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Annette Froehlich *Editor*

Post 2030-Agenda and the Role of Space

The UN 2030 Goals and Their Further Evolution Beyond 2030 for Sustainable Development

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Preface

The Sustainable Development Goals (SDGs) officially "Transforming our world: the 2030 Agenda for Sustainable Development" is a set of 17 "Global Goals" with 169 associated targets which the state community adopted on 25 September 2015. Each goal has specific targets to be achieved over the next 15 years. These 17 Sustainable Development Goals seek to build on the Millennium Development Goals and complete what these did not achieve. The commitment was taken to achieve this Agenda and utilize it to the full to transform our world for the better by 2030. But what comes after 2030? What may be the goals to achieve beyond 2030 by governments, the private sector, civil society and individuals for a sustainable future? And how can space contribute to it?

On the occasion of the UNISPACE+50 Conference, the European Space Policy Institute (ESPI), the German Aerospace Center (DLR) and the Space Generation Advisory Council (SGAC) invited students and young professionals worldwide to submit a paper on the "Post-2030 Agenda and the Role of Space" providing them an opportunity to contribute to the ongoing reflections on goals and targets beyond 2030.

The publication provides a deep insight to which extent further improvement should be envisaged to ensure and improve the sustainable development beyond 2030. As the world, its environment, economy and society are getting more and more technically advanced, it is of high interest to analyse how space and its various applications can support this development. Once the goals of the "2030 Agenda for Sustainable Development" will be achieved, new challenges are awaiting. The analysis takes first of all into account a proactive use of artificial intelligence (AI) for the development based on space infrastructure. Therefore, it is proposed to reconsider the process which led to the elaboration of the Sustainable Development Goals which was created on a problem-solving approach. However, universal goals may require a different such as an opportunity-seeking approach. In addition, AI technology should be used to enable humans to enjoy a more equal prosperous and sustainable life on Earth.[1]

Another important aspect turns around the economic development which asks for further analysis of the cryptocurrencies relationship with space applications and how to use space-based cryptocurrencies for development. Indeed, the high cost associated with remittance transactions limits the development especially in developing and evolving countries. In consequence, the increased use of space-based cryptocurrencies would lead to lower remittance costs and contribute hence directly to the achievement of the Sustainable Development Goals.[2]

Environment-wise the challenges for a sustainable development not only on Earth, but also in outer space, are questioned ensuring a sustainable exploration and exploitation of space and its orbital resources. Hence, a high topic of the global agenda is and will still be the access to fresh drinking water. Satellite data can provide useful and reliable data to increase water use and foster water awareness in order to meet the requirements of the Brundtland Report which requires that a sustainable development "meets the needs of current generations without compromising the ability of future generations to meet their own needs".[3]

The sustainable development should also take into account an extraterrestrial sustainable development as humans will have moved far beyond low Earth orbit. The current SDGs are purely focused on the management of social and economic development aspects on Earth. Its targets are related to situations on Earth; therefore, comparable sustainable development programmes for the exploration and exploitation of extraterrestrial orbits will be needed.[4] Moreover, rules should be set up to ensure a sustainable development of orbital resources. The preservation of major global resources, the Earth orbits, was overlooked at the time of the drafting of the United Nations' 2030 Agenda for Sustainable Development. Nevertheless, important orbits may be filled up quite quickly by satellites and space debris. This is why an "International Clean Up Station" is proposed.[5]

Moreover, it has to be analysed how space and its applications can be of use for a possible contribution of the post-2030 space industry to global economic development. Therefore, the possibility of the modern global space industry serving as a techno-economic driver in the establishment of an advanced global economy with

[1] Rf. Takuya Wakimoto, "Proactive Use of Artificial Intelligence for the Development: Space Satellites as a Key Infrastructure", p. 1.

[2] Rf. David Lindgren, "Global Remittances and Space-Based Cryptocurrencies: A Transformational Opportunity for the Post-2030 Agenda", p. 11.

[3] Rf. Chris Kotze, "Towards Total Water Awareness: A Technology Framework", p. 27.

[4] Rf. Samuel Anih, "Earth and Extra-Terrestrial Sustainable Development: The Challenges of Post-2030 Earth and Space Regime", p. 47.

[5] Rf. J. Claire Wilhelm, "The Keys to Rule Them All: Sustainable Development of Orbital Resources", p. 59.

systems in space feeding into the planet's sustainable development and management should be analysed furthermore.[6]

In addition, space has to be taken into account as engine for prosperity. Indeed, the space industry has demonstrated its competence to serve as a high-growth sector which remained strategic for many countries despite economic crisis in order to promote a sustainable economic increase and provide decent work. This approach is underlined by a study on the European and Italian market; its arguments may be extended to other countries.[7]

Finally, it is of utmost importance to enlarge the scope of application of satellite data in administration and justice to ensure a development of effective, accountable and transparent institutions at all levels to promote growth, stability, security and peace on global level.[8] In conclusion, a case study on the European Space Exploration Programme is added to underline the evolution of innovative mechanisms to support the Post-2030 Agenda Goals.[9]

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February 2018

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[6] Rf. Anton Alberts, "The Probable Contribution of the Post-2030 Space Industry to Global Economic Development", p. 71.

[7] Rf. Rosa Maria Lucia Parrella, "Space as Engine for Growth, A European and Italian Analysis", p. 83.

[8] Rf. Anne-Sophie Martin, "Satellite Data as Evidences Before the Mechanisms of International Courts", p. 97.

[9] Rf. Clelia Iacomino, "Evolution of Innovation Mechanisms to Support the Post-2030 Agenda Goals: Case Study on the European Space Exploration Programme", p. 107.

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Proactive Use of Artificial Intelligence for the Development: Space Satellites as a Key Infrastructure

Takuya Wakimoto

Abstract If we are to think about the post-SDGs agenda, it would be worth considering using a new approach to set new goals and targets. One new approach could be an opportunity-seeking approach. This approach is a change from the current problem-solving approach, which is more proactive and focused on exploring new vectors to realize new goals. Using this approach, one potential goal that could be considered for the post-SDGs agenda is an adaption of Artificial Intelligence. However, scarce financial and human (experts) capitals could be obstacles to install Artificial Intelligence systems in developing countries. To fill these gaps, promotion of space satellites to run and support Artificial Intelligence systems will be indispensable.

1 Introduction

When we look at the process in which Sustainable Development Goals (SDGs) are designed, we could notice that the SDGs have been developed through a problem-solving approach.[1] First, we define and identify the global challenges we are facing. Then, solutions to tackle these challenges are considered to create the Goals. In general, this is a common and efficient agenda-setting technique. However, if we take into account the fact that former universal goals, specifically the Millennium Development Goals (MDGs), were not fully accomplished, and if

[1]UN SDSN "Chapter 3: Tools for designing SDG strategies and roadmaps" (2015) Getting Started with the Sustainable Development Goals—A Guide for Stakeholders https://sdg.guide/chapter-3-tools-for-designing-sdg-strategies-and-roadmaps-a8172680d5ef accessed on 6 January 2018.

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we suppose that the SDGs would not be fully accomplished within the proposed timeframe as well, it must be worth considering whether the problem-solving approach is appropriate, or sufficient, to achieve universal goals. Universal goals may require a different approach to achieve completion.

Although the MDGs had great influence in improving various global issues, it is also true that many goals could not be accomplished within a prospected timeframe. Hence, the SDGs, a follow-up agenda from the MDGs, were developed. The question here is, will the SDGs ensure ubiquitous peace and prosperity by 2030, even though it took a similar problem-solving approach to develop the goals as the MDGs? And do we continue the same approach for the post-2030 agenda setting? Based on the fact that the MDGs were not a panacea approach to alleviate the global issues, this paper proposes a new approach that could be used as an agenda for post-2030 goals: an opportunity-seeking approach.

An opportunity-seeking approach is desirable because it focuses more on exploring new ideas or technologies to realize goals and is a more proactive approach than the problem-solving approach (in another word, a defensive strategy) that is often used to describe entrepreneurial management.[2] This new approach may provide different outcomes when implementing the post-SDGs. In detail, one potential goal that could be incorporated in the post-2030 agenda would be *an adaption of Artificial Intelligence (AI).* This new goal is neither attempting to identify universal problems nor setting solutions to tackle them. Rather this is an approach to proactively utilize a new opportunity (in this context, technology) to argument feasibility or outcomes of goals raised in the post-2030 agenda. By using AI technology, humans may enjoy more equally prosperous and sustainable planet earth beyond 2030.

As an attempt to take an opportunity-seeking approach into the post-2030 agenda, this paper aims to address why and how an adaptation of the AI could be a potential goal. First, the study defined the AI; second, it provided insight into why an adaptation of the AI could be a potential post-SDGs goal, a brief trend of technological advancement since the first industrial revolution was introduced; third, the paper addressed two examples to show how an AI could contribute to development goals; and finally, it discussed some key issues to adapt an AI into development projects, and how space satellites could solve these issues.

[2]Adrian Belcham, *Environmental Management: Revision Guide for the IEMA Associate Membership Exam and NEBOSH Diploma in Environmental Management* (Routledge 2014); Christian Eliasson and Per Davidsson, “Entrepreneurial management, corporate venturing, and financial performance” 2003. *Frontiers of Entrepreneurship Research,* 2002–2006, 461–470 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1783669 accessed on January 6, 2018.

2 WHAT Is AI?

An AI is a computing system or a design of systems that has a capacity "to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages[3]." Advancement of information, communication and technology (ICT) enabled us to collect and accumulate a gigantic amount of data; however, a human capacity (e.g., number of well-trained analysts) to analyze and interpret those data are often inadequate. Here, an AI is expected to replace human intelligences by "convert[ing] unstructured information into actionable knowledge,"[4] which used to be an activity only human can do.

Life is full of decision-making. How we go to the school, when to plow the soil for farming, or what to buy to maintain a sanitation facility often requires intelligence to choose one or more options from alternatives. An AI can create alternative decision "options" based on criteria (e.g., input data, past records) and provides most optimal solution(s)[5] to support human activities. Therefore, installing an AI into our society means that computing systems will support find a "better" alternative option(s), or in some systems, an AI will make decisions on behalf of humans.

3 WHY Adapting AI Could Be a Post-SDGs Goal?

Within years, not decades, the world is expected to benefit from increased applications of AI.[6] That is more autonomous and more human power-less society than the present world. In fact, AI is already reshaping domains as varied as transportation (including autonomous vehicles), finance, and health care. This AI society could be deemed as a fourth industrial revolution if we think back on our science and technology advancement since the first industrial revolution.

The first industrial revolution occurred in the late eighteenth century, when water-steam-powered mechanical manufacturing was introduced. Then, the second industrial revolution began during the late nineteenth century when electrically

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[3]Oxford University Press, *English Oxford Living Dictionary (artificial intelligence)*, (2017), https://en.oxforddictionaries.com/definition/artificial_intelligence accessed on November 25, 2017.

[4]Leebong Lee, "The rise of artificial intelligence: what does it mean for development?" (2017) The World Bank http://blogs.worldbank.org/ic4d/rise-artificial-intelligence-what-does-it-mean-development accessed on November 25, 2017.

[5]Gloria Phillips-Wren "Intelligent decision support systems" in Michael Doumpos and Evangelos Grigoroudis (eds), *Multicriteria Decision Aid and Artificial Intelligence: Links, Theory and Applications* (John Wiley & Sons 2013).

[6]Stuart Russell, "Robotics: Ethics of artificial intelligence" (2015) The Nature.com www.nature.com/news/robotics-ethics-of-artificial-intelligence-1.17611 accessed on December 10, 2017.

powered mass production system was introduced into the manufacturing industry. By 1970s, an introduction of computing and development of ICT realized that manpower requirement will be less when automated manufacturing took momentum, which became the third industrial revolution.[7]

Now, we are getting closer to achieve the fourth industrial revolution by developing a system to integrate mass data garnered by ICT. Electrically preserved data were accumulated since the third industrial revolution occurred; nevertheless, we could not integrate dispersed information that was necessary to evolve our automation technology from a mere computing (calculation) to a decision-making (autonomously "find and suggest" most optimized options). If computers started to provide decision options to humans, then an AI society becomes a reality.

4 HOW Can AI Contribute to Tackle Global Issues?

Since an AI is a design of systems, it could be adapted in various fields (see Appendix A for some example usages of AI for development). For instance, AI will realize a driver-less autonomous car, which requires consecutive decision-makings (e.g., distinguish safe and dangerous).[8] In a science research field, such as medicine, an AI systems' accuracy, cost competitiveness and efficiency, and replication capability will enhance research and production capability.[9] Illiterate people could express ideas by using an AI system's text-to-voice (and vice versa) translation function.[10] But for the purpose of this paper, two scenarios will be considered as an example to demonstrate how AI can tackle some of the global issues: AI for farming and AI for a sustainable access to clean water.

