountability for destructive operations in space as well as on Earth.

The broadest concept that globally governs sustainable development includes the “polluter pays” principle, widely accepted and deriving from the Rio Declaration of 1992. According to this principle, individuals who cause pollution should be responsible for paying the costs associated with controlling it in order to protect public health and the space and terrestrial environment. For instance, on Earth, a company is often held accountable for the proper disposal of any potentially toxic waste that is produced as a by-product of its operations.

In accordance with the United Nations Charter and the fundamental principles of international law, States have the sovereign right to exploit their own resources in accordance with their own environmental and development policies. Standing on Principle 6 of Rio Declaration, States also have the obligation to ensure that activities under their jurisdiction or control do not harm the environment of other States or of areas outside of their borders. This prohibition is widely known as the “no harm” rule.

The "precautionary principle" is the last and most significant point. It applies to novel fields when the outcomes are unknown, such as in space exploration. Although it is regarded as a broad principle, there is disagreement over its place in international customary law. Because

---

https://www.un.org/en/conferences/environment/rio1992 there was no prior proof that the behaviour was dangerous, states cannot argue that they should not have taken the required precautions to reduce the risk.

A generally accepted definition is provided by Principles 2 and 15 of the Rio Declaration, which are not legally binding but do serve as an international standard: "Where there is a threat of (...) harm, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation."[31] Moreover, standing on the legal space regime, public and private parties who engage in environmentally harmful space activities run the possibility of being held liable, according to a clear responsibility mechanism. The latter demonstrates Space Law has the potential to be both an instrument for regulation and a tool for punishment. The clear responsibility mechanism has attempted to reconcile the shortcomings of the Outer Space Treaty, which fails to address accountability for actions that caused harm to another State-party. The mechanism also gives a definitive understanding of blame for international law. J. A. Dennerley defines liability as the legal duty to make up for harm caused to another after an incident that results in damage SDG 13 - Climate Action - on the other hand mandates that states adopt proactive measures to mitigate climate change and its effects.[32]

The Paris Agreement[33], entered into force on 4 November 2016 and adopted to limit global temperature rise to well below 2 degrees Celsius, switched the emphasis to the execution of disaster risk reduction methods under which nations must actively protect themselves from environmental degradation measures, including initiatives addressed to explore space. To effectively address climate change, the issue to be investigated is how States can guarantee one another's adherence to the SGD 13's goals.

To ensure that states are held responsible for failing to follow environmentally friendly practices, particularly in space activities, the consequences of the idea of accountability might be put in place. As a result, in order to fully realise the goals of the SDG 13, agreements governing space operations may also rely on the doctrine of accountability under liability. With regard to the Outer Space Treaty, Article 7 states that a launching State shall be liable to pay damages for harm caused by its space objects on the surface of the Earth or to aircraft, as expanded by the Liability Convention.

[31] Report of the United Nations Conference on Environment and Development, Rio de Janeiro, Volume 1, Resolutions adopted by the Conference, 3-14 June 1992, https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf (accessed 11.06.22)
[32] J.A. Dennerley, State Liability for Space Object Collisions: The Proper Interpretation of 'Fault' for the Purposes of International Space Law, Eur. J. Int. Law, 29, 1, (2018), 281–301.
[33] United Nations Framework Convention on Climate Change (UNFCCC), The Paris Agreement, 2015, https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf (accessed 22.06.2022)

This Convention stipulates that those damages caused on the Earth's surface or in the atmosphere are to be indemnified with absolute liability, which means they must be compensated without even the need to verify whether the launching state was negligent or inexperienced. In order to make both governmental and private entities accountable at the same time, along with unrestrained private parties who harm the Earth's atmosphere by using space in a way that is not environmentally favourable, both Article 7 of the Outer Space Treaty and the Liability Convention can be utilised. If that is the case, stringent liability laws can encourage governments and related communities to engage in ecologically favourable operations.

Recommendations

- Opening a multi-stakeholder forum to deepen the comprehension and collaboration on binding and non-binding legal instruments at international level. The organisation of dedicated events could capture the attention of non-legal stakeholders.
- Generating an information process involving intergovernmental and international organisations (UN, UE) in order to bring light over non-ratified space treaties. The ratification of the five treaties and the recognition of fundamental space legal principles will facilitate dialogues, harmonise objectives and open the door to future coordinated treaties amendment.
- Space law has the potential to be both an instrument for regulation and a tool for enforcement. If sustainability policies will be progressively streamlined, the consequent approach of international and intergovernmental bodies could go toward the adoption of binding environmental guidelines, as opposed to soft guidelines.
- The participation of space attorneys as public activists in the achievement of SDG 13 can help to limit the scope of companies, including New Space established and non-companies, participating in environmentally unfavourable activities owing to a lack of adequate guidance.
- Facilitate the inclusion of Space Lawyers, Space Economy experts, and International Relations experts in national environmental consultations, initiatives, and political working groups

3. Space Technology and Science

The applications of space technologies and research have been a game-changer in the climate crisis. This not only includes EO satellites and the data used for monitoring, modelling, and predicting climate change - but also the spin-off technologies and contributions to sustainable development achieved through space exploration. This section explores the various ways in which space technology and science can be, and has been, a major proponent in climate action.

Technology and Data

Earth Observation Satellites

The need for information from satellites is growing at an increasing rate. Satellite Earth Observation is not a disruptive technology anymore, it is mainstreamed in everyday life, e.g. weather forecasting, agriculture forecasting.

EO satellites have the capability to contribute to achieving the main goals of the Paris Agreement for Climate in many ways, particularly by supporting effective policymaking and further policy implementation monitoring. They have wide area observation capabilities, they are objective, and they can provide uniformity, rapid measurement and continuity. According to the Report "Earth Observations in support of the 2030 Agenda of Sustainable Development", published in 2017 by the Group on Earth Observation, this first space application is the number one item of global government investment, given its ability to address numerous challenges, such as food scarcity, climate change, water health, and environmental disasters.[34]

EO satellites are characterised by the presence of sensors, either active or passive, capable of capturing radiation emitted or reflected from the Earth, and then producing scientific data that is useful to policy makers, NGOs, private companies, etc.[35] Passive sensors, such as spectrometers and radiometers, can measure temperature, roughness, and soil hydration, capturing near infrared radiation, while active sensors, such as radars, lasers, and lidars, by

[34] Japan Aerospace Exploration Agency (JAXA), Group on Earth Observations (GEO), Earth Observations in support of the 2030 Agenda for Sustainable Development, March 2017, https://www.earthobservations.org/documents/publications/201703_geo_eo_for_2030_agenda.pdf (accessed 20.06.2022)

[35] Kimani J. M. and Okeng'o G. O., 2019, Earth Observation for Sustainable Development in Africa: Through the Adoption of Cost-effective Small Satellite Programs to Attain Data Democracy and Achieve Sustainable Development Goals in Africa. International Astronautical Congress.

themselves emitting beams of radiation that penetrate the atmosphere, also capture microwaves, thus allowing for greater data accuracy, even in harsh weather conditions.[27]

Satellites enable us to monitor the atmosphere, oceans, and surface temperatures at very high spatial and temporal resolutions. By having this data, we have been able to enhance our models and predictions of climate change. Simultaneously, this data can be used to assess the effectiveness of our mitigation and adaptation solutions, as well as predict the risks and impacts of our current trajectory.

The Global Climate Observing System (GCOS) was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all. In 1995, the GCOS Plan published included a Plan for Space-based Observations, highlighting the importance of satellite data in obtaining systematic observations.

In 2004, the United Nations Framework Convention on Climate Change (UNFCCC) established the Implementation Plan for the Global Observing System for Climate, highlighting the importance of satellite data in obtaining systematic observations. Of the 54 Essential Climate Variables (ECVs) identified, satellite data can help address about 60% of the variables.[36]

An ECV is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterisation of Earth's climate. Categories of ECVs include Atmospheric, Oceanic, and Land Variables. Some ECVs monitored by satellites include ozone, clouds, aerosols, greenhouse gases, sea levels and surface temperatures, sea ice, land cover, glaciers and ice caps.

The European Space Agency's Climate Change Initiative (CCI) was created in 2008 to address these ECV requirements and coordinate research efforts.[37] In the framework of the Climate Change Initiative, the European Space Agency has implemented twenty-five dedicated Essential Climate Variables (ECVs) projects, each addressing a specific variable. CCI undertakes activities necessary to meet its objective of supporting the UNFCCC, including:

- Periodic processing of the Earth Observation (EO) data sets applying the most up-to-date algorithms

[36] "Essential Climate Variables." GCOS | WMO, https://gcos.wmo.int/en/essential-climate-variables/
[37] "ESA Response to GCOS." European Space Agency, https://climate.esa.int/media/documents/ESA_Response_to_GCOS_v3_2a.pdf. Accessed 13 December 2022

- Developing improved algorithms for the ECV production from emerging data sources consistent with the long-term record
- Creating an Open Data Portal to allow end users in a range of fields to access data on ECVs from EO satellites
- Producing data records of the 21 ECVs that cover the entire planet and stretch back more than thirty years
- Fully validating data sets, with high levels of traceability and consistency, including estimates of uncertainty

In particular, the EU Copernicus Program aims to use EO satellites from ESA and EUMETSAT to provide free and open access to data.[38] The Copernicus Climate Change Service (C3S) supports adaptation and mitigation policies of the European Union by providing consistent information about climate change, and it includes both space-based (EO data) and ground-based segments (in-situ data).[39] Its demonstrator projects include monitoring snow cover, global biodiversity, hydrological impacts, storm surges, as well as flood risk assessments.

Below are some selected examples of EO data applications to support climate action and sustainability. More information can be found in the sources linked.

Examples of EO Data Applications
• Operational services for water resource management *(Source: Copernicus)* • Predicting extreme events e.g. flood risk assessments *(Source: Copernicus)* • Supporting infrastructure and transport resiliency *(Source: Copernicus)* • Informing global biodiversity efforts *(Source: Copernicus)* • Advising agriculture and forestry sectors *(Source: Copernicus)* • Assessing climate impacts on energy sector *(Source: Copernicus)* • Monitoring impacts on marine ecosystem, coastal areas, and fisheries *(Source: Copernicus)* • Supporting the UN-Habitat's resilience program *(Source: Copernicus)*

[38] "ESA CCI Open Data Portal Project." Copernicus, https://www.copernicus.eu/en/documentation/research-projects/esa-cci-open-data-portal-project

[39] "Copernicus Climate Change Service (C3S)." Copernicus, https://climate.copernicus.eu/.