[7]Klaus Schwab, "The Fourth Industrial Revolution: what it means, how to respond" (2016) World Economic Forum www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/ accessed on November 26, 2017.

[8]Toyota News Release, "Toyota Concept-i Makes the Future of Mobility Human" (2017) Toyota US Newsroom http://pressroom.toyota.com/article_display.cfm?article_id=5865 accessed on November 25, 2017.

[9]Arvin Agah "Introduction to Medical Application of Artificial Intelligence" in Arvin Agah (eds), *Medical Applications of Artificial Intelligence* (CRC Press 2013).

[10]ITU & XPrize "AI for Good Global Summit: Artificial Intelligence can help solve humanity's greatest challenges" (2017) International Telecommunications Union www.itu.int/en/ITU-T/AI/Documents/Report/AI_for_Good_Global_Summit_Report_2017.pdf accessed on November 25, 2017.

5 AI for Farming

One in nine people in the world are undernourished today,[11] and this huger rate may increase as the world population reaches ten billion in the coming decades. Improvement in farming productivity is, thus, a critical issue we have to tackle. Among several approaches to improve farming productivity, farmers in developing countries (hereinafter defined as farmers) have to have an intelligence to reduce a risk of disease among staple crops.

Reduce a risk of disease among staple crops is not easy especially in developing countries because farmers have to be well-educated to monitor crops, identify symptom of crop disease, and distinguish ill crops to healthy ones. In most cases, however, farmers are less knowledgeable to make sound judgments. Hence, for instance, trained agriculturalists from developed countries are required to visit areas of cultivation and make assessment of crop health.[12] However, as Quinn, Frias-Martinez, and Subramanian suggest, sending agriculturalists to local fields in the developing country are "expensive, untimely, and inadequate, including the scarcity of suitably trained staff, the logistical difficulty of transport, and the time required to coordinate paper reports." As a consequence, this high-cost structure seems to limit sustainable supports from donors, which is important to supplement farmers' knowledge. Thus, if there is a system to transfer agriculturalist's intelligence to farmers at small expense (e.g., less physical transportation of experts or goods), it will have a great impact to increase survivability of crops. Here, an AI system could supplant costly transfer of agriculturalist's intelligence.

An AI system can make a diagnosis using photo images of crops. Photos can be taken directly by farmers or taken from outer space by remote-sensing satellites. Then, an AI can do a health check on each crop by color and shape features. No need to expend time and human resources to send experts to remote lands. Rather, an AI system can make a real-time map of crop disease.[13] Thus, an AI system can supplant the human intelligence that can support less-educated farmers in a timely manner.

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[11] United Nations Development Programme "UNDP Support to the Implementation of the Sustainable Development Goals" Sustainable Development Goals www.undp.org/content/undp/en/home/sustainable-development-goals.html accessed on November 26, 2017.

[12] Quinn, John, Vanessa Frias-Martinez, and Lakshminarayan Subramanian "Computational sustainability and artificial intelligence in the developing world" 2014. *AI Magazine,* 35, (3) (Fall), 36–47 http://proxygw.wrlc.org/login?urlhttps://search-proquest-com.proxygw.wrlc.org/docview/1611002320?accountid=11243 accessed on November 26, 2017.

[13] Quinn et al. (n 36).

6 AI for a Sustainable Access to Clean Water (from a Management Perspective)

Access to clean water and sanitation facility is an essential element for our health and a good life. However, many people still suffer from inadequate supply of clean water.[14] Issues vary from cultural and gender considerations to economic resources and politics. Yet, some experts suggest that fundamental issues of contaminated water and non-functioning sanitation system attribute to a "lack of expertise and experience, poor supervision, failure caused by well users, and poor technology choice."[15] Josephine Phillip Msangi, a researcher who studies water scarcity in the Southern Africa, also concluded her project in Namibia that "effective strategies for water quality management" is important to achieve sustainable clean water supply.[16] An AI system can play an important role to fill this gap, that is, lack of human intelligences.

An AI could be used as a decision-making system to help less-educated people in the remote places to manage, perform maintenance, and implement water service. AI can provide decision options by using enormous input data accumulated in the system. In particular, this capability will be more precious during the post-project phase, after donors and experts left the project. That is because, for instance, if users (recipients of projects) do not understand the mechanism of clean water pipelines developed by foreign experts, then they may fail to do maintenance of the pipelines properly.[17] This will limit sustainability. In contrast, if users can take photos of the pipelines and input them into an AI system to make a diagnosis of water equipment, I believe most people can utilize AI system without experts. In such case, an AI system will be an effective tool to supplement less-educated user's maintenance capability by providing decision-making options.

7 Some Concerns to Install AI System in the Developing Country

There are two potential concerns that might restrict an installation of an AI system into the developing country: inequality in funding and a cost of experts.

[14]United Nations Development Programme (n 9), Public-Private Infrastructure Advisory Facility & the World Bank, *Approaches to private participation in water services: a toolkit* (The World Bank 2005).

[15]Hylton Ferreira "International Donor Agencies—Africa" (2017) International Project Leadership Academy http://calleam.com/WTPF/?p=8390 accessed on November 26, 2017.

[16]Josephine Phillip Msangi "Conclusions and Recommendations" in Josephine Phillip Msangi (eds) *Combating water scarcity in Southern Africa: case studies from Namibia* (Springer 2014).

[17]Ferreira (n 12).

An AI system requires equipment to collect information, integrate and process data, and output suggestions (e.g., camera and sensor to monitor crops, transmitter to send data to the AI system, computers to run an AI system, and gadgets to screen outputs). However, finding a funding source for this equipment may not be easy because investing on an equipment means that a fund goes merely toward a particular project or people. This may increase an inequality between recipients and non-recipients, while these basic infrastructures are necessary to run an AI system.

Another concern is the fact that an AI is not fully automatic which requires human assistance to cook a data set. Presenters at the AI for Good Global Summit argue that some eighty percent of analysis could be completed by an AI system but rest of twenty percent requires human analysis to transform AI outputs into practical information.[18] Thus, for instance, even if an AI system has been installed to one local community in the developing country, high-educated experts to analyze the mass data seems to be inevitable. Experts are often expensive not only because of their high salary but also due to the transportation cost from the urban city to the remote place. Distance from the infrastructure (e.g., roads, airports, and cities) increases the cost of time and money to send experts. Financial burden tends to make projects difficult to continually monitor and sustain assistance from donors. This will become a contradicting argument against the advantage of AI suggested in the previous section.

8 Overcome Concerns by Using Space Applications

A space satellite could be an effective tool to overcome concerns of an AI system suggested in the previous section. Two characteristics of satellite, if compared to the land equipment, can reduce concerns of an AI system installation in the developing country: a broad spectrum and a multiple-locations-simultaneous-broadcast capability.[19] A broad spectrum is a major advantage of satellites that allow data transmissions to distant locations at a certain cost. A multiple-locations-simultaneous-broadcast capability is a capability to send data to multiple locations simultaneously. This helps reduce inequality of information sharing. These inherent characteristics of space satellite will help overcome concerns: inequality in funding and a cost of experts.

Funding for satellites may be less controversial because a constellation of satellites can be used for multiple projects and recipients. Meaning, an investment on satellites will cause less inequality concern compared to an investment on AI infrastructures for particular communities. Due to a broad spectrum and a multiple-locations-simultaneous-broadcast capability of the satellite, an investment could be justified by appealing public goods aspect. Consequently, fewer protests

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[18]ITU & XPrize (n 8).

[19]Kazuhito Suzuki, *Space Development and International Politics* (Iwanami-shoten 2011).

against garnering funding sources could be expected as compared to spending money for specific people.

Next, suppose an international organization successfully raised funds to purchase satellites, then interactions between remote communities and developed countries will begin. Remote-sensing satellites capture photo images of crops in local farms in developing countries. Images are transferred and analyzed by AI systems and experts in the developed country. Then, optimized suggestions are being sent to people who need instruction in developing countries via communication satellites. Images, situation reports, and suggestions could be received via mobile phones,[20] which many people in developing countries often possess. The only investment, if necessary, required for communities in the developing country is a mobile phone. Cameras, transmitters, and computers to run AI system are not necessary to be possessed by those who needed if they can be connected to the system in the developing country.

Moreover, satellites and their applications can fill a distance gap that allows experts to monitor and consult in a timely manner without visiting remote sites. Experts can interact with people at the hard-to-access areas by using communication satellites. They can supplement information to AI systems and/or make decisions from an office in New York, if necessary. Hence, utilization of satellites to run AI systems for the developing country will reduce the cost on experts who used to visit remote areas periodically for maintenance and to support the post-project phases.

9 Conclusion

This paper argued that a new goal which we can take into account in the post-SDGs agenda is an adaptation of AI system in the development. Installation of AI systems in developing countries, however, has two concerns. Inequality issue may arise from an investment on a particular community to build AI infrastructures. Expenses to send experts to remote places may be required to supplement AI systems. Yet, using space satellite would mitigate these potential concerns. Compared to land-based infrastructures that can be used for particular area, constellation of satellites can exchange same data with almost any places simultaneously. This characteristic of satellite explains that investment on satellite systems would have less risk of generating inequality issue, and thus, more possibility to raise funds from the international community could be expected. Once local people in developing countries are connected to satellites, then they can use AI systems based in the developed country. No need to fully possess AI infrastructures in their local communities. Moreover, communication satellites can reduce expert's travel cost

[20]Jeffrey James, "Patterns of Mobile Phone Use in Developing Countries: Evidence from Africa" (2014) *Social Indicators Research*, 119, 2, 687–704.

and burden to get to the fields. Less physical and financial burden will increase sustainability of the post-project phases, which must be crucial factor to achieve the SDGs, and post-SDGs.

To conclude, an AI system is not a panacea to augment various projects to tackle global issues, but it would have profound expectations to realize better world. Thus, adaption of AI systems into the development should be included in the post-2030 goals. And space satellites are indispensable to increase a feasibility of AI systems in the development.

10 Appendix 1

Potential AI contribution to the SDGs

1. AI can map poverty from space enabling real-time resource allocation.
2. Automation and predictive analytics can increase agricultural productivity.
3. AI can analyze vast quantities of healthcare data leading to scientific breakthroughs.
4. AI can revolutionize classrooms by providing individualized learning pathways and virtual mentors.
5. AI can drive balanced hiring practices and spotlight gender inequality.
6. Sensors can predict consumption patterns for efficient and safe water provision.
7. Machine learning can improve photovoltaic energy capture, lowering the cost of solar power.
8. Intelligent automation can increase productivity for economic growth.
9. Automation, compression, convergence, and connectivity will drive exponential innovation.
10. Disability robotics can build a more equal and inclusive society.
11. AI-powered urban planning makes cities smart and sustainable.
12. AI can predict and identify optimal production levels to reduce waste.
13. AI-powered climate modeling can help predict climate-related disasters.
14. Pattern recognition software can track the movement of fishing boats to combat illegal fishing.
15. Computer science and game theory can be used to outwit poachers in the wild.
16. AI-integrated e-government can reduce discrimination, prejudice, and corruption.
17. Multi-sectoral collaboration is essential and beneficial for the safe, ethical development for AI.

Note Adopted from the “AI for Good Global Summit: Artificial Intelligence can help solve humanity’s greatest challenges,” ITU & XPrize, 2017, www.itu.int/en/ITU-T/AI/Documents/Report/AI_for_Good_Global_Summit_Report_2017.pdf accessed on November 25, 2017.

Global Remittances and Space-Based Cryptocurrencies: A Transformational Opportunity for the Post-2030 Agenda

David Lindgren

Abstract Remittance flows constitute a significant source of financing in support of global development efforts as part of the 2030 Agenda for Sustainable Development and beyond. Annually, remittances roughly total three times the amount of official development assistance from developed countries to developing countries and prove a more reliable and predictable source of resources as compared to private capital flows measured by foreign direct investment. However, the high costs associated with sending remittances limit their potential, resulting in tens of billions lost each year to excessive fees. New trends in the space industry, particularly with the growth of the nano- and microsatellite industry and launch service providers dedicated to this market segment, promise new potential for contributing toward development efforts. Coupled with a rising acceptance of cryptocurrencies as a legitimate means of transacting and storing wealth, space-based cryptocurrencies may prove a solution to remedying the high transaction costs associated with remittances. The introduction of space-based cryptocurrencies offers significant potential for the global community in its development efforts, but also poses questions for the post-2030 agenda in how risks associated with these new technologies, especially around regulatory compliance, will be addressed.