Satellite Navigation & Positioning

EO satellites work even better in synergy with global navigation satellite systems (GNSS), as this way they can be geo-referenced.[40] The applications of GNSS are many and can also be used in the context of development projects. One example is precision agriculture, in which remote sensing, GNSS, and Geographical Information System (GIS) are integrated "to support farm planning, field mapping, soil sampling, tractor guidance, and crop assessment".[41] Through an automated system, in fact, agricultural machinery is able to release a different number of pesticides, fertilizers, and water for each part of the field, depending on the health of the crop. In this way, it is possible to reduce both costs and environmental impact, as well as have an always current assessment of the crops.

Another area that can benefit from GNSS is disaster management, as GNSS can provide real-time location of all vehicles involved in the relief effort, guiding them to the precise location.[42] With GNSS, it is also possible to make a real-time damage assessment and organise rescue operations promptly. Also when it comes to disease monitoring, GNSS can play an important role: after using EO satellites to map the areas at highest risk, in fact, through the position system it is possible to know the location of both the human settlements affected, and the most recent medical cases, to see if specific diseases have been treated.[43] Several organisations use this technique to reduce malaria transmission.

Governments in developing countries can also use GNSS for urban planning, from housing to infrastructure. The integration of this system to EO satellites, allows, in fact, to obtain continuous and perfectly positioned images; using, for example, the Lidar with GNSS, it is possible to have key information on the status and positioning of key infrastructures.

Satellite Communication

Satellite communication systems are indispensable when it comes to connecting remote parts of the world that are permanently or temporarily without access to terrestrial telecommunications infrastructure. A very frequent application is disaster management, when affected regions suddenly find themselves isolated, following the malfunction or

---

[40] United Nations Office for Outer Space Affairs (UNOOSA), European Global Navigation Satellite System and Copernicus: Supporting the Sustainable Development Goals. Building Blocks towards the 2030 Agenda, United Nations, Vienna, 2018.

[41] NovAtel, An Introduction to GNSS: GPS, GLONASS, Galileo and Other Global Navigation Satellite Systems, second ed. Calgary, 2015, pp.73.

[42] S. Madry, Global Navigation Satellite Systems and Their Applications, New York: Springer (SpringerBriefs in Space Development), 2015.

[43] D. Wood, K.J. Stober, 2018. Small Satellites Contribute to the United Nations' Sustainable Development Goals, SSC18-WKVIII-08, 32nd Annual AIAA/USU Conference on Small Satellites, Utha, US, 2018, 4 – 9 August.

destruction of telephone lines. In such cases, satellite communication makes it possible to keep communication channels open with rescue teams, whether by land, sea or air.[44]

Spin-off Technologies for Sustainable Development

Space exploration has had significant impacts on our understanding of Earth's changing climate. This is largely due to the data we can obtain from satellites, and it is now common knowledge that the global climate is changing at an accelerated pace. As it continues to do so, it threatens many aspects of society. Space exploration can not only show that it is possible to sustainably inhabit other planets, but also help us to develop alternative methods of living on this one. It can be used to mitigate or exacerbate environmental impacts, depending on how we pursue it.

The impacts of space on sustainable development and climate action are all-encompassing. This includes spin-off technologies that can be leveraged to address the climate crisis, by adapting and improving the quality of life on Earth. Some of these technologies allow us to better address the environmental impacts caused by anthropogenic climate change. In particular, space technology is expected to have a significant influence on the future of energy generation and use, agriculture and land management, natural resources conservation, and infrastructure resilience.

The table below presents a few examples of how spin-off technologies developed through space R&D support climate action. More information can be found in the sources linked.

Examples of Spin-off Technologies
• Carbon capture *(Source: NASA)* • Energy efficiency and insulation materials *(Source: NASA)* • Clean energy production and solar panels *(Source: NASA)* • Space sensors reducing emissions from heating systems *(Source: ESA)* • Mars spectrometer to detect methane gas leaks *(Source: NASA)* • Detoxifying soil and groundwater *(Source: NASA)* • Space-inspired farming in vertical farms and closed-loop systems *(Source: NASA)* • Green buildings and smart monitoring systems *(Source: NASA)* • Durable wind turbines using Mars technologies *(Source: NASA)*

[44] F. Halais, Making satellite technologies work for sustainable development, 2 October 2017, https://www.devex.com/news/making-satellite-technologies-work-for-sustainable-development-90730 (accessed 20.06.2022)

These spin-off technologies, although developed with space exploration in mind, have contributed to developing sustainable solutions for life on Earth as well. This includes water resource management, energy efficiency and infrastructure, monitoring and mitigating air pollution, accessibility for education, agriculture in harsh environments, as well as remote medicine, to name a few. Developing ways to streamline the application of these technologies to sustainable development on Earth can further propagate the benefits of space exploration and show more clearly how it affects life on our home planet.

Additionally, technologies developed and tested through analog space research have the potential to benefit life on Earth as well. Analog facilities or missions are those that aim to simulate living on an extraterrestrial surface, such as the Moon or Mars. There are several analog research bases around the world, typically in harsh environments such as deserts or volcanoes. Due to the extreme and isolated environment these facilities are based in, as well as the need to be as efficient as possible with resource generation and consumption, their research is largely applicable to sustainable development goals on Earth as well. Although several analog facilities have been developing sustainable mission scenarios and goals, the Jordan Space Research Initiative explicitly aims to bridge sustainable development with space exploration.[45] For emerging space countries like Jordan, which do not have an established space program or agency, it is essential to show the benefits that space exploration and technologies can have for life on Earth as well. By focusing on national priorities and challenges[46], emerging or non-space faring countries can use analog research as a tool to contribute to space exploration, while simultaneously working towards their national goals and bettering life on Earth for their citizens.

Planetary Science

Earth is central to the study of other planetary bodies. Our planet is used as a guide to the search for Earth-like planets in other solar systems[47] and as a model for understanding the other planets of our solar system. It is significant to scientists that Mars has no plate tectonics, magnetic field, or liquid water on its surface because those attributes make life possible on Earth. However, other planets have a lot to teach us about our own world. For

[45] El-Shawa, S, Alzurikat, M, Alsaadi, J, Al Sona, G, Abu Sha'ar, Z, 2021, Valley of the Moon: Societal Benefits of Lunar Exploration in Jordan. International Astronautical Congress, Dubai, UAE.
[46] El-Shawa, S, 2020, Jordan and the United Nations Space2030 Agenda: A Roadmap for Space and Sustainable Development. International Astronautical Congress.
[47] Borucki, William, David Koch, Natalie Batalha, Douglas Caldwell, Jorgen Christensen-Dalsgaard, William D Cochran, Edward Dunham, Thomas N Gautier, John Geary, and Ronald Gilliland. 2008. 'Kepler: search for Earth-size planets in the habitable zone', Proceedings of the International Astronomical Union, 4: 289-99.

example, both Mars and Venus were once habitable, like Earth, but are now inhospitable to any known life.[48] For the sake of life on Earth, we ought to understand why they have suffered this fate.[49] In similarity to issues we now face on Earth, Venus suffered from the greenhouse effect.[50] On Venus, a runaway greenhouse led to the loss of all water – replaced with rivers of molten iron.[51] Mars suffered the opposite effect, losing its magnetic field and atmosphere with it, resulting in a cold and radiation-filled wasteland. Expounding the processes that have led to other planets losing their habitability may help us understand how to protect our own planet, especially when it comes to problems as global as climate change.

Venus

A runaway greenhouse has been called “the ultimate climate emergency”[52] and it is a theory developed through observations of Venus. Venus is, therefore, an important case study for studying climate change on Earth. Venus got as hot as it is (~475 °C) because global warming increased the rate of water evaporation, causing an elevated concentration of water vapour (a greenhouse gas) in the atmosphere. Resultantly, more heat was trapped in the atmosphere, heating the planet further, and generating additional water vapour. This led to a positive feedback loop as more water vapour created more water vapour, leading to now extreme surface temperatures[31]. This process implores the question: could a runaway greenhouse occur on Earth too? The runaway greenhouse effect already occurs locally in the tropics due to high concentrations of water vapour.[53] And in a widely cited book, James Hansen, a prominent climate scientist has said “if we burn all reserves of oil, gas and coal, there is a substantial chance that we will initiate the runaway greenhouse. If we also burn the tar sands and tar shale, I believe the Venus syndrome is a dead certainty”.[54] Modelling the runaway greenhouse using data and observations of Venus will help us narrow down the thresholds for such a scenario to occur. Breaking down barriers between the space and climate science communities is an essential part of this effort.

[48] F. Westall, D. Loizeau, F. Foucher, N. Bost, M. Betrand, J. Vago, G. Kminek, Habitability on Mars from a microbial point of view, Astrobiology, 13 (2013) 887–897.
[49] M.J. Way, A. D. Del Genio, N. Y. Kiang, L.E. Sohl, D. H. Grinspoon, I. Aleinov, M. Kelley, T. Clune, Was Venus the first habitable world of our solar system', Geophysical research letters, 43 (2016), 8376–8383.
[50] G. Di Achille, B. Hynek, Ancient ocean on Mars supported by global distribution of deltas and valleys. Nature Geosci 3 (2010) 459–463.
[51] A.P. Ingersoll, A. P. (1969). The Runaway Greenhouse: A History of Water on Venus, J. Atmos. Sci. 26 (1969), 1191-1198. Retrieved Aug 30, 2022.
[52] Goldblatt, Colin, and Andrew J Watson. 2012. 'The runaway greenhouse: implications for future climate change, geoengineering and planetary atmospheres', Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370: 4197-216.
[53] Pierrehumbert, R Thermostates. 1995. 'Thermostats, radiator fins, and the local runaway greenhouse', Journal of the atmospheric sciences, 52: 1784-806.
[54] Hansen, James. 2010. Storms of my grandchildren: The truth about the coming climate catastrophe and our last chance to save humanity (Bloomsbury Publishing USA).

Not only does Venus warn us of the worst-case scenarios, but also of ways that we can mitigate climate impacts on a smaller scale. Venus' runaway greenhouse demonstrates the power of positive feedback loops in a climate system, encouraging scientists to investigate other similar mechanisms that may occur on Earth. For example, CO_2 currently trapped in high-altitude permafrost is being released as temperatures increase[55], resulting in further global warming. Moreover, global warming heats the oceans, which diminishes their ability to absorb CO_2 from the atmosphere.[56] On the human side, climate change impacts such as drought and desertification are forcing agriculture to intensify or expand to meet demand, which greatly increases agricultural greenhouse gas emissions.[57] These scenarios (among others), when combined, present a plethora of positive feedback loops that may cause unexpected and potentially extensive climate change impacts that must be closely monitored.