1 Introduction

Global development efforts, as informed and guided by the Sustainable Development Goals (SDGs) adopted by the United Nations (UN), remain varied and diverse. Seventeen discrete and wide-ranging SDGs comprise the 2030 Agenda for Sustainable Development that was adopted by UN countries during the UN

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Sustainable Development Summit held from 25 to 27 September 2015.[1] As such, the 17 SDGs carry with them 169 targets[2] and 232 associated indicators[3] that the global community will use for monitoring progress and evaluating success in achieving implementation of the goals. Because of the varied nature of the SDGs, which range from poverty reduction to environmental protection to social inclusion and quality education, the resources needed to implement the goals require diverse sources of support from multiple sectors, including the governmental and inter-governmental, non-profit, and private sectors.

1.1 Official Development Assistance

While official development assistance (ODA) from developed to developing countries, which is defined as government aid designed to promote the economic development and welfare of developing counties,[4] constitutes a sizable portion of development resource flows, this type of assistance proves largely stagnant and insufficient compared to the global development needs identified within the SDGs, with minimal significant changes having taken place between 2006 and 2016. Whereas net official development assistance in terms of real US dollar terms grew from 109 billion US dollars in 2006 to 143 billion US dollars in 2016, official development assistance as a percentage of gross national income (GNI) only increased from .30% in 2006 to .32% in 2016.[5]

This stands in contrast against the internationally recognized and accepted target for countries to aspire, which is .70% of GNI devoted toward official development assistance. Furthermore, performance by individual countries and their governments in delivering official development assistance varies greatly country to country. For example, while the USA gives the most official development assistance in terms of real dollar terms, 33 billion US dollars as of 2016, this only constituted .18% of US GNI. Comparatively, Norway exceeded the internationally accepted ODA/GNI target by giving 1.1% of its GNI toward official development assistance, even though in real dollar terms this only represented 4.6 billion US dollars in 2016. Uneven provision of official development assistance from developed to developing countries, particularly in the context of the SDGs which will

[1]United Nations, 'The Sustainable Development Agenda' (2016) www.un.org/sustainabledevelopment/development-agenda/ accessed January 2018.

[2]Ibid.

[3]United Nations, 'SDG Indicators' (2017) https://unstats.un.org/sdgs/indicators/indicators-list accessed January 2018.

[4]Organisation for Economic Cooperation and Development (OECD), 'Net ODA' (2017) https://data.oecd.org/oda/net-oda.htm accessed January 2018.

[5]Organisation for Economic Cooperation and Development (OECD), 'Official Development Assistance 2016' (2017) www.compareyourcountry.org/oda?cr=20001%cr1=oecd&lg=en&page=1 accessed January 2018.

require trillions of US dollars for their successful implementation,[6] demonstrates only one challenge facing the resourcing of global development efforts.

1.2 Foreign Direct Investment

Separately, resource flows for development from the private sector also encounter their own set of challenges in fulfilling their potential as dependable sources of support in achieving the 2030 agenda. Private capital flows, measured by foreign direct investment, and remittances, defined as personal transfers of cash or in-kind giving between resident and non-resident individuals and employer compensation of border, seasonal, and short-term workers,[7] constitute private sector resources in support of development.

Unlike official development assistance, which has remained relatively stable with modest overall increases year to year during the 2006–2016 period, foreign direct investment from countries within the Organisation of Economic Cooperation and Development (OECD) has fluctuated wildly year to year, largely due to prevailing global economic conditions. Notably, foreign direct investment from OECD countries was at 1.14 trillion US dollars in 2006, which then jumped to 1.89 trillion US dollars in 2007.[8] Following the 2007–2008 financial crisis and subsequent global recession, foreign direct investment dropped dramatically to 870 billion US dollars in 2009 with a minor recovery in 2011 to 1.21 trillion US dollars, which was further followed in 2014 by the lowest recorded foreign direct investment of the 2006–2016 period at 806 billion US dollars.[9] As of 2016, foreign direct investment from OECD countries was at 1.08 trillion US dollars.[10] The history of foreign direct investment over this preceding ten year period well demonstrates the volatility of private capital flows and unreliability of this resource to consistently and evenly deliver for global development efforts.

[6]United Nations, 'The Sustainable Development Agenda' (2016) www.un.org/sustainabledevelopment/development-agenda/ accessed January 2018.

[7]World Bank, 'How do you define remittances?' (2018) https://datahelpdesk.worldbank.org/knowledgebase/articles/114950-how-do-you-define-remittances accessed January 2018.

[8]Organisation for Economic Cooperation and Development (OECD), 'FDI flows' (2017) https://data.oecd.org/fdi/fdi-flows.htm accessed January 2018.

[9]Ibid.

[10]Ibid.

1.3 Remittances

Conversely, remittance flows to developing countries have steadily and markedly increased over the 2006–2016 period, rising from an estimated 268 billion US dollars in 2006[11] to 429 billion US dollars in 2016 despite year to year decreases of 1% in 2015 and 2.4% in 2016.[12] Over the 2006–2016 period, this represents a 60% increase in remittance flows. The World Bank further projects that remittances will have grown by an additional 3.3% in 2017 to total 444 billion US dollars.[13]

As demonstrated above, remittance flows found within the private sector offer reliable and significant support toward contributing to global development efforts envisioned by the 2030 agenda. Despite having lower annual totals compared to foreign direct investment, remittances offer a steady and reliable source of financing as compared to foreign direct investment's significant year to year volatility. As noted by the Migration Policy Institute, "…the flow of money [remittances] increases when financial markets decline, [and] they behave very differently than private capital flows…Because they are a large and stable source of foreign currency, remittances are also likely to curtail investor panic and prevent sudden account reversals during a crisis."[14]

Moreover, remittances as of 2016 annually represent more than three times the amount of official development assistance given by developed countries to developing countries. Research has demonstrated that remittances closely link to improved development outcomes as those who receive remittances make higher investments in sectors such as healthcare and education than those who do not receive remittances.[15] Furthermore, those who receive remittances earn higher incomes and spend more as consumers and experience lower rates of extreme poverty as compared to those who do not receive them.[16]

Compared to both the official development and private capital sectors, remittances provide a sustainable and reliable source of financing for the global development agenda to 2030 and beyond.

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[11] Muzaffar A. Chishti, 'The Phenomenal Rise in Remittances to India: A Closer Look' (Migration Policy Institute, May 2007) https://www.migrationpolicy.org/pubs/MigDevPB_052907.pdf accessed January 2018.

[12] World Bank, 'Migration and Remittances' (April 2017) http://pubdocs.worldbank.org/en/992371492706371662/MigrationandDevelopmentBrief27.pdf accessed January 2018.

[13] World Bank, 'Trends in Migration and Remittances 2017' (April 2017) http://www.worldbank.org/en/news/infographic/2017/04/21/trends-in-migration-and-remittances-2017 accessed January 2018.

[14] Dilip Ratha, 'The Impact of Remittances on Economic Growth and Poverty Reduction' (Migration Policy Institute, September 2013) https://www.migrationpolicy.org/pubs/Remittances-PovertyReduction.pdf accessed January 2018.

[15] Ibid.

[16] Ibid.

2 Remittances and Development

2.1 Challenges with Remittance Flows

However, despite the opportunities offered by remittance flows in realizing the 2030 agenda, the sector faces unresolved challenges in unlocking its full potential as a driver of development. Namely, the high costs associated with remittance transactions limit the sector's potential and reduce its utility as a mode of financing. The UN has identified 3% of the total remittance amount as the target for transfer operators to charge; however, according to the latest December 2017 report from the World Bank, "Globally, sending remittances costs an average of 7.09% of the amount sent."[17] This far exceeds the UN's designated target. Moreover, different categories of transfer providers, ranging from post offices to commercial banks, incur markedly different costs. For example, post offices and money transfer operators, such as Moneygram and Western Union, charge an average 6% on the amount that is sent, while commercial banks charge an average of 11%.[18] Mobile operators, which rely on space-based applications, represent the only category of transfer providers meeting the UN target by only charging 2.9% of the amount that is remitted.[19]

Although the cost of sending remittances from G8 countries compared to sending from G20 countries varies slightly from 6.66 to 7.20%, respectively, countries such as South Africa remain well beyond the UN target of 3% by incurring an average cost of 16.17% for sending remittances.[20] This suggests that the most developed economies, as represented by the G8, retain relatively sophisticated money transfer and regulatory regimes that enable lower transactional costs as compared to the broader G20 group of countries. In the case of South Africa, it serves as the economic hub for Southern Africa and hosts workers from many UN-defined least developed countries (LDCs) in the region, including Angola, Lesotho, Malawi, Mozambique, and Zambia,[21] yet suffers from excessively high transaction costs for sending remittances. This example tangibly demonstrates how meeting the UN target of 3% could well unlock the potential of remittances in financing development, particularly in countries such as the Southern African LDCs that require the most support. In total, 32 billion dollars annually do

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[17]World Bank, 'Remittance Prices Worldwide' (December 2017) https://remittanceprices.worldbank.org/sites/default/files/rpw_report_december2017.pdf accessed January 2018.

[18]United Nations, 'The Sustainable Development Goals Report' (2017) https://unstats.un.org/sdgs/files/report/2017/TheSustainableDevelopmentGoalsReport2017.pdf accessed January 2018.

[19]Ibid.

[20]World Bank, 'Remittance Prices Worldwide' (December 2017) https://remittanceprices.worldbank.org/sites/default/files/rpw_report_december2017.pdf accessed January 2018.

[21]United Nations Committee for Development Policy, 'List of Least Developed Countries' (June 2017) https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/ldc_list.pdf accessed January 2018.

not reach remittance beneficiaries globally because of high transaction costs,[22] which represents at least 7% of the remittance sector as of 2016.

Remittance costs remain high because of a variety of factors. Experts have argued that money transfer (i.e. remittance) fees remain high because of the number of regulations, licenses, and institutional and human resources required to facilitate transfers.[23] These include the need for the agent to receive funds from the sender, submit those funds through the agent's bank, the agent's bank to send those to a corresponding bank able to make international transfers, and then a separate corresponding bank in the receiving country to receive the transfer, transmit those funds to a local bank, and finally an agent for the local bank to hand those funds over to the intended recipient.[24] These institutional and human resource costs contribute to the high fees associated with remittances, in addition to the numerous laws and regulations banks and money transfer operators need to comply, including anti-money laundering regulations that require banks and transfer operators to identify and report on transactions valued over 10,000 US dollars.[25]

2.2 Remittances and the Sustainable Development Goals

Therefore, it remains important to identify and implement ways to reduce transaction costs associated with remittances to fully unlock their potential as a source of support for development. A fully enabled remittance sector would contribute directly toward the achievement of Sustainable Development Goal 8, which aims to "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all."[26] Reduced transaction costs would lead to more annual remittances benefitting recipients in developing countries, and therefore support the achievement of SDG 8's targets, particularly target 8.10 which aims to "strengthen the capacity of domestic financial institutions to encourage and expand access to banking, insurance and financial services for all."[27]

Moreover, increasing financial flows to developing countries through remittances would further contribute to Sustainable Development Goal 1, which seeks to

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[22]Sophie Edwards, '5 trends affecting the remittance industry' (Devex, 2016) https://www.devex.com/news/5-trends-affecting-the-remittance-industry-89275 accessed January 2018.

[23]Ben Schiller, 'The Fight for the $400 Billion Business of Immigrants Sending Money Home' (Fast Company, April 2017) https://www.fastcompany.com/3067778/the-blockchain-is-going-to-save-immigrants-millions-in-remittance-fees accessed January 2018.

[24]Ibid.

[25]Ibid.

[26]United Nations, 'Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for the Sustainable Development' (2017) (https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework_A.RES.71.313%20Annex.pdf accessed January 2018.

[27]Ibid.