More generally, studying other planets exposes the scientific and engineering communities to chemistry that would otherwise have never been observed. The high temperatures on Venus drive a highly active chemical environment, riddled with new and exciting chemical reactions for scientists to study, and engineers to apply to novel situations. For example, observations of the interactions of cosmic dust with the Venusian atmosphere have inspired new technologies for converting vehicle emissions such as nitrogen dioxide and carbon monoxide into their fewer toxic counterparts.[58] Upcoming missions to Venus, such as VERITAS and DAVINCI will surely uncover a plethora of new chemical reactions and pathways that could potentially be applied on Earth. Additionally, missions studying the atmospheres of other planets and moons, such as ExoMars orbiting Mars, and the upcoming dragonfly mission to Titan will add to this knowledge.

Mars

Some space enthusiasts have made plans to terraform the red planet. Terraforming is now firmly planted in the scientific literature, with journals such as *The International Journal of Astrobiology* and the *Journal of the British Interplanetary Society* listing it in their scope. Geoengineering is the earthly equivalent of terraforming and they both come under the remit

---

[55] Schädel, Christina, Martin K-F Bader, Edward AG Schuur, Christina Biasi, Rosvel Bracho, Petr Čapek, Sarah De Baets, Kateřina Diáková, Jessica Ernakovich, and Cristian Estop-Aragones. 2016. 'Potential carbon emissions dominated by carbon dioxide from thawed permafrost soils', Nature climate change, 6: 950-53.
[56] Le Quéré, Corinne, Taro Takahashi, Erik T Buitenhuis, Christian Rödenbeck, and Stewart C Sutherland. 2010. 'Impact of climate change and variability on the global oceanic sink of CO2', Global Biogeochemical Cycles, 24.
[57] Bajželj, Bojana, and Keith S Richards. 2014. 'The positive feedback loop between the impacts of climate change and agricultural expansion and relocation', Land, 3: 898-916.
[58] James, Alexander. "Cosmic dust from Venus is inspiring new air pollution-busting technology." The Conversation, 23 June 2022, https://theconversation.com/cosmic-dust-from-venus-is-inspiring-new-air-pollution-busting-technology-185270.

of planetary engineering. Planetary engineering is defined (on Wikipedia) as "the development and application of technology for the purpose of influencing the environment of a planet." Scientists have modelled extreme planetary engineering plans involving the use of giant mirrors in space to deflect the sun's rays away from Earth[59], thus monitoring our own heat influx and limiting climate change. Millions of sunshades situated at the Earth-Sun lagrange point could block 1.8% of incident solar radiation.[60] While this proposition is probably too expensive to see reality, other planetary engineering strategies such as carbon dioxide removal techniques (including reforestation) and releasing energy-reflecting aerosols into the atmosphere may help save Earth, inspired by the spirit of the planetary science and space exploration communities.

The cause of Mars' uninhabitable environment was an atmospheric process caused by the sun's solar influx. It lost its atmosphere because the magnetic field-generating dynamo effect shut down. This left the atmosphere unprotected against the solar wind, which stripped away the atmosphere and removed Mars' ability to retain heat. Mars is what happens to a planet when there is too little greenhouse effect. The result is a cold environment where all water is frozen – unsuitable for life at the surface. Mars is a red alert in the night sky, warning us that we ought not to meddle with our greenhouse effect in ways that we do not understand. Geoengineering of a mechanism as vital as our greenhouse effect could result in unforeseen and altogether worse scenarios. Extreme solutions to climate change such as releasing aerosols could unpredictably alter Earth's natural life support systems. Consider an example from ecology. An ecosystem engineering strategy involving the intentional release of the cane toad to control cane beetles (pests to sugar cane plantations) was implemented in Australia.[61] Despite positive intentions and extensive background research and tests[62], the new species became invasive across Australia, outcompeting and killing the native wildlife in a great ecological disaster[63]. The greenhouse effect is essential for life on Earth. If we lose control of the geoengineering of our extremely complex atmosphere, the consequences will most certainly be grave.

[59] Moore, John C, Svetlana Jevrejeva, and Aslak Grinsted. 2010. 'Efficacy of geoengineering to limit 21st century sea-level rise', Proceedings of the National Academy of Sciences, 107: 15699-703.
[60] Angel, Roger. 2006. 'Feasibility of cooling the Earth with a cloud of small spacecraft near the inner Lagrange point (L1)', Proceedings of the National Academy of Sciences, 103: 17184-89.
[61] Shanmuganathan, T, J Pallister, S Doody, Hamish McCallum, T Robinson, Adrian Sheppard, C Hardy, D Halliday, D Venables, and R Voysey. 2010. 'Biological control of the cane toad in Australia: a review', Animal Conservation, 13: 16-23.
[62] Easteal, Simon. 1981. 'The history of introductions of Bufo marinus (Amphibia: Anura); a natural experiment in evolution', Biological Journal of the Linnean Society, 16: 93-113.
[63] Boland, CRJ. 2004. 'Introduced cane toads Bufo marinus are active nest predators and competitors of rainbow bee-eaters Merops ornatus: observational and experimental evidence', Biological conservation, 120: 53-62.

Recommendations

- Venus and Mars should be treated as valuable case studies for understanding the climate of our own planet.
- Planetary protection law should include preserving signs of the ancient geological and atmospheric history of other planets, not just potential signs of life.
- Limit technologies that could have unpredictable and potentially negative impacts on our global climate – the focus should be on limiting our impacts on the climate system.
- Place more focus on analog research and spin-off technologies for addressing sustainable development goals.
- Highlight benefits of space technology and EO data in addressing the climate crisis, and foster their implementation by organisations and governments particularly in emerging space countries
- Recognize long term goals in current global planning to inspire innovators and create long-lasting change.

4. Education and Outreach

In the last decades, earth observation data have gone from a powerful role in raising awareness by showing evidence of climate change to a central place in not only modelling future effects but also in the development of tools, such as digital twins able to better connect decision-making and long-term consequences. Yet, geospatial data are only of interest if they are processed, used and shared[64], which requires adapted skills to present and future needs[65].

Capacity Building and Education

In the last decades, space-earth observation data have gone from a powerful role in raising awareness by showing evidence of climate change to a central place in not only modelling future effects but also in the development of tools, such as digital twins able to better connect decision-making and long term consequences.

Yet, geospatial data are only of interest if they are processed, used and shared[43], which requires adapted skills to present and future needs[44]. In addition, the growing demand of data for building complex models is raising the need for societal engagement such as citizen participation and knowledge exchange between the public and the private sectors. In recent years, the European Union has financed several projects aimed at studying educational needs in the field of earth observation and geospatial data. While these studies did not specifically address the question of climate change several points must draw our attention:

1. Lack of harmonisation in skills definition and identification is creating gaps in the ways those skills are being teach[44]
2. EO and GIS teaching is still suffering from gaps between assimilation of knowledge i.e information learning and to the development of competences i.e *"the proven ability to use knowledge, skills and personal, social and methodological abilities in work or study situations and in professional and/or*

[64] F. Welle Donker, G. Vancauwenberghe, B. van Loenen, Business Models for Geographic Information, in: J. Brown Kruse, J. Crompvoets, F. Pearlman (Eds.), GEOValue, The Socioeconomic Value of Geospatial Information, CRC Press, Boca Raton, 2018.
[65] EO4GEO Alliance, Space/Geoinformation sector skills strategy in action, 2021, http://www.eo4geo.eu/download/the-space-geoinformation-sector-skills-strategy/?wpdmdl=8739 (accessed 21.06.2022)

personal development"[66] which include a need in better understanding of matching between stakeholders needs and available type of training[67]

3. Demands in data competences and consequently of education vary depending on the environmental context (e.g : coastal regions, forest areas …) leading to a need in adaptation of curriculum design depending on the present and future needs of a country for example regarding climate change adaptation (water management, fire management …)[68]

Current competence needs are, however, not only suffering from a lack of adequate training. Lack of vocation for the field but also of awareness in different fields of academic education (e.g: Humanities) can have long-term consequences in data collection and usage in fighting climate change while data awareness, training, access and usage at a larger scale (primary and secondary school, local community, etc.) can have positive impacts in sustainable development including environmental aspects in addition to raising vocation for skills

Perspective Shift

Overview Effect

The latest Intergovernmental Panel on Climate Change (IPCC) report on climate change mitigation outlined the importance of narratives on shifting behavioural and socio-cultural drivers related to sustainability.[69] Space can play an important role in driving motivation for sustainable behaviour on Earth, in addition to its technological benefits. This is especially embodied by the phenomenon of the *Overview Effect*. It describes a cognitive shift in awareness reported by astronauts and cosmonauts during spaceflight, often while viewing the Earth from orbit or from the lunar surface.

The experience has been cited as enabling astronauts to have a renewed long-term perspective on their life's purpose and the world as a whole, driving them to advocate for

[66] Recommendation of the European Parliament and of the Council of 23 April 2008 on the establishment of the European Qualifications Framework for lifelong learning (Text with EEA relevance) Official Journal, C 111, 1-7. CELEX, 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008H0506(01) (accessed 21.06.2022)

[67] J. Crompvoets, Z. Bacic, V. Posloncec-Petric, Survey Report European Spatial Data Research Academia-Business Survey on Needs and Cooperation in Field of Spatial Data Infrastructures, BESTSDI / EuroSDR, 2020, http://www.eurosdr.net/sites/default/files/uploaded_files/eurosdr_academia_business_survey.pdf (accessed 21.06.2022)

[68] Erasmus +, SEED4NA, Preliminary results, newsletter no. 5, October 2021 http://seed4na.eu/wp-content/uploads/2021/11/SEED4NA_Newsletter5_Final.pdf (accessed 21.06.2022)

[69] Intergovernmental Panel on Climate Change (IPCC): Sixth Assessment Report on Climate Change Mitigation, Chapter 5: Demand, services and social aspects of mitigation, 2021, https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter_05.pdf (accessed 23.06.2022)

environmental and social justice back on Earth. This term was first coined by space philosopher Frank White, who described it as follows: "*It refers to the experience of…Earth in space, a tiny, fragile ball of life, hanging in a void, shielded and nourished by a paper-thin atmosphere. Some common aspects of it are a feeling of awe for the planet, a profound understanding of the interconnection of life, and a renewed sense of responsibility for taking care of the environment.*"[70]

As profound as this experience may be, it is not accessible to the majority of humankind. The demographics of astronauts in general has historically been very exclusive. Only 12% of all 500+ astronauts to date have been women, and even fewer were from minority groups.[71] This remains to be true, even with the rise of space tourism, as typically only extremely wealthy individuals can afford commercial spaceflight. As access to space remains severely limited, so does access to the Overview Effect. One solution to address this inaccessibility may be Virtual Reality (VR). Over the past couple of years, several studies and organisations have attempted to replicate the space experience on Earth using VR.[72] Preliminary results have suggested that VR simulations can also impart a sense of awe and wonder, improve mental health, and promote sustainable behaviour.[73]

Educational and outreach programs can use VR, bridging art and technology, in order to enable more people to access the Overview Effect experience and feel the perspective shift needed to drive sustainability on Earth.

Astrobiology

Understanding our place in the universe can offer new perspectives and demonstrate the cosmic importance of protecting our biosphere. The search for extraterrestrial intelligence (SETI) has not discovered any other technological civilisations. This "great silence" is surprising for three reasons: (1) Life originated on Earth almost as soon as the planet became habitable, (2) our solar system formed 3 billion years after the formation of the universe, and (3) it probably only takes about a million years for a spacefaring civilisation to travel the galaxy. These points indicate that it may be quite easy for life to originate, that

[70] F. White, The Overview Effect: Space Exploration and Human Evolution (Library of Flight), third ed., American Institution of Aeronautics and Astronautics, Virginia, 2014.
[71] Smith, M. G. et al. (2020). A brief history of spaceflight from 1961 to 2020: An analysis of missions and astronaut demographics. Acta Astronautica.
[72] Gallagher, S. et al. (2015). A Neurophenomenology of Awe and Wonder: Towards a Non-Reductionist Cognitive Science. Palgrave Macmillan.
[73] Nezami, A. (2017). The overview effect and counselling psychology: astronaut experiences of earth gazing. (Doctoral thesis, City, University of London)

there has been plenty of time for it to originate and develop a civilization on another planet, and that they could have spread throughout the galaxy in that time. Many leading philosophers have suggested that the lack of life in our universe indicates that existential risks are likely to destroy technological civilisations before they can become a spacefaring civilisation, termed “The Great Filter”. Therefore, the discoveries we are making in space urge us to tackle climate change (and other existential risks such as nuclear war, biotechnology, and AI) urgently and diligently as they are likely to have already destroyed other civilisations before us. Additionally, suppose life on Earth is the only life in our universe. In that case, Earth is so much more special than we could ever truly grasp or appreciate, endowing us with the responsibility of protecting our planet and its inhabitants.

Recommendations

- Adapt educational curriculums for EO and GIS competences related to climate change and specific contextual (national, regional ...) needs
- Make education and training related to climate data more active and adapted to concrete usages and foster the promotion of existing data in open access within curriculums
- Promote career in EO and GIS field by facilitating geospatial data training in secondary school and encouraging interdisciplinary dialogue and courses at the university level
- Use VR and story-telling tools to educate and drive a sustainable shift in behaviour, particularly by making the phenomenon of the Overview Effect more accessible
- Encourage outreach from SETI scientists and astrobiologists and incorporate a wider perspective into curriculums concerning Earth and life sciences
- Discoveries from astrobiology and planetary sciences should be communicated and left open to interpretations from philosophers and the general public

5. Ethical and Political Considerations

When it comes to climate change, the relationship between science and geopolitics becomes increasingly complicated, especially when viewed from an ethical perspective. Scientific research has a responsibility to investigate the catastrophic consequences of global warming, while also considering scientific approaches that, if fully implemented, can mitigate the effects of climate change. On the other hand, it is typically not scientists who make the final decisions, but politicians and policymakers, where scientific and technical considerations may clash with the political values of a certain majority political group. The politicization of the climate crisis is a huge detriment to global action, where all of humanity is at stake yet only a portion of it believes or acts upon climate warnings. Implementing strategies to mitigate the effects of climate change touches upon the interests of many and opposing groups. Change of the status quo and current behaviour is rarely popular and generally met with opposition on all levels, from big companies to individuals. When the needs of the many (i.e. the world at large) outweigh the needs of the few (e.g., fossil fuel companies), how can ethical considerations be taken into account when there are clear conflicts of interests?

Ethics of Climate Change

In 1970, the German philosopher Hans Jonas coined the 'imperative of human responsibility', having in mind the ecological problems that were beginning to be discussed at that time: "*Act so that the effects of your action are compatible with the permanence of genuine human life*".[74] This principle is in line with the definition of sustainable development coined by the United Nations in 1987, namely the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".[75] From here, a first ethical challenge arises, since the ethical responsibility focuses primarily on not causing harm to those closest to us, on whom we think the consequences of our actions might fall.[76] Therefore, the fact that the damage of climate change will affect people who will be born in the future, brings ethics and intergenerational justice into consideration. In this regard, it is important to extend our thinking and responsibility beyond our life on Earth, learning to

---

[74] H. Jonas, The Imperative of Responsibility – In Search of an Ethics for the Technological Age, Hum. Stud. 11 (1984) 419-429.
[75] World Commission on Environment and Development (WCED). Our Common Future; Brundtland Report 1987. https://www.are.admin.ch/dam/are/en/dokumente/nachhaltige_entwicklung/dokumente/bericht/our_common_futurebrundtlandreport1987.pdf.download.pdf/our_common_futurebrundtlandreport1987.pdf
[76] Brown, Donald A., The Ethical Dimensions of Global Environmental Issues (2001). 130 Daedalus, Journal of the American Academy of Arts and Sciences 59, Widener Law School Legal Studies Research Paper No. 13-54, Available at SSRN: https://ssrn.com/abstract=2304395

weigh all our actions and think about their long-term consequences on future generations as well.

Focus Box: The Ethical Principles of Climate Change
In November 2017, the United Nations Educational Scientific and Cultural organisation (UNESCO) adopted a *Declaration of Ethical Principles in relation to Climate Change*, based on six ethical principles: **1. Prevention of harm:** anticipating the effects of climate change by implementing responsible policies and actions **2. Precautionary approach:** not postponing the implementation of such measures **3. Equity and justice:** ensuring that everyone, especially the most vulnerable, has access to resilience and mitigation strategies **4. Sustainable development:** adopting more sustainable daily practices **5. Solidarity:** supporting the people and groups most vulnerable to climate change **6. Scientific knowledge and integrity in decision-making:** improving the relation between science and policy to facilitate resilience to climate change.

Another ethical issue arises from the fact that the people most vulnerable to climate change are the poorest people who, paradoxically, are also least responsible for global warming. This is because the effects of climate change are not evenly distributed around the world: some regions will warm more than others, some will see a greater increase in rainfall and storms, while others will suffer more from droughts.[77] Furthermore, more vulnerable populations are less able to cope with the damage caused by these environmental disasters, due to a lack of adequate infrastructure and the institutional and financial ability to adapt to change.

Carbon inequality between the richest 1% of the world population and the rest is significant, and the divide is only increasing. It is predicted that by 2030, this 1% of the population will have a carbon footprint 30 times higher than that required to reach the goal set by the Paris Agreement.[78] It is imperative that those causing more harm bear greater responsibility in addressing the problem. Any other course of action which shifts responsibility onto vulnerable populations is unethical at its core.

[77] "Climate Change Hits Vulnerable Communities First and Hardest." International Institute for Sustainable Development. Accessed June 17, 2022. https://www.iisd.org/articles/insight/climate-change-hits-vulnerable-communities-first-and-hardest.
[78] T. Gore, Confronting carbon inequality, Putting climate justice at the heart of the COVID-19 recovery, 21 September 2020, https://oxfamilibrary.openrepository.com/bitstream/handle/10546/621052/mb-confronting-carbon-inequality-210920-en.pdf (accessed 20.06.2022)

Developing Countries and Disaster Management

Environmental disasters are the direct consequence of climate change, with catastrophic effects in the entire world. They include floods, storm surges, earthquakes, landslides, droughts, wildfires, and extreme temperatures, all events that can lead to humanitarian emergencies when they affect a large group of people and prevent them from meeting their basic needs, such as food, water or shelter.

According to a report by the World Meteorological organisation, published in 2021,[79] over the past 50 years there have been more than 11,000 reported disasters, more than 2 million fatalities and US$ 3.64 billion in economic loss. Of the top 10 disasters, the hazards that led to largest human losses during the period have been droughts (650,000 deaths), storms (577,232 deaths), floods (58,700 deaths) and extreme temperatures (55,736 deaths). And more than 91% of these deaths occurred in developing countries.

However, despite these worrying numbers, the report also notes how, over the 50 years, the number of deaths has decreased almost threefold, from more than 50,000 in the 1970s to less than 20,000 in the 2010s, more extreme weather and improved reporting notwithstanding. This is due not to a decrease in environmental disasters, but to improved early warnings and disaster management, which sees space applications as fundamental.

Role of Satellite Applications

Indeed, satellite applications, which include earth observation, communication and navigation satellites, are key tools to be used from the pre-event to the post-event phase of the disaster management cycle. First, risk maps show hazard exposure and vulnerability to events and their impacts, before they occur: this is possible thanks to the historical analysis of past events, which identifies threat thresholds. Having this information is crucial for making strategic decisions and strengthening resilience to climate change. In addition, during the event itself, again through remote sensing technology, it is possible to have real-time and accurate information on the extent and severity of damage, in order to organise a rapid response by rescuers. In this regard, satellite navigation and communication are also crucial, allowing first responders to locate the affected areas, which are often remote and lack adequate infrastructure, and to communicate with each other to coordinate rescue

[79] WMO. "Weather-Related Disasters Increase over Past 50 Years, Causing More Damage but Fewer Deaths." Last modified August 31, 2021. Accessed June 24, 2022. https://public.wmo.int/en/media/press-release/weather-related-disasters-increase-over-past-50-years-causing-more-damage-fewer.

operations. Finally, in the post-event phase, it is crucial to have information on the extent and scope of the damage for the reconstruction of affected facilities.