"end poverty in all forms everywhere."[28] Individual targets within the first goal that would most closely link and benefit to lower remittance costs include target 1.4 that would "ensure that all men and women, in particular the poor and vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance," and target 1.a that aims to "ensure significant mobilization of resources from a variety of sources, including through enhanced development cooperation, in order to provide adequate and predictable means for developing countries, in particular least developed countries, to implement programmes and policies to end poverty in all its dimensions."[29]

2.3 The Role of Remittances in the Post-2030 Agenda

New opportunities would arise for the post-2030 agenda if remittance cost targets were met in compliance with UN targets and the resultant changes increased access to financial services for those in developing countries. As argued by Dilip Ratha, "Policymakers can do much more to maximize the positive impact of remittances by making them less costly and more productive for both the individual and the country of origin…Beyond reducing costs, which puts more money directly into the hands of migrant who send and/or families who receive remittances, measures to ensure the recipients of these funds have access to other financial services, such as micro insurance (especially health) or education financing would go a long way to boosting development outcomes."[30] Ratha continues, "Policymakers can put in place sufficient incentives and mechanism for migrants and their families to invest remittances in capital-accumulation projects (involving both human and physical capital) that are beneficial to the whole economy."[31]

Once those in developing countries gain greater access to banking and other financial services, made possible in part by the reduction of remittance costs and the leveraging of an increased user base of remittance recipients into other financial products and services, the post-2030 development landscape would appear significantly different as compared to the present. In the post-2030 world, assuming the global community meets the goals and targets set out by the 2030 Sustainable Development Agenda, emphasis for development outcomes would likely shift from ending poverty and increasing access to financial services to growing incomes and

[28]Ibid.

[29]Ibid.

[30]Dilip Ratha, 'The Impact of Remittances on Economic Growth and Poverty Reduction' (Migration Policy Institute, September 2013) https://www.migrationpolicy.org/pubs/Remittances-PovertyReduction.pdf accessed January 2018.

[31]Ibid.

sustaining access and increasing quality of services received by those in developing countries for genuine inclusion in the global economy.

3 Space Applications and Development

3.1 The Evolution of Space Applications for Development

Global development efforts will likely achieve mixed and uneven outcomes as they relate to the 2030 Sustainable Development Goals. Since the Sustainable Development Goals emerged from their predecessor, the Millennium Development Goals (MDGs), past results can indicate future performance on such a global and comprehensive effort as the 2030 Agenda for Sustainable Development. As explained by the Brookings Institution, “They [findings] show that, especially on matters of life and death, 2015 outcomes [for the MDGs] were not on track to happen anyhow. Some shifts were dramatic, and Africa was responsible for many of the greatest incremental gains, not simply China and India. However, outcomes on basic needs were mixed.”[32] Therefore, a likelihood exists that the Sustainable Development Goals will achieve mixed success similar to the MDGs.

However, due to the growth of space-based technologies and acceleration of the products and services made available by these technologies in the last decade, the Sustainable Development Goals and those working to achieve them have powerful new tools at their disposal to deploy in global development efforts. In particular, applications of space-based satellite technologies in support of development, especially for earth observations, have proven benefits. According to the World Bank, “Satellite Earth Observation technology has tremendous potential to inform and facilitate sustainable development work…Satellite Earth Observation systems provide scientific data to help communities in the developing world protect their forests, plan for urban growth, harness water resources, manage coastal zones, and increase resilience.”[33] Deployment of space applications beyond earth observations, however, holds additional potential yet unfulfilled in support of development, particularly in the application of space-based technologies for banking and related financial services for development purposes. Space applications represent a key sector especially for the remittance industry in facilitating development, and in turn meeting development outcomes as envisioned by the 2030 agenda and beyond.

[32]John McArthur and Krista Rasmussen, ‘How successful were the Millennium Development Goals?’ (Brookings Institution, January 2017) https://www.brookings.edu/blog/future-development/2017/01/11/how-successful-were-the-millennium-development-goals/ accessed January 2018.

[33]World Bank, ‘Earth Observation for Development’ (2018) (http://www.worldbank.org/en/topic/sustainabledevelopment/brief/earth-observation-for-development accessed January 2018.

3.2 Cryptocurrencies Relationship with Space Applications

Moreover, the growth in popularity of cryptocurrencies, based on blockchain technology, in recent years has attracted significant investment to that industry as individuals and companies seek more secure, cost-effective, and accessible means for their transactions. Companies now seek to host cryptocurrency networks on satellites in order to increase their security and accessibility.

For example, SolarCoin Foundation entered into a deal with a satellite company, Cloud Constellation, to "purchase data center capacity in space in order to secure its blockchain wallets from hacking."[34] Another company, Blockstream, announced in 2017 that it would launch a satellite network which would broadcast bitcoin, a type of cryptocurrency, around the world.[35] According to the company, "This will make the cryptocurrency more accessible to almost anyone, even in places where data costs are high and living standards and incomes are low."[36] Blockstream continues to write about its network: "The satellite network provides an opportunity for nearly 4 billion people without internet access to utilize bitcoin while simultaneously ensuring bitcoin use is not interrupted due to network interruption."[37] Finally, and most recently, a company that developed its own cryptocurrency, Nexus, has announced plans with a nanosatellite launch company, Vector, to host its blockchain across several satellites by 2019.[38] According to Nexus, "By using a satellite virtualization platform through GalacticSky [Vector's satellite-based software platform], Nexus can distribute its blockchain across multiple satellites, providing it enhanced reliability and performance. Nexus' secure cryptocurrency and decentralized peer-to-peer network will grant greater freedom and transactional transparency for global access to financial services."[39] The benefit hosting the cryptocurrency in space comes from it existing outside of an individual country and its ability to "create the backbone for a more decentralized financial ecosystem."[40]

Provided the innovations in the cryptocurrency and satellite markets, new opportunities exist that did not in previous years, especially in relation to the deployment of space applications to achieve certain global development outcomes.

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[34]Sean Gallagher, 'Satellite cloud startup inks deal for space-based cryptocurrency platform' (Ars Technica, September 2016) https://arstechnica.com/information-technology/2016/09/satellite-cloud-startup-inks-deal-for-space-based-cryptocurrency-platform/ accessed January 2018.

[35]Karla Lant, 'Bitcoin now comes from satellites in space. Welcome to the future,' (Futurism, August 2017) https://futurism.com/bitcoin-now-comes-from-satellites-in-space-welcome-to-the-future/ accessed January 2018.

[36]Ibid.

[37]Blockstream, 'Blockstream Satellite' (2017) https://blockstream.com/satellite/blockstream-satellite/ accessed January 2018.

[38]Vector, 'Vector and Nexus Team Up to Bring Cryptocurrency to Space,' (PRNewsWire, December 2017) https://www.prnewswire.com/news-releases/vector-and-nexus-team-up-to-bring-cryptocurrency-to-space-300573678.html accessed January 2018.

[39]Ibid.

[40]Ibid.

Indeed, space applications, rooted in earth observations as described above, were used toward the latter years of the MDG period ending in 2015 for development purposes; however, accelerating innovations in the digital currency and satellite sectors now offer the opportunity for expanding the applicability and relevance of space applications beyond traditional development outcomes, such as agriculture, health, and education. These innovations have expanded to the banking and financial services sector and portend greater support to achieving development outcomes in these areas for developing countries. New technologies and approaches, as embodied by the hosting and transacting of cryptocurrencies on satellites, serve as evolving and potentially transformational tools in global development efforts.

3.3 Significance of Space-Based Cryptocurrencies for Development

As suggested by the review of the above-described entrants into the space-based cryptocurrency sector, the space applications and space-based services sector retain significant potential for growth, particularly as these initiatives have only developed in the preceding two years as concepts with full deployment, at least in the case of Nexus, expected by 2019. These current innovations and those to come arise at a time when a confluence of trends emerge in the space sector, namely the introduction of cost-effective launch service providers, developments in technology and greater accessibility of nano- and microsatellites, and increased acceptance of cryptocurrencies and blockchain technology as means of transacting and storing value.

For example, innovative financial service providers, including Abra, utilize cryptocurrencies, such as bitcoin, to reduce money transfer fees between customers. Other innovators, such as TransferWise and WorldRemit, use other methods of trying to reduce costs in order to ensure money senders and receivers obtain the most value from their transaction. These new companies seek to overcome the regulatory and institutional and human resource costs associated with sending remittances as described above. These companies, relying on innovative approaches and new technologies, actively pursue new business methods that would contribute to the reduction of remittance costs, which has been identified as a priority by numerous global development stakeholders.

As suggested by the Overseas Development Institute, "Governments and regulatory authorities in sending countries should do far more to promote competition and encourage innovation."[41] Because of excessive fees charged by money transfer

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[41]Kevin Watkins and Maria Quattri, 'Lost in intermediation' (Overseas Development Institute, April 2014) https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8904.pdf accessed January 2018.

operators such as Moneygram and Western Union, the Overseas Development Institute estimates that 586 million US dollars are lost each year in remittances to Africa because of a super-tax imposed by these operators, which is embodied by the fact that senders of remittances to African countries pay almost double the global average (i.e. 12%) of remittance fees.[42] The Institute suggests this super-tax on remittances to Africa exists because of "weak competition, concentration of market power, and flawed financial regulation."[43]

Therefore, the potential role such companies as Abra, TransferWise, and WorldRemit hold in the future of the remittance industry remains significant, particularly if global development stakeholders increasingly recognize the size and reliability of the sector in financing development efforts as compared to official development assistance and private capital flows as previously argued. Abra, a company that relies exclusively on bitcoin as the cryptocurrency for facilitating transactions, circumvents the traditional money transfer structure by asking senders to upload money to its facility, which it then converts to bitcoin and transfers across the blockchain, and finally settles in the local currency for the receiver.[44] Because the company uses bitcoin and does not take ownership of the funds directly once they are uploaded to its bitcoin conversion facility, Abra considers itself non-custodial and therefore exempt from banking regulations and the need to obtain banking licenses in some locations.[45] This therefore results in significantly lower transaction costs for the sender and recipient of the remittance. Circle, a similar company to Abra using bitcoin for facilitation of money transfers, does take ownership of funds when they are uploaded, however, which requires it to comply with additional regulations.[46] The potential of providers such as these to greatly or complete reduce remittance fees exists, as argued in a 2016 Aite Group market report.[47]

3.4 *Trends Supporting the Growth of Space-Based Cryptocurrencies*

The growth in the cryptocurrency-money transfer market suggests the growing acceptance of blockchain technology as a secure and legitimate way of transacting

[42]Ibid.

[43]Ibid.

[44]Ben Schiller, 'The Fight for the $400 Billion Business of Immigrants Sending Money Home' (Fast Company, April 2017) https://www.fastcompany.com/3067778/the-blockchain-is-going-to-save-immigrants-millions-in-remittance-fees accessed January 2018.

[45]Ibid.

[46]Ibid.

[47]Talie Baker, 'Cross-Border Remittances: Emerging Players' (Aite Group, June 2016) https://aitegroup.com/report/cross-border-remittances-emerging-players accessed January 2018.

and storing value. However, these companies, which still operate terrestrially, encounter regulatory and compliance challenges and will likely do so even more as they attempt to take a greater portion of the leading, traditional money transfer operators' market share and which may prompt these current market leaders to file complaints against new entrants in order to discourage them from joining the market. Therefore, companies, including Nexus as described earlier, now increasingly seek to avoid such compliance hurdles by hosting transfer operations in space via satellites and satellite platforms such as Galactic Sky.

The emerging trend here with space-based cryptocurrencies coincides not only with the growing acceptance of cryptocurrencies, but also the increasing use of nano- and microsatellites for providing such services. Market analysts project that this specific satellite market will reach a total valuation of nearly five billion US dollars by 2025,[48] which represents significant growth from its current position at 1.21 billion US dollars in 2017.[49] The growth in the market is expected because of increasing investments in the technologies that make these satellites possible, their low cost of manufacturing as compared to other satellites, and their high demand.[50] Nano- and microsatellites have been used for Earth observation missions and have been a key field in which the cost-effectiveness of these satellites was demonstrated and which now appears poised to host other missions and services. "As these [nano- and microsatellites] have paved the way for cost-effective earth observation missions along with the development of small launchers and small ground stations connected with cost-effective data distribution methods, industry participants have shifted their focus toward developing nanosatellites and microsatellites."[51] The report continues, "Nanosatellites and microsatellites have proven to be dynamic for embracing new developments in various sectors such as weather information and climatic research, multimedia communications, telephone and television, data distribution, transportation and logistics, navigation, safety, security, and rescue."[52] Of particular interest to those entering the space-based cryptocurrency market remains the ability to cost-effectively use the benefits of space applications to overcome regulatory and compliance costs, while also ensuring speed and security of their transactions. Since the nano- and microsatellite market offers the potential to safely

[48]Grand View Research, Inc., 'Nanonsatellite & Microsatellite Market Size Worth $4.97 Billion by 2025: Grand View Research, Inc.' (November 2017) https://www.prnewswire.com/news-releases/nanosatellite–microsatellite-market-size-worth-497-billion-by-2025-grand-view-research-inc-658783753.html accessed January 2018.

[49]MarketsandMarkets, 'Nanosatellite and Microsatellite Market worth 3.49 Billion USD by 2022' (2017) https://www.marketsandmarkets.com/PressReleases/nanosatellite-and-microsatellite.asp accessed January 2018.

[50]Ibid.

[51]Grand View Research, Inc., 'Nanonsatellite & Microsatellite Market Size Worth $4.97 Billion by 2025: Grand View Research, Inc.' (November 2017) https://www.prnewswire.com/news-releases/nanosatellite–microsatellite-market-size-worth-497-billion-by-2025-grand-view-research-inc-658783753.html accessed January 2018.

[52]Ibid.

store, transfer, and distribute the data upon which blockchain technologies rely, the satellite market portends a significant opportunity for new actors to emerge in the money transfer market and facilitate the reduction of remittance costs by several orders.

One example briefly mentioned previously exists in the form of Galactic Sky, Vector's satellite virtualization platform. Vector, a private space company focusing on launch services for nanosatellites, offers Galactic Sky as a platform that includes "satellite design tools, space application lifecycle and container management, cloud-based space simulation services, [a] full suite of SDK's and API's for quick development, [and] purpose-built Linux implementation (Galacticos) executing customer workloads."[53] Vector, through Galactic Sky, essentially offers its platform so that "ideas, experiments, and algorithms can be rapidly executed on orbit to demonstrate their true utility and viability" via Vector's satellite constellation.[54] Nexus proves as one early example of a cryptocurrency operator adopting space-based technologies to overcome regulatory challenges. With the growth and acceptance of other cryptocurrency-money transfer operators, including Abra and Circle, the market for hosting these types of blockchain-based financial transactions in space will likely grow significantly alongside the already expected rapid pace of development for the nano- and microsatellite industry itself.

3.5 Space-Based Cryptocurrencies and the Post-2030 Agenda

As remittances grow to play an increasingly important role in financing global development efforts, the objective to reduce or nearly eliminate the costs associated with them, and thereby grow the overall remittance industry, will serve as a strong driver in encouraging the development of space-based cryptocurrency systems. The use of space-based cryptocurrencies would not only allow new companies to compete in the money transfer market, but also support the lowering of remittance costs as companies circumvent expensive regulations governing money transfers, which up to the present have necessitated and led to the development of institutional and personnel-intensive systems of sending and receiving money across borders. By transferring, storing, and hosting cryptocurrency-based transactions via satellites, companies would be able to safely, securely, and inexpensively facilitate international money transfers. This would in turn lead to more money reaching intended recipients of remittances, and overall growth in the remittance industry.

Therefore, the advent of space-based cryptocurrencies in support of lowering remittance costs directly contributes to the achievements of the Sustainable Development Goals, particularly Sustainable Development Goals 1 and 8 as

[53]Vector Space, 'Galactic Sky' (2016) http://www.galacticsky.net/ accessed January 2018.
[54]Ibid.

described earlier in this paper. However, with the proliferation of such transactions in the coming decades, these developments portend additional challenges for the post-2030 development agenda. Indeed, banking and international money transfer regulations exist in the first place to curtail illegal activity and financing for nefarious purposes, such as with anti-money laundering and anti-terrorism financing laws. While companies such as Nexus claim to use space-based cryptocurrencies for their ability to "decentralize,"[55] and implicitly operate outside of the restrictions that accompany centralization, different types of risk emerge, particularly around verifying and authorizing that those who try to use the transfer system do so without ill-intended aims.

Official development assistance, and to a somewhat lesser extent private capital flows, offers some measure of control for how resources can be directed toward certain purposes; for example, development projects in the case of official development assistance or investment and new business in the case of private capital flows. However, money transfers between individuals by nature remain less controlled and directed if the marshalling of resources toward a particular effort is required. This does not undermine the fact that remittances indeed promote better development outcomes as explained in detail previously in this essay, but as individuals gain greater financial control through the use of mechanisms such as space-based cryptocurrencies they may introduce greater risk. In an interview, Western Union used this argument to justify the fees associated with its money transfers: "Technology doesn't solve all those business and regulatory issues. Some pure technology plays forget that. We live in a world with criminal networks and entities that you have to keep out of your infrastructure. There's a pretty high barrier to entry because of the risks associated with the market."[56]

Therefore, it will remain incumbent upon the post-2030 agenda and development stakeholders to address the question of how to most effectively lower remittance costs and promote the role of remittances in global development, while mitigating the risks that accompany the introduction of new technologies which would facilitate these development objectives. The current phrasing of Sustainable Development Goal 8, which most closely relates to the concern of increasing financial services, suggests this goal may transition to a post-2030 agenda as part of efforts to continue to increase financial inclusion while also enhancing the quality of financial services by ensuring safe banking and financial practices. The post-2030 agenda will also need to address the role of new technologies in not only finance, but more broadly across all sectors as new and different types of risk may emerge with their development, as seen with space-based cryptocurrencies.

Therefore, a post-2030 agenda may further highlight the importance of shared global governance as it comes to promoting the benefits of new technologies that

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[55]Nexus, 'Mission' (2018) http://www.nexusearth.com/ accessed January 2018.

[56]Ben Schiller, 'The Fight for the $400 Billion Business of Immigrants Sending Money Home' (Fast Company, April 2017) https://www.fastcompany.com/3067778/the-blockchain-is-going-to-save-immigrants-millions-in-remittance-fees accessed January 2018.

may develop in the coming decades in support of development efforts, while simultaneously mitigating any new risks they may pose. An agile and responsive shared governance platform providing guidance and oversight to new technologies, particularly space-based technologies, may prove necessary for consideration in any post-2030 agenda that emerges.

4 Conclusion

Official development assistance and private capital flows serve as important means for financing global development efforts; however, remittances offer more resources as compared to official development assistance and more stability as compared to private capital flows. In order to unlock the potential for remittances to serve as an even greater force in the Agenda 2030 effort and any post-2030 agenda which may emerge from it, it remains imperative to reduce the high costs of remittances so that more resources may become available for development and not lost to excessive or unnecessary fees owing to complex international financial transactions and the need therein to comply with varying international and national regulations.

Space-based cryptocurrencies offer a secure means of reducing and nearly eliminating these high costs associated with remittances. New companies and technologies have made it possible to safely and securely send and receive local currencies via cryptocurrency-based transactions. Satellites and space-based applications and services offer secure and cost-effective manners in which to host, store, and transmit data for the successful completion of such transactions. Therefore, space-based cryptocurrencies have a significant role to play in the achievement of the Sustainable Development Goals and a post-2030 development agenda by growing the remittance industry through lower fees and increased accessibility.

However, challenges remain in governing space-based cryptocurrencies. While these innovations will bring reduced costs to remittances and support the broader development agenda, they also carry with them increased risk in the need to verify and authorize those who use the systems for ensuring transactions do not facilitate illegal activities. The post-2030 will need to address the benefits and risks of such innovations and harness them toward an equitable, inclusive, and sustainable development effort.

Towards Total Water Awareness: A Technology Framework

Christoffel Kotze

Abstract The world is running out of fresh water to support a growing population. Aquifers around the world on which whole communities depend are being depleted at a rapid rate. Apart from exploring new technologies to make more fresh water available, conservation efforts need to be stepped up—starting with awareness. Lack of awareness can seriously hamper water conservation efforts—take the example of Cape Town South Africa. The city is currently battling a severe water crisis that has put Cape Town on a road to a day, when the taps will literally run dry—"day zero". The city stepped up efforts to create awareness of the increasingly dire situation through various channels. So why as of January 2018 with "day zero" two months away, has 60% of the city's population still not adjusted their usage? The study of water consumption is an active field that has produced concepts like virtual water, water footprint and water accounting which all can help to provide a deeper understanding amongst users regarding the impact of their usage. Technology creates a potential opportunity to collect and present usage data in such a way as to influence user behaviour to favour a sustainable approach.

1 Introduction

> Water is an astonishingly complex and subtle force in an economy. It is the single constraint on the expansion of every city, and bankers and corporate executives have cited it as the only natural limit to economic growth—Margaret Catley-Carlson.[1]

[1]Margaret Catley-Carlson as Vice-Chair of World Economic Forum.

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The Brundtland Report defined “sustainable development” as “development which meets the needs of current generations without compromising the ability of future generations to meet their own needs”.[2] Nowhere is this more important than caring for our water resources. With an ever-increasing population putting strain on precious water resources, awareness of the consequence of our collective individual consumer behaviour will be a key determinant whether our current water resources will be adequate to sustain future generations. Though much has been achieved through various initiatives, there are still 663 million[3] people without ready access to safe fresh water. For most of these people—access to water often involving long daily retrieval trips—there is a natural awareness about the state of their water resource’s quantity and quality. Water awareness of users in the developed world is naturally more limited as supply is mostly “black box”—typically the only reminder of use—the monthly utility bill. Conservation efforts can benefit from a greater awareness, and an understanding of what the consequence of water consumption is in greater terms. The idea explored in the following sections is that of a high-level framework to illustrate how technology can potentially be used to achieve greater user awareness of consequence of water use amongst users in the developed world.

2 Beyond 2030

A world without poverty, thirst or hunger. Where healthy educated people engage in lifelong learning are productively employed in efficient industry, producing responsible consumables fuelled by innovation and sustainable energy. The Gini coefficient will be merely a historical curiosity, where a diverse, equitable and inclusive society will be housed in safe “smart” settlements—supported by sustainable practice in agriculture and resource extraction—driven by a responsible consumption demand. Methods to prevent, fight and remediate the effects of climate change will be developed, as well as protocols to reverse the damage done to local ecosystems, land and marine resources through irresponsible exploitation by previous generations. This society will foster peace and stability by building transparent, accountable institutions at local, country and global levels. Most of all such a society will have to pursue and refine sustainable development at to benefit all stakeholder levels.

Sounds like the proverbial “pie in the sky”, no, this could be the world of 2030 if all of the UN SDG’s are implemented by then.[4] The reality will more than likely be

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[2]Gro Harlem Brundtland, Report of the World Commission on environment and development: “Our common future.” (UN, 1987).

[3]“Water, Sanitation and Hygiene” www.unicef.org/wash/ accessed 6 February 2018.

[4]“The Sustainable Development Agenda” www.un.org/sustainabledevelopment/development-agenda accessed 15 January 2018.

that not all targets will be achieved globally by 2030. A likely scenario being—a mixed bag of most—but not all of the goals implemented at 100% as per the set targets, with an uneven implementation of the goals across certain countries, especially those plagued by regional conflict.

Whichever scenario plays out by 2030, the reality is the population would have reached the 8.5 billion[5] mark, one billion people more than the 2017, and is expected to reach almost ten billion by 2050. One of the areas impacted most by population growth is the availability of usable fresh water, the topic of SDG 6—"*Achieve universal and equitable access to safe and affordable drinking water for all*". Though there are encouraging signs of technological breakthroughs potentially providing abundant potable water cheaply, e.g. graphene-aided desalination[6] and passive atmospheric water generation (Warkawater[7]), one will have to assume that SDG 6 will have to continue in one form or the other as the population keeps growing with a resulting increase in water usage.

3 Water Scarcity

Access to fresh water is a matter of biological survival, and through replenishment of waste with fresh water, a healthy fluid balance is maintained—a critical component of homeostasis. Earth often referred to as the "Blue Planet" with more than 70% of its surface covered by water has surprisingly little of it (0.3%) readily available fit for human use. Most fresh water for human consumption revolves around "surface water" such as rivers, which unfortunately only represents a very tiny percentage of fresh water. The majority of fresh water is in actual fact captured as groundwater; i.e. it is stored underground. Groundwater can be accessed in a number of ways—indirectly when it adds to river and streams flows through underground "recharge" or directly via well points, fountains and boreholes.

Of this small amount of freshwater available to a growing population, the vast majority of available water resource is allocated to agriculture (almost two-thirds) followed by industrial allocation (one-fifth) and municipal/household use only a twelfth (Fig. 1).[8]

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[5]"UN projects world population to reach 8.5 billion by 2030, driven by growth in developing countries" www.un.org/sustainabledevelopment/blog/2015/07/un-projects-world-population-to-reach-8-5-billion-by-2030-driven-by-growth-in-developing-countries/ accessed 15 January 2018.

[6]Ben Robinson, "Graphene sieve turns seawater into drinking water" 2017 University of Manchester News www.manchester.ac.uk/discover/news/graphene-sieve-turns-seawater-into-drinking-water accessed 3 February 2018.