There are two United Nations entities who are working on facilitating the use of space applications on the ground where they are most needed: UNOSAT and UN-SPIDER. Since 2003 the United Nations Satellite Centre, UNOSAT, hosted at the United Nations Institute for Training and Research, is providing a Rapid Mapping Service to provide satellite image analysis during humanitarian emergencies, both natural disasters and conflict-situations, such as floods, earthquakes, storms, landslides, volcanoes, oil spills, chemical waste, refugee and Internally Displaced Person (IDP) camp mapping, conflict damage assessment and situation analysis.[80] The United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) is a platform, established in 2006, that facilitates the use of space-based technologies for disaster management and emergency response.[81]

Case Study: Urban Development in Mali
In 2018, the European Space Agency, in the framework of the EO4SD initiative, undertook a project in collaboration with the World Bank in the city of Bamako, Mali, with the aim of integrating EO satellite applications into the city's broader urban planning program. The African nation, in fact, suffers severely from the impacts of climate change and the safety of the population is often threatened by phenomena such as floods and drought.[82] The aim of the World Bank is to strengthen the managerial and financial capacity of the government to deal with this problem, through urban planning aimed at improving waste management and sanitation services and increasing resilience to floods. The project can count on a funding of $250 million, divided by different objectives, among which $17 million will be used in strengthening institutional capacity, both at central and local level. ESA's role was to support the project by providing a portfolio of geospatial services and products related to public spaces in the urban area of the city of Bamako, in order to make it easier to assess the spatial dimensions of the project and the challenges to be faced. This portfolio had to be user-friendly, as it would be used not only by WB experts, but also by the Maltese interface, which would perform the in-situ verification through local surveys.

[80] UNOSAT Rapid Mapping Service. Data and other products produced by UNOSAT in response to humanitarian emergencies related to disasters, complex emergencies and conflict situations. https://www.unitar.org/maps/unosat-rapid-mapping-service
[81] United Nations Platform for Space-based Information for Disaster Management and Emergency Response. Recommended Practices. https://www.un-spider.org/advisory-support/recommended-practices
[82] World Bank. Bamako Urban Resilience Project. https://documents1.worldbank.org/curated/en/265971620032577848/pdf/Project-Information-Document-Bamako-Urban-Resilience-Project-P171658.pdf

Among the various services and final products provided by ESA is the Urban Land Use Land Cover – Status of year 2018, which provides a detailed overview of the distribution of various areas in the city of Bamako in 2018. The Very High-Resolution satellite data used to create these maps were purchased from commercial providers such as Airbus, thanks to mono-licence agreements without which the price of the products would have been significantly higher.

Accessibility and Usability of Data

It appears only logical that to be able to be used, data produced in-situ and by satellites must be accessible through infrastructures. Nevertheless, establishment of such a structure requires sound analysis of their sustainability (e.g., time limitation of international organisation funding)[83] and contextual consideration such as easy access to web-portal or data legislation.

In addition, providing access to data through the creation of national or international infrastructures will not have an effect on the usability of those data if academics, companies or citizens cannot access those data either for technological reasons, access to capitals either financial, social or cultural[84] or legal considerations.[85] Thus, accessibility and usability of data in the context of spatial data should, furthermore and in a complementary way with infrastructure sustainability, be understood in three different dimensions:

1) The availability of the data i.e. spatial data infrastructures, interoperability, open access [86]
2) The availability of technological tools such as internet access, computer capacity, digital literacy [87]
3) Inclusiveness of standards design i.e. possibility to be used by persons with disabilities or adapted to minority cultures[58,59]

[83] G. Giff, D. Coleman, Funding Models for SDI Implementation: from Local to Global, 2002, https://www.academia.edu/22265609/Funding_models_for_SDI_implementation_From_local_to_global (accessed 20.06.2022)
[84] Van Schalkwyk, Francois & Cañares, Michael & Chattapadhyay, Sumandro & Andrason, Alexander. (2015). Open Data Intermediaries in Developing Countries.
[85] WGIC (2021), Public-Private Geospatial Collaborations: Exploring Potential Partnership Models -WGIC Policy Report, https://wgicouncil.org/publication/reports/industry-reports/wgic-geospatial-ppps-report-report-public-private-partnership-models-geospatial-collaborations-2021/
[86] Global Partnership for Sustainable Development, Inclusive design principles, 12 July 2021, https://www.data4sdgs.org/index.php/resources/inclusive-design-principles (accessed 20.06.2022)
[87] CBM Global Disability Inclusion, Disability Data advocacy toolkit, 2021, https://cbm-global.org/wp-content/uploads/2021/12/Disability_Data_advocacy_toolkit_English.pdf (accessed 20.06.2022)

Besides, and as underlined above, vulnerable and minority populations will also be the most at risk as a consequence of global warming. Nevertheless, those populations are also the least likely to access data either for technological reasons but also because those data are not always adapted to their culture or language, even though the data could help improve their adaptation to new environmental conditions through monitoring and to implement a new policy on data-based evidence and modelling. And this, even though the “first line” position of those countries and populations could contribute to the improvement of climate monitoring.

As an example, it should be recalled that according to the International Telecommunication Union (ITU), 37% of the world population still doesn’t have any access to the internet.[88] Thus, access and usability should be understood from a way broader perspective than the establishment of a portal to reach open access data.

International Cooperation

In the light of this technological advancement, the ethical problem returns again that many countries, sometimes the most affected by disasters, do not have access to multi-hazard early warning systems. Also, the gaps in weather and hydrological observing networks cannot be overlooked. For this reason, it is also important that those who have these services make them available to these countries, in an exercise of international cooperation. On the basis of this principle, various initiatives by various organisations and space agencies have sprung up to tackle the problem of climate change worldwide.

[88] ITU, Facts and Figures 2021 (2021), https://www.itu.int/en/myitu/Publications/2021/11/25/14/45/Facts-and-figures-2021

World Meteorological Organization

WMO is dedicated to international cooperation and coordination on the state and behaviour of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources.

Applied Sciences Program

The Program provides support and funding to help institutions and individuals make better decisions about our environment, food, water, health and safety.
Among the focus areas there are Ecological forecasting, Disasters, Water Resources and Capacity Building.

Climate Change Initiative (CCI)

It is a coordinated research and development program among ESA's Member States, which aim is to generate robust, long term global satellite derived data sets for key indicators of climate change.

International Partnership Program (IPP)

IPP focuses strongly on using the UK space sector research and innovation strengths to deliver a sustainable economic or societal benefit to emerging and developing economies around the world. Lots of the implemented projects tackle climate change

As stated by Mami Mizutori, Special Representative of the Secretary-General for Disaster Risk Reduction and Head of UNDRR:

"More international cooperation is needed to tackle the chronic problem of huge numbers of people being displaced each year by floods, storms and drought. We need greater investment in comprehensive disaster risk management ensuring that climate change adaptation is integrated in national and local disaster risk reduction strategies".[89]

[89] World Meteorological organisation (WMO), WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019) (WMO-No. 1267), WMO, 2021.

In this regard, it is crucial that synergies are created between the private sector, nongovernmental organisations (NGOs), and governments through public-private partnerships. Indeed, innovation requires a high sum of financial capital and climate-smart infrastructure that can be leveraged by a coordinated effort, resulting in the most efficient use of resources. The high risk associated with the climate change issue that leads the private sector to invest little on climate action can be indeed mitigated thanks to incentives for private companies from the government and an enhanced cooperation.

Recommendations

- Conceiving contemporary social life by integrating concern for the sustainability of the system in the very long term, including future generations within the scope of our responsibilities.
- The environmental concerns must be accompanied by contemporary ethical requirements, such as respect for human rights and equal consideration for all human beings.
- International cooperation between governments, organisations, the private sector and NGOs must be strengthened to assist the most vulnerable-to- climate change countries to tackle its catastrophic effects.
- Ensuring that policy to develop access to data are not only considering data infrastructures as such but also possibility to access technologically or inclusively to data

6. Green Economy and Finance

Although there is no internationally agreed definition of green economy, UNEP's definition is the most commonly used: it defines green economy as one which is "low carbon, resource efficient and socially inclusive".[90] More broadly, the green economy is a concept focused on a sustainable way to enhance people's lives and the environment, thus supporting climate action. The objective of the green economy is to improve the use of resources, especially trying to reduce them, with the overall aim to decrease GHG emissions.

The green economy encompasses several sectors, from agriculture to the blue economy, from transport to sanitation and waste management. Governments should establish a strategic goal to implement green technology, since innovation is a key aspect of this concept; and in this regard, space technology can serve as an important tool to facilitate the transition toward a green economy. Table 5 shows some examples.

Table 5: Examples of satellite use cases to foster green economy

Sector	Satellite Use Case
Urban	• Assessing the extent of urban footprint and its growth over time • Warnings about potential infrastructure instability
Agriculture	• Analysing climate impact on crops and fields' productivity • Identifying conditions for disease outbreak, famine, or disasters
Transport	• Supporting real-time traffic management systems • Detailed mapping of roads and their features
Waste	• Identifying the optimal waste landfill sites • Detecting and early warning of landfill subsurface fires
Energy	• Optimising of operations to minimise costs and emissions • Supporting authorities to define, manage, and monitor compliance with the law
Forestry	• Detecting forest carbon stocks/ emissions • Monitoring illegal deforestation
Blue economy	• Monitoring of coastal and ocean environments/ecosystems • Assessing ocean conditions for workers/fishers at sea

[90] United Nations Environment Programme, "Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication," 2011.

Space for Finance

Climate Finance

Climate finance is "funding at the local, national or transnational level that supports the actions needed to combat climate change".[91] Large scale investments are, indeed, necessary to mitigate the effects of climate change and to adapt to them. In 2016, the UNEP Adaptation Gap Report estimated that the annual costs of adaptation to climate change in developing countries could be between US$ 140 billion and US$ 300 billion by 2030. However, according to the newest Adaptation Gap Report[92], this cost has been raised, since economic climate change impacts are higher than previously predicted.

More recently, UNFCCC published the "First report on the determination of the needs of developing country Parties related to implementing the Convention and the Paris Agreement",[65] which analysed a big number (not specified in the report) of national documents to identify developing countries financial needs, among the others. This explored quantitative information which was derived from economic modelling (costed needs), as well as qualitative information derived from descriptions of strategic directions, national priorities, and planned activities. The table below shows a summary of the results:

Table 6: Needs expressed in nationally determined contributions by region[93]

Region	Number of expressed needs	Number of expressed needs with financial information (i.e. costed needs)	Costed needs based on available financial information (US$ billion)
African States	1,529	874	2,459.56 - 2,460.56
Asia-Pacific States	1,677	630	3,180.39 - 3,250.39
Eastern European States	282	112	9.36
Latin American and Caribbean States	771	166	168.18–168.26

[91] International Fund for Agricultural Development (IFAD), IFAD Annual Report 2021, 2022, https://www.fao.org/family-farming/detail/en/c/1600796/ (accessed 22.06.2022)
[92] United Nations Environment Programme, "Adaptation Gap Report 2021." UNEP - UN Environment Programme. Last modified October 31, 2021. Accessed June 27, 2022. http://www.unep.org/resources/adaptation-gap-report-2021.
[93] UNFCCC. "First Report on the Determination of the Needs of Developing Country Parties Related to Implementing the Convention and the Paris Agreement (NDR) | UNFCCC." Last modified 2021. Accessed June 27, 2022. https://unfccc.int/topics/climate-finance/workstreams/determination-of-the-needs-of-developing-country-parties/first-report-on-the-determination-of-the-needs-of-developing-country-parties-related-to-implementing.