[7]"Warka Tower" www.warkawater.org/warka-tower/ accessed 3 February 2018.

[8]"Aquastat Water withdrawal by sector, around 2007" 2014 Global Agriculture www.globalagriculture.org/fileadmin/files/weltagrarbericht/AquastatWithdrawal2014.pdf accessed 15 January 2018.

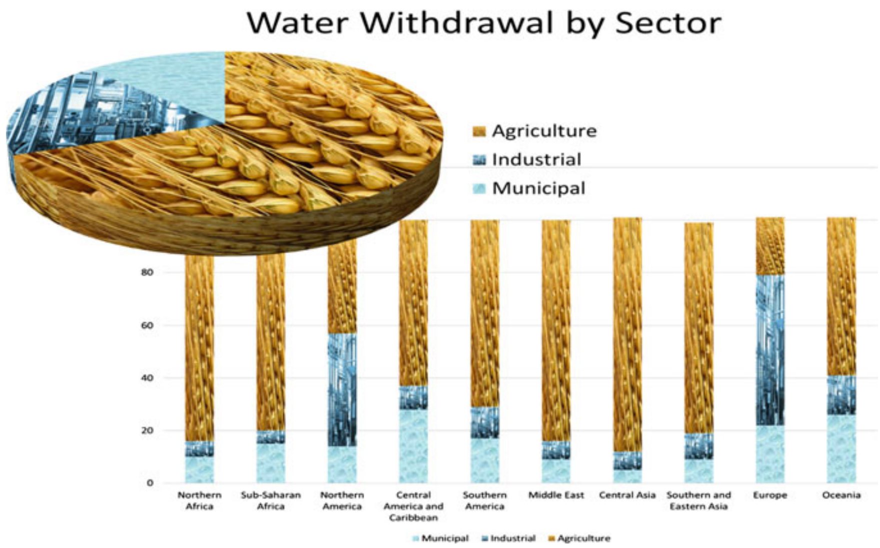

Fig. 1 Global and regional water consumption by sector

Though a human being can survive with very little (<7l) water per day to sustain life, the reality is a much larger quantity is required—according to the World Health Organisation (WHO) 50–100 l/d—per day to ensure a healthy hygienic existence. Water is vitally important to maintain sanitary conditions and prevent hygiene-related diseases by washing food, personal sanitation, washing clothes, cleaning, etc.

So with an increase in population and only so much water to go around, the proverbial water "pie" has been getting smaller for all concerned. Technology has been able to support the growing population so far, making more efficient use of available resource through reuse and recycling but also through desalination and groundwater use.

As population pressure and water consumption increase in a region, it will eventually reach a tipping point when the regional sources will not be able to supply enough water to the local population—a condition known as "water stress". This condition can be brought on by many factors but is essentially a function of quantity (how much water is available) and quality (potable or polluted). Such a condition can be brought on suddenly (catastrophic water source pollution, natural disaster, etc.), gradually (population increase, climate change) and periodically (lower rainfall leading to droughts). Baseline water stress is expressed as a percentage of the total annual water withdrawals (agricultural, industrial, municipal/personal) of the total annual available flow for the measured area.[9] Water stress can take on

[9]"Aqueduct Country and River Basin Rankings" Aqueduct water risk indicators World Resources Institute www.wri.org/applications/maps/aqueduct-country-river-basin-rankings/ accessed 15 January 2018.

different magnitudes when expressed as exposure of users in a specific area to baseline water stress, essentially reflecting the competition for available water for use. Higher values indicate more competition amongst users. This indicator was used by the World Resources Institute (WRI) in the Aqueduct[10] project to classify global water stress as;

- **Low**: Less than 10% as ratio of withdrawals versus supply.
- **Low to Medium**: 10–20% as ratio of withdrawals versus supply.
- **Medium to High**: 20–40% as ratio of withdrawals versus supply.
- **High**: 40–80% as ratio of withdrawals versus supply.
- **Extremely High**: Greater than 80% as ratio of withdrawals versus supply.

In the 2017 UN SDG 6 progress report,[11] it is noted that globally in excess of two billion people are exposed to water stress in excess of 25% and ten countries withdrawing over 100% of their renewable freshwater resources. It is clear that there needs to be better management of the global water resource and understanding of consumption patterns, and a good point of departure is to start with different perspectives of consumption.

4 Expanded Views on Water Consumption

As seen in the previous section, the municipal (personal) water use category represents the lowest total direct use as compared to agriculture and industrial, one would rightly think then most conservation efforts should be directed at these two high use categories. But is it a true reflection of use and how significant is personal water use in the “bigger picture”? Agricultural and industrial activities are both a response to collective individual consumption demand. One could thus argue that ultimately individual demand drives the water consumption of all sectors. This section briefly explores three important interrelated perspectives on water consumption “virtual water”, “water footprint” and “water accounting”.

4.1 Virtual Water

Introduced by Professor John Allan[12] in 1993, the term “virtual water” was initially used to describe the coincidental “water trade” resulting from food imports by

[10]Andrew Maddocks, “Water Stress by Country” 2013 World Resources Institute www.wri.org/resources/charts-graphs/water-stress-country accessed 15 January 2018.

[11]“Progress of goal 6 in 2017” 2017 Sustainable Development Goal 6 https://sustainabledevelopment.un.org/sdg6 accessed 3 February 2018.

[12]John Allan, ‘“Virtual water”: A long term solution for water short middle eastern economies?’ 1997 Water Issues Group, Sch. of Orient. and Afr. Stud., King's College, London, U. K.

water-scarce countries from countries with more available water sources. The term has since been expanded to include the amount of fresh water used to produce any commodity. Firstly, a view of water consumed at the location of production is referred to as the “production-site definition”. Alternatively looking at “virtual water” from the consumption side, i.e. as the amount of freshwater it would have required to produce at the location of consumption—“consumption-site definition”. Generally unless otherwise stated, the default view will be the “production-site definition”. This very important concept can be seen as the elephant in the room when it comes to individual water awareness since most people are completely unaware of their daily “hidden” water use. In practical terms, the water usage involved to produce a cheeseburger and small orange juice would have relieved the relevant production sites of almost 2700 l of “virtual water” through the supply chain. The following table illustrates how choices of popular food (meat and grains) and beverages impact virtual water (Table 1).

In addition to the virtual water used per commodity, another perspective involves looking at “virtual water” in terms of distance it needs to travel from production to consumption. “Zero Kilometre Products”[13] are products produced and consumed locally creating less of an impact through the supply chain. To highlight the issue initiatives such as The Virtual Water Project has created detailed printed matter as well as an iOS app to bring the matter to public awareness.[14] Creating awareness around this concept and including it in consumption data is crucial for integrated water management.

4.2 Water Footprint

Water footprint—the concept was first put forward by Dutch Professor Arjen Y. Hoekstra to aid understanding in how our choices of consumption and production influence the usage of available water resources.[15] This is especially pertinent with a growing, ageing population striving towards an ever-increasing standard of living. Water footprint is the measurement reflecting the water required to produce each of the goods and services consumed by an individual or group. It can be measured at different levels, for an individual product, a process, an organisation, etc.

The water footprint comprises three components green, blue and grey which is used to calculate a total water use picture.

[13]Oscar Tomasi, “‘Zero kilometre’ food products start to take Spain by storm” 2016, Euractive Agrifood www.euractiv.com/section/agriculture-food/news/sr-agri-local-zero-kilometre-products-start-to-take-spain-by-storm/ accessed 15 January 2018.

[14]“Virtual Water” http://virtualwater.eu/#about accessed 15 January 2018.

[15]Hoekstra, Arjen Y. “The water footprint: The relation between human consumption and water use.” In The water we eat, pp. 35–48. Springer, Cham, 2015.

Table 1 Virtual water consumption of common consumables

Mass (kg)	Food	Vwater	Unit	Volume	Beverage	Vwater	Unit
1	Beef	15,000	l	1 l	Coffee	1200	l
1	Pork	4800	l	1 l	Milk	1000	l
1	Chicken	3700	l	1 l	Apple juice	950	l
1	Maize	1700	l	1 l	Orange juice	950	l
1	Barley	1200	l	1 l	Wine	960	l
1	Wheat	800	l	1 l	Beer	600	l
1	Potato	500	l	1 l	Tea	120	l

'Good water, water to "eat". What is virtual water?' Water Civilization International Centre, Venice, www.unesco.org/fileadmin/MULTIMEDIA/FIELD/Venice/pdf/special_events/bozza_scheda_DOW04_1.0.pdf accessed 5 February 2018

- **Green water footprint** is the water from precipitation that is stored in the root zone of soil, evaporated, transpired or incorporated by plants associated with agriculture, forestry, etc.
- **Blue water footprint** is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time. Agriculture using irrigation, industrial and domestic water are examples.
- **Grey water footprint** is the amount of fresh water required to assimilate pollutants to meet specific water quality standards. The grey water footprint takes into account, direct (piped) or indirect (leaching, runoff, etc.) pollution discharged to freshwater resources.

Calculating the water footprint for a country takes into account the "export" and "import" of "virtual" water as set out below:$Wf = (Dc - Ve) + Vi$ where

Wf National water footprint
Dc Consumption of domestic water resources
Ve Virtual water export
Vi Virtual water import.

A country importing a high percentage of its foodstuff will theoretically be importing large quantities of virtual water which needs to be taken into account when calculating its local water footprint. Of the total annual per capita water footprint of The Netherlands, 90% is considered to be from "outside" (essentially using the water from a source outside of the country) as compared to Paraguay that only uses as little as 3% "outside" contribution to its footprint.[16] The water footprint of a nation will be influenced by the consumption pattern and food choices of its citizens. Currently, individual product water footprint is not necessarily filtering down to the consumer level as a rule, though there are examples of companies

[16]"National water footprint" Water Footprint Network http://waterfootprint.org/en/water-footprint/national-water-footprint/ accessed 6 February 2018.

making the information available voluntary to consumers. Chilean winery Viña Concha y Toro[17] started declaring their water footprint already in 2010.

4.3 Water Accounting

To understand the use of water resources, it is necessary to use objective methodologies to create reliable data sets to determine consumption. The concept of water accounting[18] was originally put forward by Dr. David Molden and Delft University from International Water Management Institute (IWMI), and subsequently, a set of methodologies "WA2+" was produced and made available in the public domain. These methodologies have the objective to create a transparent governance system for all water users and enable sustainable water consumption.

5 Water—Awareness of Consequence

Water usage is well researched, information-rich topic, a simple Google search for each of these terms produced a significant amount of "hits", "Virtual Water" (55 million+), "Water Footprint" (19 million+) and "Water Accounting" (40 million+), and there are also many calculators available to compute an individual or organisational usage as well. With so much information out there, why are areas suffering drought struggling to change user behaviour?

Take two communities—the first one is dependent on storage dams only for water, whilst the second one is dependent on underground water only.

The first community dependent on a storage dam replenished by rainfall only is reminded of the state of their resources daily, simply because they can see the level rise or fall. Level rising too quickly, they can prepare for flooding. In drought conditions due to low rainfall, their awareness will be reinforced every day the level drops, and they can throttle back water usage. This community, is aware of an impending crisis due to the consequence of the state of the dam level, can take action and plan accordingly.

The other community dependent on groundwater water, via a borehole, cannot see the direct consequence of their daily use. Not having awareness of the condition of the underwater resources, they might pump till one day the borehole water simply stops, giving them no time to plan for remedial action. In addition to the threat, their unchecked usage holds to their own survivability and there could be a

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[17] "Water" Sustainability https://www.conchaytoro.com/sustentabilidad/water/ accessed 5 February 2018.

[18] Daved Molden, and Ramaswamy. Sakthivadivel, 1999 "Water accounting to assess use and productivity of water." International Journal of Water Resources Development 15, no. 1–2 (1999): 55–71.

secondary knock-on effect. Lack of awareness about the state of their borehole might motivate implementation of agricultural practices requiring unsustainable use of the water resource. Such use of the distressed aquifer can stop groundwater-dependent rivers further down the system to stop flowing, which yet another community depends on—who will now suffer the consequence of the abuse. The communities suffering consequential damage through the abuse of the “culprit” community might now also have to resort to using groundwater perpetuating a similar chain of events. The obvious solution is to change the behaviour of the water abusers.