The Paris Agreement has foreseen a financial mechanism to support the pooling of climate finance for developing countries: it states that financial operations can be entrusted to one or more existing funds. In this regard, the main entities that serve the Paris Agreement are the Global Environment Facility (GEF), which manages the Special Climate Change Fund (SCCF) and the Least Developed Countries Fund (LDCF), and the Green Climate Fund (GCF).

Global Environment Facility

The largest multilateral trust fund focused on enabling developing countries to invest in nature, and supports the implementation of major international conventions including on biodiversity, climate change, chemicals and desertification. It has provided more than US$21.7 bn in grants and mobilised an additional US$119 bn in co-financing for more than 5,000 projects and programmes. GEF has a long history with the use of EO and other geospatial technology: "Many GEF projects and programs use Earth observation data to design, implement, monitor and evaluate interventions. However, the uptake and use of Earth observation technology by GEF agencies is uneven."[94]

Green Climate Fund

The world's largest climate fund, mandated to support developing countries raise and realize their Nationally Determined Contributions (NDC) ambitions towards low-emissions, climate-resilient pathways. The Green Climate Fund has a full-time secretariat in South Korea and as at July 2022, has a fund balance of over US$9 billion. The World Bank is the trustee.

Supporting Climate Finance with Space

In order to move large sums of capital, it is important to assess the risks. For this reason, investors always seek to understand the sustainability credentials of the companies in which they invest, in order to make more informed decisions. To do so, they typically rely on companies' self-reported annual reports, but this type of reporting is voluntary, and therefore often incomplete or biassed. In addition, the methodologies used by companies differ, and comparing data across companies and sectors becomes complicated; most importantly, the

[94] GEO. "New Publications to Promote the Use of Earth Observations at the Global Environment Facility." GEO Observations Blog. Last modified 2020. Accessed July 2, 2022

frequency of releases is too low, with most companies and private agencies publishing these reports only once a year.[95]

In this context, data provided by satellites can add a strong value, since they can complement current information sources within the financial sector. Differently from self-reported documents, these data are complete, accurate and unbiased. Moreover, they solve the problems derived from both the fragmentation of methodology among different companies and sectors - since data captured from the same instrument allows a standardised analysis - and the frequency of information - since these types of data are timely.

Space technology can help accelerate the alignment between finance and climate action, especially when combined with other data sources and technologies. It is therefore important to raise financial companies and investors' awareness about space benefits, even as we are going toward a democratisation of space that is making satellite imagery always more accessible.

Recommendations

- Global stakeholders should understand and assess the financial needs of developing countries, as well as understand how these financial resources can be mobilised
- Provision of resources should aim to achieve a balance between adaptation and mitigation
- Raising financial companies and investors' awareness about space benefits, even as we are going toward a democratisation of space that is making satellite imagery always more accessible
- Governments should establish a strategic goal to implement green technologies, since innovation is a key aspect of this concept

[95] European Space Agancy (ESA), How Space supports the Financial sector to foster the transition towards a green and sustainable future, 20 April 2021, https://commercialisation.esa.int/2021/04/how-space-supports-the-financial-sector-to-foster-the-transition-towards-a-green-and-sustainable-future/ (accessed 27 June 2022)

7. New Space Economy and Space Industry

According to the OECD Handbook on Measuring the Space Economy,[96] the full range of activities and resource uses that generate value and benefits for people while exploring, researching, understanding, managing, and using space are what constitutes the space economy. The New Space economy can be defined as a fast-expanding approach propelled by the commercialisation of the space sector, historically centred on institutional activities. Public-Private Partnerships (PPPs), new investment philosophies, alternative funding schemes, and disruptive technology developments have enabled the expansion of the space private space sector, primarily motivated by business interests.

Along with the expansion and significant transformation of the space industry, the space economy is expanding and changing, as shown by the steady entanglement of space, society and economy. Today's deployed space infrastructure paves the way for the creation of new services, which in turn opens the door for new applications in fields like meteorology, energy, telecommunications, insurance, transportation, maritime, aviation, and urban development.

The space industry is not only expanding on its own, but it also plays a critical role in fostering the development of other industries, generating a positive impact on the economy and society. Due to these factors, it has been predicted that the space sector could surpass the oil industry as the next industry to generate a trillion dollars by 2040.[97] The main trends that are currently affecting the space economy are strictly connected. The worldwide public interest in investing in space operations is still growing at a similar pace to the number of actors in the space ecosystem. In 2021, the space private investments registered a record amount that is connected to its increased profitability, as well as to the booming venture capital (VC) sector.[98]

The space economy has also been affected by the growth of worldwide commercial activities such as cubesats, mini satellites, and micro launchers as well as prospective new industries like space tourism and in-orbit servicing.

[96] OECD (2022), OECD Handbook on Measuring the Space Economy, 2nd Edition, OECD Publishing, Paris, https://doi.org/10.1787/8bfef437-en.

[97] "The space industry is on its way to reach $1 trillion in revenue by 2040, Citi says." CNBC, 21 May 2022, https://www.cnbc.com/2022/05/21/space-industry-is-on-its-way-to-1-trillion-in-revenue-by-2040-citi.html.

[98] "Investors Poured Record 145 billion into space companies in 2021." Forbes, https://www.forbes.com/sites/sergeiklebnikov/2022/01/18/investors-poured-record-145-billion-into-space-companies-including-elon-musks-spacex-in-2021/?sh=78af6a5341f5

Space 4.0

After the 2016 and the conclusion of ESA Ministerial Council (CM16), the definition of the Space 4.0 era has been largely accepted as a time when space is evolving from being the preserve of the governments of a few spacefaring nations to an increased number of diverse space actors' involvement worldwide,[99] including the emergence of private companies, participation with academia, industry and citizens, digitalization and global interaction. Space 4.0 represents the evolution of the space sector into a new era, characterised by a new playing field. This era is an advancement through strict interaction between governments, private sector, society and politics. Space 4.0 is analogous to, and is intertwined with, Industry 4.0, which is considered as the unfolding fourth industrial revolution of manufacturing and services. To meet the challenges and to proactively develop the different aspects of Space 4.0, the European space sector can become globally competitive only by wholly integrating space into European society and economy. This requires a sustainable space sector intrinsically connected with the foundations of society and economy. For this to happen, space must be safe, secure, easily and readily accessible, and built on a foundation of excellence in science and technology, broadly and continuously over time.

Terrestrial Markets

Our terrestrial living can benefit from space technologies in many ways: traditional space assets such as Earth observation (including space weather satellites), satellite navigation, satellite communications, and human spaceflight technologies can serve and support vertical markets on Earth. Telecommunication satellites yet serve this purpose and contribute to this on the ground and in space. Equally, EO capabilities provide us data to be transformed into information on the status of the monitored area. A valuable example of space technologies penetrating more than one vertical market are smart cities. One of the ultimate goals of a smart city is data and information services interconnectivity, the ability of all the green technological components, and non, to exchange data for operation accuracy and results optimisation. Climate change is showcasing how all space technologies are essential for the green development of vertical markets is clearly one of the main ones, also acting as a push toward digitalization boost and green technologies development.

[99] ESA - What is space 4.0? (n.d.). European Space Agency. https://www.esa.int/About_Us/Ministerial_Council_2016/What_is_space_4.0

Smart Cities

Cities are sprawling and causing close to three-quarters of GHG emissions - while also increasingly suffering from the impact of climate change. According to a report from the United Nations Development Programme (UNDP) they are responsible for 70% of global greenhouse gas (GHG) emissions.[100] Cities are highly exposed to many impacts of climate change they contribute to, in particular heat stress, flooding and health emergencies. In fact, making cities more resilient, sustainable, inclusive, and safe is one of the United Nations' Sustainable Development Goals (SDG 11), which requires sustained and steady investments.

During the third quarter of 2020, the European Space Agency's Downstream Gateway launched an initiative called Space for Smart and Circular Cities,[101] with the intent to understand the need, trends, synergies, and the practices of global municipalities adopting, or need to adopt, smart and sustainable solutions for the cities of the future. The discussions among stakeholders explored how space acts as an enabler and driver in the smart cities' development, while promoting further collaboration among new invited stakeholders. By becoming climate-smart, cities can avoid locking-in to high-emissions and exposed pathways, while enhancing future attractiveness and competitiveness. As the world's population becomes increasingly urban, it is critical that cities invest in physical infrastructure and natural capital solutions that will enable them to reduce their emissions and increase their resilience to climate change and other shocks and stresses. A climate-smart city minimises environmental damage, monitors and reduces air pollution and GHG emissions, and maximises opportunities to enhance urban resilience and local mobility, thereby improving the natural environment and overall livability and appeal of the city.

Efforts to address climate change in urban areas through investments to enhance air quality, the circular economy, green buildings, green spaces as well as compact, optimal densification and urban form, add up to the quality of life, which, in turn, attracts talent and businesses and increases the competitive edge of a city. Green investments can also support in decreasing the cost of living and help attract or retain cross-sectoral talents in urban centres. Taking into account the global climate-smart urban infrastructure only, the investment potential across Earth's existing infrastructure is substantial. Space assets could boost some $29.4 trillion in opportunities that exist in developing countries alone across four urban sectors that reduce emissions: green energy, mobility, climate-smart water, and

[100] "Urban Issues | Climate Promise." UNDP Climate Promise, https://climatepromise.undp.org/what-we-do/areas-of-work/urban-issues.
[101] "Space for Smart and Circular Cities - ESA Commercialisation Gateway." ESA Commercialisation Gateway, https://commercialisation.esa.int/2021/07/space-for-smart-and-circular-cities/.

green buildings.[102] In this respect, the private space and non-space sectors have an important role to play, and their perception of climate investment is changing, particularly in cities. Despite the investment potential, cities are still facing unique challenges in accessing finance to fill the climate-smart investment gap. Also in this specific market, the private space sector shares the key message of considering satellites not just as technology demonstrators, but as components of a critical communication and information-based infrastructure for modern societies.

Many of the barriers cities face in attracting private investment are rooted in their limited control over broader enabling environmental conditions, such as national policies and regulations, as well as limited institutional capacity to plan and design climate-aligned investment opportunities for the private sector. In this context, the space sector is crucial, as it provides different sources of funding and opportunities at international and national level.

Space Commercialization and the Role of Private Entities

The global landscape of space activities is constantly undergoing profound changes. Whereas the vast majority of space activities are still led by governments, with private industries acting as suppliers for public programs and relying massively on public funding, a disruptive and commercially driven ecosystem has emerged over the last decade. Marked by ambitious private endeavours featuring innovative schemes and business models, the space market saw a steady increase in the involvement of commercial firms in space activities since the early 2000s. Also in 2021, two-thirds of the revenue in the $370 billion space economy comes from commercial applications, although military and institutional orders still make up a sizable portion of the overall profit.[103] As climate change becomes a more potent macroeconomic trend with real-world effects, climate resilience also offers considerable private investment opportunities. The value, significance, and return of businesses and assets that are inherently resilient or offer resilience solutions, like the space sector ones, will increase as the climate change issue deepens and becomes better understood by markets.

[102] IFC Report Identifies More Than $29 Trillion in Climate Investment Opportunities in Cities by 2030. (n.d.). IFC Press Releases. Retrieved from https://pressroom.ifc.org/all/pages/PressDetail.aspx?ID=25011

[103] "Euroconsult estimates that the global space economy totaled $370 billion in 2021." Euroconsult, https://www.euroconsult-ec.com/press-release/euroconsult-estimates-that-the-global-space-economy-totaled-370-billion-in-2021/.

As ESA illustrated at COP26, the international community is at a pivotal moment for climate action, and space is part of the resolution.[104] In Europe, the Agency is committed to enabling governments and businesses to take advantage of satellite technology to enable the transition to a more sustainable economy. So far, it has supported over one hundred companies in the development and advancement of applications that support Europe's green objectives, facilitating decarbonization in key areas of the economy.

In this historical moment, there is the need and urge to demonstrate how the space sector is adapting to reduce its own impact on climate change. This can be achieved by disseminating to the general public the latest initiatives in which space technologies and applications are actively contributing to climate change mitigation and adaptation. For the United Nations Office for Outer Space Affairs, 'Space Economy' is a concept that captures, in the broadest sense, the role space is playing to support sustainable socio-economic development. In the wake of NASA's Commercial Orbital Transportation Services, the disruptive commercial approach to space, New Space, has emerged.

In this new ecosystem, public actors are eager to explore new ways to conduct space programs and to foster the development of the commercial space sector. In turn, private actors also seek to play a more prominent role, leveraging public funding and private investment to develop new business models and to address new markets. The result in years has been cheaper access to space, a provision of richer and affordable information through space technologies, and a new entrepreneurial spirit investing in disruptive technology.

New Space Market Volatility

The swift reaction to user's demand has been steadily emerging in Europe in a moment where the total private space investment reached a record number of €611 million (2021).[105] If the European Space start-ups market is closely analysed, it reveals consistent developments and a high pace of technological innovation, intertwined with a widespread European geographical distribution in terms of investments. Reaction times in the world of business are a challenge.

[104] "ESA accelerates space-based climate action at COP26." European Space Agency, 1 November 2021, https://www.esa.int/Applications/Observing_the_Earth/ESA_accelerates_space-based_climate_action_at_COP26
[105] European Space Policy Institute. Space Venture Europe 2021 - ESPI. (2022, June 23). https://www.espi.or.at/reports/space-venture-europe-2021/

In March 2021, Josef Aschbacher was appointed as the new Director General at ESA. The new ESA DG worked with the Member States to define the Agency's aspirations for the coming years.[106] The resulting Agenda 2025 established 5 main priorities, one of which addresses the facilitation of commercial activities for green and digital space technologies. The Agency recognizes the quick reaction of space to user demand, either in critical and ordinary circumstances. It underlines that climate change, hence climate actions supported by space-based technologies, are among the priorities of ESA as the intergovernmental space agency, and its internal and external ecosystem, e.g, space and non-space industry, well-established and-non companies, investors, academia.

On an industry level, data demand volatility in relation to data demand forecasting is one of the most significant difficulties for today' business. While data availability grows, customer purchase patterns become more complicated and hence more difficult to discover or anticipate. When looking at the climate change market, the pattern is even more unclear. In this regard, the added value of space relies on its capacity to quickly react to the demand of users, either in terms of real-time data provision (see section 3) and as a support to nascent markets feeding their need for accurate data.

Space as an Imperfect Model of Engagement

As another engagement priority, the ESA Agenda 2025 sets the acquisition and retention of talents with the skills and technical capability to strengthen and accelerate the development of green technologies driving our future. Despite the numbers showing a diversity gap that still characterises the space sector, especially in terms of STEAM and gender diversity, the ability of strong cooperation and technical collaboration with newly created markets, adjacent sectors, and new stakeholders is in place. It can be considered as an imperfect model of inclusive engagement, standing for the enlargement of cross-sectoral collaboration, cross-technologies, innovations, their accessibility, and new models of business acceleration.

On a technical level, since space is not recognized as a category in international standards of industrial classification, worldwide national space statistics differ in definition, coverage, and methodology, generating a lack of international comparability. Also, the use of space economy data is highly fragmented, and the space sector is not yet set up to consistently collect and report data supporting the evaluation of socio-economic impacts. Nevertheless,

[106] "ESA - Agenda 2025." European Space Agency, https://www.esa.int/About_Us/ESA_Publications/Agenda_2025

the space sectors globally expanded and interconnected to several industry markets, also thanks to Artificial Intelligence (AI) as a technology and cross-sectoral collaboration enabler.

Cross-Industry Collaborations

In the last 8 years, the global space sector has demonstrated to be capable of innovative collaboration with the most unexpected markets. From food, to cosmetics, agriculture, biotechnologies, finance, and cultural heritage, its ability to spin-off and spin-in to adjacent sectors' technologies is at the basis of the technology transfer, as described in the section 3 of this report. The process of transferring a technology, product, or service ideated, developed, and applied in the space sector to any other terrestrial sector is defined spin-off, whereas, when the contrary happens, it is defined spin-in. However, a few specific technologies that joined forces with the space assets are essential for the development of environmental mission, future settlements, and enhancements of overall national and international security in data exchange.

Additive Manufacturing

The Additive Manufacturing (AM) technology is an example of a successful spin-in of a nascent market in the space sector. Industrial-scale 3D printing is known as additive manufacturing, which also refers to more sophisticated processes like selective laser sintering (SLS). SLS is the method of laser sintering powdered material at computer-defined locations in space using a 3D design to create a solid mass of material before the point of liquefaction.[107] Today, the technology for AM is widely available and increasingly more accessible; both large-scale manufacturers and newcomers can utilise reasonably cost 3D printers to build a wide range of goods for varied applications. The space industry has recognized the enormous capacity of the additive industry to develop a sustainable production system, innovating the existing supply chain and utilizing new advanced materials. The improvements affecting the supply chain continue to create numerous opportunities for businesses and organisations of all sizes.

Future human spaceflight and settlement will be greatly facilitated by space additive manufacturing. In reality, it has already made it possible to build less expensive and lighter satellites, facilitating efficient cargo launch into space. In systems designed for space travel, 3D printing offers the most efficient method for weight optimisation. This holds true for both

[107] Yasa, Evren. "Selective laser melting: principles and surface quality." Additive Manufacturing. Elsevier, 2021. 77-120.

launch vehicles and spaceborne systems and equipment up until a point when resources are accumulated in space. By continuing to promote the development of new materials, such as metal replacement, high-performance polymers, and composites, additive manufacturing can significantly reduce the cost of commercial space activities when combined with weight-optimised designs.

According to a recent article published by Delft University of Technology,[108] additive manufacturing might cut world energy use by 25% by 2050. Even more ambitious scenarios for the massive deployment of renewable energy would struggle to achieve that level of influence on emissions. Additive manufacturing offers the possibility of creating high-performance materials and processes with smaller carbon footprints. It promises to do so by addressing the carbon impact of the three major facets of a product's carbon footprint: materials, manufacturing, and transportation. By enabling energy-efficient designs that utilise a limited amount of material than conventional manufacturing techniques, 3D printing may play a significant role in reducing the carbon footprint of the materials component of production. This process is also known as dematerialization. 3D printing can also lower the embodied energy of a material by replacing spare components that would have typically been created using a high-embodied-energy material. On Earth, not all of the metal components of a car or piece of equipment actually need to be composed of metal. Many times, 3D-printed polymer or composite components may complete the task just as well while requiring less energy to produce (and often less weight to carry). In some circumstances, 3D printing is, also, far more energy-efficient than a conventional production method and facilitates the handling, storage, and delivery of the spare components or product to the customer. Compared to traditional production techniques, additive manufacturing enables very different businesses to be more cost-effective, adaptable, efficient, and environmentally friendly. It has been recognized that AM has the power to enable policy implementations. Additive manufacturing offers improvement for businesses to better satisfy regulations put out to combat climate change by lowering emissions and waste by products in the face of growing concerns over greenhouse gas emissions.

[108] Leendert A. Verhoef, Bart W. Budde, Cindhuja Chockalingam, Brais García Nodar, Ad J.M. van Wijk, The effect of additive manufacturing on global energy demand: An assessment using a bottom-up approach, Energy Policy, Volume 112, 2018, Pages 349-360, https://doi.org/10.1016/j.enpol.2017.10.034.

Artificial Intelligence and Machine Learning

Artificial intelligence is useful for more than just analysing large amounts of data and satellite images. It calculates, predicts, and makes decisions to mitigate the effects of climate change. AI improves our understanding of the effects across multiple geographical places by generating effective models for weather forecasting and environmental monitoring, as an EO application example. By exposing the data to artificial intelligence methods, the algorithms are able to play with the data and discover statistical links. In 2018, the European Commission defined AI-based systems as those capable of simulating human behaviour, interpreting the external environment and performing tasks with a degree of autonomy. This definition provides an idea of the technology's accuracy and why it can concretely help governments in preparing actions to counter rising sea levels, catastrophic events such as hurricanes, or to monitor changes in natural habitats.