A large population of water users in the developed world are only made aware of their impact on water resources in a reactive fashion, e.g. once a month in monetary terms on receipt of the utility bill and that normally only impacts the payee. Concepts like “virtual water” are not taken into account when making consumer choices. To be proactive, the consumer needs to be aware of the “bigger picture” and an influenced to foster a pre-cycling approach—focus on prevention of waste by making informed decisions.

So what if you could create “Total Water Awareness” by measuring and communicating the total water footprint—including real-time water usage and virtual water usage—back to the user, using a reward system to influence behaviour. The current explosion in technological development creates such a potential opportunity.

6 Technology as Opportunity

> We stand on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before.—Klaus Schwab.[19]

Unlike the three preceding industrial revolutions, the Fourth Industrial Revolution (4IR) is developing exponentially, with simultaneous rapid breakthroughs in almost all fields of technology. Characterised by Cyber-Physical Systems (CPS), the result of the integration of intelligent networks, systems and processes the key ingredient in the 4IR recipe without which it cannot exist is Internet connectivity. In terms of water usage, a number of these technologies can be used to influence users to recover, recycle, reuse and reduce.

[19]Klaus Schwab, “The Fourth Industrial Revolution: what it means, how to respond” 2016 WEF https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/ accessed 15 January 2018.

6.1 Total Water Awareness in a Nutshell

- Purpose—foster global sustainable water consumption.
- Strategy—create "Total Water Awareness" amongst the water user community to encourage responsible consumption.
- Tactic—use available technology to collect and process water consumption data and influence user's water usage behaviour to a desired outcome through positive or negative rewards via a suitable effector.
- User—can be any person, process, organisation, etc.—putting demand either direct or indirect on the available usable water resource.
- Reward—in this context, refers to a type of action to influence user behaviour, it can be positive e.g. a user receives an exchangeable token, or negative through diminished user privilege.
- Effector—a device, system or process that can be used to deliver the "reward" and feedback.

Functional requirements:

- Data—identify and collect from all sources to satisfy full-scale water accounting (real-time and virtual water usage) requirements.
- Processing—have the ability to process the large amount of data and meta-data in real time.
- Communication—platform needs to be able to support data mass collection and result feedback anywhere on earth.
- Effector—any device used to action the user, e.g. a smartphone, personal data device, a valve, social network.

6.1.1 Data and Analytics

The one thing in the future that there will be no shortage of is data. According to a recent article in Forbes, citing an IDC study, the exponential growth of data is to exceed 163 zettabytes (1 billion terabytes) by 2025, to put it into perspective, an almost tenfold increase to the 2017 figure.[20] Such vast data quantities in conjunction with advanced analytic techniques aided by development in artificial intelligence (AI) will be the fuel driving the envisioned embedded automated systems running critical processes involved future day-to-day living. Total water awareness should be one of those, along with the more glamorous examples of self-driving cars, flying taxis and drone-delivered 3D printed haute cuisine. Potential data sources to monitor water usage are everywhere, but one can look at it

[20]Andrew Cave, "What Will We Do When The World's Data Hits 163 Zettabytes In 2025?" 2017 Forbes www.forbes.com/sites/andrewcave/2017/04/13/what-will-we-do-when-the-worlds-data-hits-163-zettabytes-in-2025/ accessed 5 February 2018.

from two primary angles—the "big picture"—sourced from space and—the "little picture"—more granular terrestrial sources.

6.1.2 Space Technology

By its very nature, space technology provides a globe-spanning presence unrivalled by any terrestrial equivalent in that it can reach even the most remotest of areas on earth, making it ideal for any truly global project. Though space technology spans a number of distinct applications as far as a data collection is concerned, two applications are of particular importance to this approach.

Global Satellite Positioning
It is probably the technology first and foremost in the mind of the average person when thinking about practical space technology. As far as data collection is concerned, the "location and time" meta-data provided by GPS is essential for any truly global system. First introduced for military purposes, the technology has been rapidly adopted since the first introduction of personal navigating and the usage evolved to drive disruptive business concepts such as Airbnb and Uber through utilisation of the location meta-data. In addition to the truly global systems NAVSTAR (USA), GLONASS (Russian Federation) and Galileo (EU), there are also a number of regional systems amongst others such as BDS (China), IRNSS (India) and QZSS (Japan) providing additional data collection opportunities.

Remote Sensing
Remote sensing provides the "real big picture" view of earth employing different sensing mechanisms to provide data on many different topics including water resources. Providing through observation of inventory and location, data to build Geographical Information Systems (GIS) models are handy to determine usage and distribution. Observation of weather systems provides data to predict short-term extremes such as flooding and to model long-term trends related to climate change. Collection of groundwater data from space are of special importance, as terrestrial data collection methods are particularly difficult to collect and are mostly localised. Due to the importance of groundwater in the water supply network, collecting data on the state of resources is crucial to future capacity and risk planning. Specialist missions such as the NASA and Deutsches Zentrum für Luft- und Raumfahrt (DLR), Gravity Recovery and Climate Experiment (GRACE) launched in 2002 have provided invaluable data on the crucial state of groundwater for more than 15 years until it was retired in 2017.[21] This role will subsequently be taken over by GRACE-FO[22] a similar cooperative effort between NASA and DLR. The mission

[21]Carol Rasmussen, "GRACE Mission: 15 Years of Watching Water on Earth" 2017 NASA Earth Science News Team www.nasa.gov/feature/jpl/grace-mission-15-years-of-watching-water-on-earth accessed 15 January 2018.

[22]"Next-Generation GRACE Satellites Arrive at Launch Site" 2017 https://gracefo.jpl.nasa.gov/news/122/next-generation-grace-satellites-arrive-at-launch-site/ accessed 6 February 2018.

to be launched in 2018 will have the capability to detect changes—in addition to groundwater storage volumes—in ice sheets, glaciers and water inventory of large lakes and rivers amongst others. This data will no doubt contribute to create a more complete look of the earth from a water point of view.

6.1.3 Terrestrial Sensors

Capable, affordable artificial sensors are becoming abundant, driven by commercial demand from the IoT market and enabled by an unprecedented pace in simultaneous innovation on multiple technological fronts. Though sensors placed in the water flow network are not new, as costs are driven down and capability increases, it will find its way into more of the flow network, creating a massive collection of decentralised sensitised objects to monitor water inventory, health and distribution.

6.1.4 Communication—Satellite Broadband

The key to any global integrated system is connectivity and that involves connecting the Internet backbone to the end user—i.e. it needs to bridge the "last mile". Satellite technology provides one of the best opportunities to link the currently four billion plus people in remote and underserviced areas. Since 2015, a number of new systems poised to provide high speed, high capacity broadband Internet that have been announced by major players including Boeing, One Web, and SpaceX. SpaceX alone has lodged applications for almost 12,000 satellites with the FCC.[23] These new generation satellites will add multiple terabits of low latency bandwidth to not only bridge the digital divide but also to connect the multitudes of sensors introduced through IoT to open up a treasure trove of opportunity.

6.1.5 Effectors

By 2020, the number of mobile phone users in the world would have exceeded five billion with more than 50% of those smartphones. This creates a huge opportunity, the smartphone is an ideal way to communicate a personalised water "balance sheet", as according to the research firm Dscout, the average user–smartphone interaction is a whopping 2617 times per day.[24] Even if only a small percentage of

[23]Doug Messier, "SpaceX Wants to Launch 12,000 Satellites" 2017 Parabolic Arc www.parabolicarc.com/2017/03/03/spacex-launch-12000-satellites/ accessed 6 February 2018.

[24]Patrick Nelson, "We touch our phones 2617 times a day, says study" 2016 NetworkWorld www.networkworld.com/article/3092446/smartphones/we-touch-our-phones-2617-times-a-day-says-study.html accessed 6 February 2018.

that time can be used to communicate the users "water impact", it could be used to modify errant behaviour using gamification principles. In the future no doubt the smartphone would have been replaced by another type of personal device, more than likely incorporating elements of augmented reality to create an even more effective environment of awareness.

7 Putting It All Together

The suggestion is as such; create a smartphone app to communicate a running personalised "total water usage" account back to the user. Driven by GPS meta-data, usage will be calculated for each water consumption location the user directly impacts based on prevailing water resource conditions, and in addition, consumption patterns in the form of virtual water consumption will be added to calculate a real-time water footprint. The data will then be packaged and communicated back to the user using gamification principles. Gamification has been applied very successfully in a variety of diverse sectors from education to corporate management as behavioural change aid. The "Behavioural Change Gamification Model" developed at Duke University to encourage "green" behaviour and The Recyclebank[25] application are good examples how gamification can be used to encourage sustainable behaviour. The Total Water Awareness App will not only give the user's real-time "water footprint" but will also communicate water-related warnings (floods, contamination, disease, etc.) as well as conservation suggestions. Gamification will encourage and reward the user for pre-cycling behaviour. To achieve such a system, a number of diverse data sources and technologies will need to be integrated, and the following is a proposal on how this could be approached. As this framework can potentially be used for more than one application involving sustainable positioning, it will be referred to as T4GF—"Technology-4GreenFramework" (Fig. 2).

8 Combining It All—"Technology4GreenFramework"

Simple, easy to use technology finds easy market acceptance—take the example of the iconic Apple iPod. Taking the complexity out of the interface Apple, though not the first company to bring an MP3 player to market, was the first one to gain mass market appeal (Fig. 3).

[25]RecycleBank www.recyclebank.com/ accessed 6 February 2018.

Fig. 2 Water awareness via smartphone

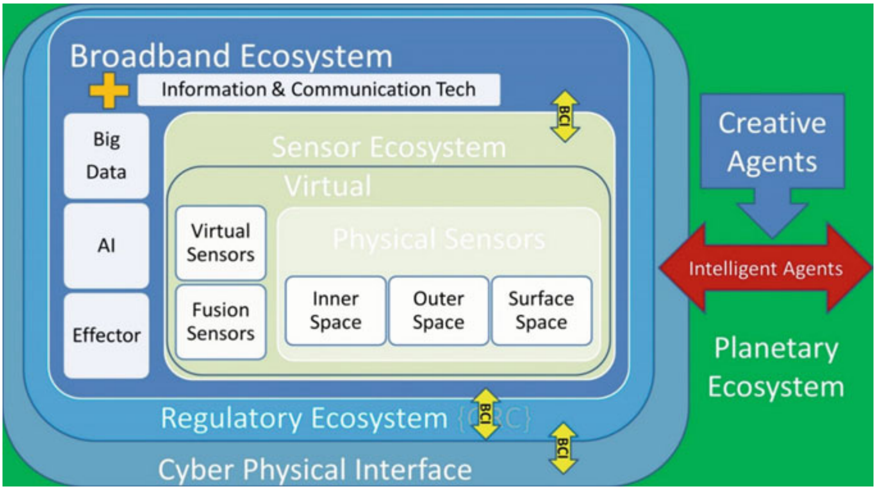

Fig. 3 Technology4GreenFramework

Similarly so if all the data required to raise awareness around water use can be presented to the user in an effortless manner, using a familiar utility device, e.g. a smartphone, chances are it will gain appeal and functional utility. To achieve this goal, effort needs to be focussed on creating a tightly integrated layered background process using embedded automation where possible. This specific proposal revolves around the "inter-connection" of three abstract "ecosystems" with the planetary ecosystem in such a manner as to remediate the impact of modern society on the environment, through the use of "technological bricolage" at the local level guided by global guidelines—"think global act local".

Framework components

Technology Ecosystems

Three technology ecosystems are defined each acting as an "authority layer" where a collection of functionally "fit4purpose" decentralised technology components connect and "trade" available data and direct actions via a "block-chain" interface. The output of each ecosystem contributes to effect the desired environmental action. Data contributions and actions can be rewarded based on its ultimate contribution towards reaching a set goal as credit to the collective "owner".

Sensor Ecosystem

It collects data using sensors regarding its target environment and presents it to a broadband communications component. This component has two subsystems, the first representing the "physical", consisting out of sensors grouped in the physical arena of operation. The second layer creates a virtual representation of the physical sensors based on combinations of results in the form of "fusion" sensors and "pure virtual" sensors based on virtual derivate data.

Physical sensor subsystem comprising of:

1. Inner space sensing, e.g. deep earth sensors to detect earthquakes
   - Subterranean
   - Subaquatic
   - In-vivo
2. Outer space—space-based sensors
   - Earth observation
   - Space weather
   - Deep space
   - Planetary discovery, etc.
3. Surface—sensors to measure all surface and air requirements, forming the bulk of sensing
   - Weather clusters
   - Atmospheric—Air quality, light, etc.
   - Surface water—quality, etc.
   - Flow networks –pipelines, transport, water, etc.