Satellites orbiting the Earth transmit hundreds of terabytes of data to ground stations every day. In this context, the role of AI in analysing huge quantities of data is crucial. If we take into account all the data transformed into information, such as the different climate variables, for instance, they operate in a non-linear fashion. Machine learning allows the sort out and grouping of these data in order to improve classification and build new statistical models. In other words, AI algorithms, computer systems that learn and act in response to their environment, can improve the capability of EO operations for analysis, understanding, and decision-making. Furthermore, AI assists in the automatic creation of statistical connections that humans would struggle to find. These 'convolutional neural network' algorithms have the potential to solve scientific evaluation and classification problems in a variety of climates.[109] Machine learning will also be increasingly useful in finding statistical links and trends between huge amounts of data, as well as for modelling and classifying ever-changing data. Hence, if applied to facilitate the extraction from data to information for weather forecasting and environmental monitoring, AI enables a better understanding of the impact of climate change in various geographical locations: this is done by interpreting data collected to predict extreme weather conditions. In the report issued by the Global Partnership presented at the COP26, it was discussed the key role AI can play in prediction, mitigation and adaptation in ways we cannot afford to ignore anymore. At industry level, significant advances in the field have been made by Microsoft, which is building a geospatial

[109] Liu, Yunjie & Racah, Evan & Prabhat, Mr & Correa, Joaquin & Khosrowshahi, Amir & Lavers, David & Kunkel, Kenneth & Wehner, Michael & Collins, William. (2016). Application of Deep Convolutional Neural Networks for Detecting Extreme Weather in Climate Datasets.

research system based on AI aimed at speeding up climate decision-making and 'averting environmental disaster'. Along with the enabling features that AI can offer, it is worthy to note the impact it could indirectly have in terms of energy consumption for its operability. In this historical moment of energy transition, the positive aspects could outweigh the negative ones since its accurate human assistance in the mitigation of climate change's effects.

Quantum Computing

Quantum Computing (QC) could support lower emissions in some of the most difficult or emissions-intensive fields, such as agriculture or direct-air capture, as well as speed developments in large-scale technology like solar panels or batteries.[110] QC is a novel technology that uses quantum mechanics rules to achieve exponentially greater performance for certain types of calculations, potentially leading to big advancements in a variety of end industries. Quantum technologies for Earth monitoring and sensing are essential to fully grasp the enormously complex dynamics that govern our natural environment. Standing on ESA's Quantum Technologies White Paper,[111] gravitational field mapping from space is critical for understanding climate change, hydro- and biosphere evolution, and tectonics and earthquake prediction.

The recent emergence of macroscopic quantum matter, such as Bose-Einstein condensates and the related Nobel Prize-winning protocols, has led to the development of inertial quantum sensors based on atom interferometry. Quantum gravity sensors use coherent quantum matter waves as test masses, resulting in instruments that are significantly more sensitive and exact. Space-based quantum sensors will increase monitoring of the earth's resources and forecasting of earthquakes and the negative effects of climate change such as draughts and floods. Two main missions are representatives of the efforts internationally undertaken in the field of quantum. NASA's gravity mission Grace recently discovered that the temperature of the water in deep ocean rifts has not altered in recent decades. It is being employed as an early warning system for floods and draughts in both the agriculturally vital Midwest of the United States and the Congolese rainforest. The gravity mission (GOCE) of the European Space Agency created precise maps of deep-sea Ocean currents, which are significant drivers of the Earth's climate. It discovered the remains of lost continents trapped

[110] IBM, What is Quantum Computing? https://www.ibm.com/topics/quantum-computing#:~:text=Quantum%20computing%20is%20a%20rapidly,available%20to%20thousands%20of%20developers (accessed 03.06.22)

[111] Quantum Technologies in Space. ESA Policy white paper https://www.cosmos.esa.int/documents/1866264/3219248/BassiA_QT_In_Space_-_White_Paper.pdf/6f50e4bc-9fac-8f72-0ec0-f8e030adc499?t=1565184619333

deep beneath Antarctica's ice sheet, as well as a post-glacial rebound. Moreover, GALILEO demonstrates Europe's ambition to gain independence in crucial space technologies, especially when considering the recent developments of technologies for space-borne high-precision gravity sensing. These sensors, with their long-term stability and minimal drift, have the potential to improve EO overall capabilities. Considering QC as a relatively new discipline, the majority of funding for fundamental research in the field is currently provided by public resources.[112]

Recommendations

- Global industries now have the opportunity to select the use of appropriate technologies to achieve environmental goals. The space sector shall advocate for the improved use of environmentally friendly technologies, like additive manufacturing, underlying the spin-in process at the basis of its adoption in the sector.
- The Space sector is a good example of cross-collaboration and contamination. It should invite global stakeholders to a cross-sectoral approach by sharing its best practices and most successful initiatives (demonstrable successfully despite being developed in a very limited time frame so far)
- Space technical experts can support polluting industries, such as the plastic one, by sharing innovative industrial processes and disruptive management practices deriving from its best practices to push for industry transition on materials selection and use, including the disposal of inorganic waste.
- The Space Industry, and consequently the environmental market, would benefit from a deeper interaction between UN, UE, particularly EC, and ESA. Conveying the same message in a harmonised way can lead to further initiatives.
- Space is the only industry that has to rely on fully recycling systems in order to achieve orbital platforms and missions' objectives. The ISS shall be technically presented and explained to the general public and to water, waste, and manufacturing stakeholders to practically inspire analogue recycling processes and systems.

[112] McKinsey and Company, The rise of Quantum Computing, https://www.mckinsey.com/featured-insights/the-rise-of-quantum-computing (accessed 03.06.22)

8. Summary of Recommendations to Stakeholders

This SGAC policy report culminates in recommendations developed based on the aforementioned research areas, targeting three main stakeholder groups: Scientific Community and Academia, Governments and Policy Makers, and Commercial Industries. The following recommendations aim to function as guidelines for these stakeholders in the adoption and use of space for climate action across various sectors and competencies.

Scientific Community and Academia

The main recommendations for academia and the scientific community centre around the development of educational programs and scientific communication to the general public:

- Adapt educational curriculum for EO and GIS competences adapted to climate change and specific contextual (national, regional…) needs
- Make education and training related to climate data more active and adapted to concrete usage and foster the promotion of existing open access data in curriculum
- Promote career in EO and GIS field by facilitating geospatial data training in secondary school and encouraging interdisciplinary dialogue and courses at the university level
- Encourage outreach from SETI scientists and astrobiologists and incorporate a wider perspective into curriculums concerning Earth and life sciences
- Use virtual reality and story-telling tools to educate and drive a sustainable shift in behaviour, particularly by making the phenomenon of the Overview Effect more accessible
- Encourage outreach from SETI scientists and astrobiologists and incorporate a wider perspective into curriculums concerning Earth and life sciences
- Venus and Mars should be treated as valuable case studies for understanding the climate of our own planet
- Highlight benefits of space technology and EO data and foster their implementation, particularly in emerging space countries and for addressing the climate crisis

- Discoveries from astrobiology and planetary sciences should be communicated clearly and without biassed interpretations

Governments and Policy Makers

Policy makers, governments, and space agencies play a key role in guiding the development of space for climate action. This also includes developing the right tools to assess and reduce the impacts of space industry on the environment, and ensuring the sustainability of space exploration endeavours:

- harmonisation of environmental impact assessments across space agencies and private entities
- Development of a space debris indicator and characterising the environmental impact of spacecraft demise
- Characterising the environmental impact of rocket launches and propellant burn in the atmosphere
- Streamlining environmental impact assessment into the requirements of ongoing space missions, as well as future projects
- Decoupling defence and space, in order to reduce militarization as well as the significant detrimental social and environmental impacts associated with it
- Opening up of a multi-stakeholders forum to deepen the comprehension and collaboration on binding and non-binding legal instruments at international level
- Generating an information process involving intergovernmental and international organisations (UN, UE) in order to bring light over non-ratified space treaties
- Ratification of the five treaties and the recognition of fundamental space legal principles in order to facilitate dialogues, harmonise objectives and open the door to future coordinated treaties amendment
- Streamlining sustainability policies such that the consequent approach of international and intergovernmental bodies could go toward the adoption of binding environmental guidelines, as opposed to soft guidelines

- Legally limiting companies, including New Space companies, from participating in environmentally unfavourable activities owing to a lack of adequate guidance
- Facilitate the inclusion of Space Lawyers, Space Economy experts, and International Relations experts in national environmental consultations, initiatives, and political groups
- Planetary protection law should include preserving signs of the ancient geological and atmospheric history of other planets, not just potential signs of life
- Governments should establish clear strategic goals to implement green technologies as spin-offs of space technologies to foster innovation
- Global stakeholders should better assess the financial needs of developing countries, as well as understand how these financial resources can be mobilised for equitable action
- Provision of resources should aim to achieve a balance between adaptation and mitigation
- Raising financial companies and investors' awareness about space benefits
- Making satellite imagery more accessible
- Limiting the use of technologies that could have unpredictable impacts on our global climate

Commercial Industries

Global industries now have the opportunity to select the use of appropriate technologies to achieve environmental goals. The space sector shall advocate for the improved use of environmentally friendly technologies, like additive manufacturing, underlying the spin-off process as the basis of its adoption:

- Inviting global stakeholders to a cross-sectoral approach by sharing the space industry's best practices and most successful initiatives towards climate action
- Support polluting industries, such as plastics, by sharing innovative industrial processes and disruptive management practices deriving from its best practices to

push for industry transition on materials selection and use, including the disposal of inorganic waste

- Deepen interaction between governmental organisations and New Space companies in order to harmonise goals and develop more synergies between initiatives
- Foster spin-off technologies based on technical space developments to aid in water resource management and manufacturing industries, particularly through the development of sustainable space analogs on Earth
- Global industries shall take advantage of satellite data and "digital twin" projects for internal business forecasting and revision of their internal policies in accordance with the international ones

Conclusion

Ultimately, the synergies between the space industry and climate action cannot be overstated. In order to fully benefit from the various benefits of space exploration, stakeholders must harmonise their actions and efforts for the benefit of Earth. From educational initiatives and capacity building to information sharing and policy development, as well as technological advancements - our work in space has the potential to change the way we interact with and understand our planet. SGAC, as an organisation representing international students and young professionals, has vested interest in ensuring that these recommendations are carried out in order to save our environment and future generations. The aim of our report, along with subsequent work from SGAPP in its implementation during the upcoming advocacy stage, is to highlight the many considerations that space offers in our fight against climate change, and to foster collaboration across industries and space actors around the world in order to preserve our shared future.

You can find us on:

spacegeneration.org