- Mobile—smartphones, self-driving cars, aeroplanes, ships, wearables, etc.
- Other, etc.

Virtual Sensor subsystem

- Virtual sensors—virtually created sensors, e.g. social media.
- Fusion sensors—derived values from combinations of physical sensors data.

Broadband Ecosystem
It is the collection of various Information and Communication Technology (ICT) clusters using "best fit4form" technology with the ability to collect, process and transport data between supply and demand sides. There are four core technology functions.

Communication
Is the core component of the whole system, used to connect all the different components, without this layer the system is not functional, redundancy can be ensured though through emergence of new capacity, most notably the planned satellite broadband mega constellations.

i. Backhaul—fixed or wireless, e.g. fibre optics, microwave, satellite trunking.
ii. "Last mile"—typical wireless, e.g. satellite broadband, Wi-Fi, xG.

Big Data
In this context "Big Data" is a collective term for technology clusters used to store and process vast amounts of structured and unstructured data into a presentable form for decision support, including analytics and cloud technologies.

AI—Artificial Intelligence
Artificial intelligence (AI) is a name given to a technology cluster attempting to mimic the human sense, learn, reason and action cycle. The AI component in the framework is responsible for directing an appropriate action to the relevant effector set constrained by the regulatory ecosystem (RE) to ensure optimal outcome for environment and society. Currently, there are various approaches to which could be more or less appropriate based on the data and scenario.

ICT
All additional hardware and software not covered by the other core components (Fig. 4).

Regulatory Ecosystem
It is the collection of all statutory and regulatory requirements pertaining to the local area of operation, any additional high-level best practice guidelines and recommendations. This layer will guide the effector agent to firstly conform to all minimum compliance requirements whilst looking for further improvement opportunities based on the additional broader institutional or community

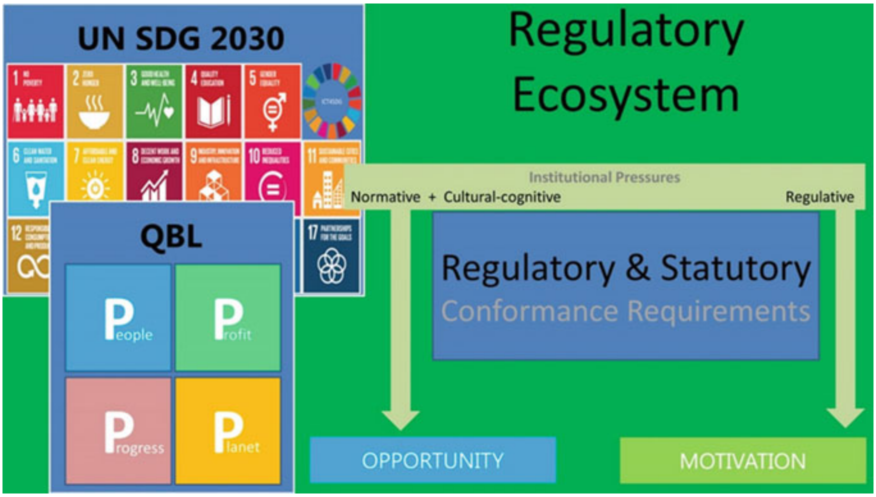

Fig. 4 Regulatory ecosystem view

recommendations. Probably the best example of a global-level institutional objective is the UNSDG2030. Acceptance of voluntary initiatives such as TBL[26] (Triple Bottom Line) and the expanded QBL (Quadruple Bottom Line) can also act as powerful influencers at organisational level, e.g. corporations where a powerful influence over environmental and societal interaction is held.

Block-Chain Interface—BCI

Block-chain technology—a digital decentralised ledger keeping record of all digital transactions across a peer-to-peer network without the need of a centralised third party. In the context of this framework, a "BCI" or block-chain interface is a ledger used to validate and track data transactions between interface points of the defined abstract "ecosystems". It can also be used to add a value to the transaction if so required.

Cyber–Physical Interface (CPI)

The NIST defines Cyber-Physical Systems, often referred to simply as "smart" systems, as "Co-engineered interacting networks of physical and computational components".[27] Such a system has the ability to improve quality of life for its stakeholders in general and is the product of the convergence of multiple technologies. This CPI is the abstract interface layer directing the collective action of

[26]John Elkington, "Partnerships from cannibals with forks: The triple bottom line of 21st-century business." 1998 Environmental Quality Management 8, no. 1 (1998): 37–51.

[27]Samuel Topping and others, "Framework for Cyber-Physical Systems: Volume 1, Overview" NIST 2017.

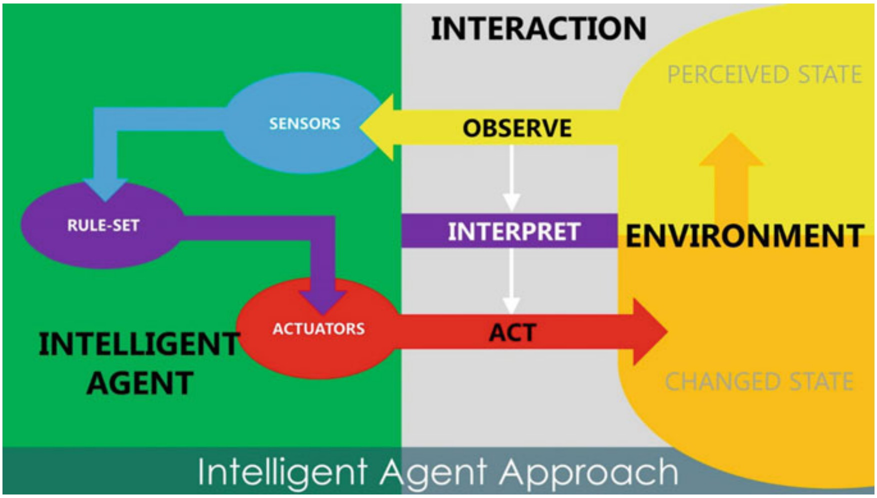

Fig. 5 Intelligent agent schematic

the other "ecosystems", effecting its influence on the physical environment through the use of an intelligent agent.

Intelligent Agent (IA)
The intelligent agent in this model is defined as the representation of the physical or virtual symbiotic relationship between sensors, processes and actuators to fulfil a **single task** as per the directive using all available resources (bricolage). The agent is the "worker" by taking the data provided by the sensor system, comparing it against the ruleset determined by the "regulatory ecosystem" and finally taking the "recommendation" coming out of that step and interpreting it as an action into the environment (Fig. 5).

Creative Agent
The "creative agent"—a software agent acting on behalf of all environmental stakeholders with the purpose of observing tasks effected by the IA and interrogate it for further opportunity against the 4R's—Recycle, Reuse, Reduce and Rethink—which is communicated back to the stakeholders.

9 Conclusion

Though a proposal like this might not sound feasible just as yet, it should be considered with a future in mind where awareness of sustainable practice needs not only be installed in human consumers but similarly in the automated processes and machines that will increasingly govern the world of tomorrow. The technological-driven post-2030 world will at some level have to embrace sustainability via algorithm using all the available building blocks.

Earth and Extra-Terrestrial Sustainable Development: The Challenges of Post-2030 Earth and Space Regime

Samuel Anih

Abstract The Sustainable Development Goals (SDGs) were designed to build on the success of the fifteen-year experimentation with Millennium Development Goals (MDGs). The focus of these development goals has been on Earth-based sustainable development—tackling issues that deal with sustainability only on Earth. However, in the post-2030s at the end of the present SDGs, it is envisaged that humans would have moved far beyond low Earth orbit. By then it is expected that public and private space entities would have extended human presence further into the solar system, possibly on the Moon, near Earth asteroids and Mars for exploration and exploitation of resources with the prospect of making humans a multi-planetary species. When this happens the goals contained in the present SDGs would no longer be adequate and would require some levels of adjustment to accommodate these developments. This document discusses the implication of the post-2030 Earth and extra-terrestrial regimes as well as the role of sustainability at the end of the present SDGs, it also highlights areas where these changes could be effected.

1 Background to MDGs and SDGs

This section gives a brief background of both MDGs and SDGs from the inception to conclusion of MDGs in 2015 leading to the current SDGs with various goals and targets. It also discusses similarities and difference of both goals. It further highlights the importance and the commitments required to sustain SDG until 2030.

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Studies in Space Policy 17, https://doi.org/10.1007/978-3-319-78954-5_4

1.1 Millennium Development Goals (MDGs)

Millennium Development Goals (MDGs) are the eight international development goals established following the Millennium Summit of the United Nations in 2000 for the year 2015. The MDGs were adopted following of the United Nations Millennium Declaration. All 191 United Nations member states at that time, and at least 22 international organizations, committed to help achieve the Millennium Development Goals by 2015. The Declaration was made to represent a global partnership to address growing poverty and basic needs for the world's poorest. These MDGs were result of many years of development work that were based on various concepts and strategies for achieving them. The MDGs focused on the following eight goals designed to eradicate extreme poverty: eradication of hunger, universal primary education, gender equality and empowerment of women, reduced child mortality, improved maternal health, eradication of HIV/AIDS, Malaria, and other diseases, environmental sustainability and global partnership for development (Fig. 1).

The MDGs were hailed as a success at the end of 2015 and laid the foundation for the adoption of the Sustainable Development Goals (SDGs).[1] The SDGs are the successor to the MDGs that guided international development efforts from 2000 to 2015. Upon the conclusion of the MDGs in 2015, the sustainable development goals were agreed upon as major goals to be achieved over the next 15 years by the United Nations.

1.2 The Sustainable Development Goals

Also known as "Transforming our World: The 2030 Agenda for Sustainable Development" or Agenda 2030 are a collection of 17 global goals with a total of 169 targets set by the United Nations which cover a broad range of social and economic development issues such as poverty, hunger, health, education, climate change, gender equality, water, sanitation, energy, environment and social justice. The SDGs in many ways share similarities with the MDGs,[2] but unlike the MDGs, the SDG framework covers a much broader range of issues and does not distinguish between "developed" and "developing" nations. Instead, the goals apply to all countries (Fig. 2).

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[1]United Nations, 'The Millennium Development Goals Report 2015' (2015).

[2]Casey Stevens and Norichika Kanie, 'The Transformative Potential of the Sustainable Development Goals (SDGs)' (2016) 16 International Environmental Agreements: Politics, Law and Economics 393.

Fig. 1 Millennium development goals (United Nations, 'MDGs' http://www.un.org/apps/news/infocus/UNdecoded/UNdecoded.asp?NewsID=1330&sID=48, accessed 10 January 2018)

Fig. 2 Sustainable development goals (United Nations, 'SDGs' (2015) http://www.un.org/sustainabledevelopment/blog/2015/12/sustainable-development-goals-kick-off-with-start-of-new-year/, accessed 10 January 2018)

1.3 Focus and Projections of Current Sustainable Development Goals

The present goals of SGDs purely focus on the management and mitigation of far-reaching social and economic development issues on planet Earth. Though the MDGs specifically focused on poor or emerging nations, the outcome of the "experiment" subsequently required more global sustainable development goals which would involve both developing and developed nations as beneficiaries. The global approach—as demonstrated in the goals and targets of the SDGs—is not only apt but necessary if full cooperation of the international community would be brought to bear in the process, after all, the entire SDG-related venture is estimated to need investments of up to 7 trillion dollars per year globally with total SDG-related investment needs in developing countries ranging from $3.3 to $4.5 trillion annually until 2030![3] (Fig. 3).

2 The Space Factor

A description of human affinity for space and the dream of becoming extra-terrestrial species, the progress made including the challenges involved in achieving those goals in the future. This section also gives a brief introduction to possible space destinations for exploration and exploitation of resources as well as the need for future regulations in these areas.

2.1 The Appeal and Challenges of Space

From the beginning of time, there has always been the dream of humans settling on extra-terrestrial colonies be it on the Moon, Mars, or other celestial bodies. At the turn of the twentieth-century belief was rife about the likely presence of intelligent life on Mars with canals and flourishing cities,[4] there were even proposals for settling on planet Venus.[5]

However, the farthest humans have achieved of this dream was the landing of American astronauts on the Moon—a mere 384,000 km from Earth—between 1969 and 1972, and not spending up to a week at a time on the Moon. However, proponents of future space exploration are projecting that humans would colonize and settle on the Moon and Mars starting from the 2030s. This has huge implications on these celestial bodies, the settlers and the Earth itself (Fig. 4).

The space environment is harsh and requires some form of environmental control and life support system for human survival, usually most of the consumables are brought from Earth to space. Till date nothing—apart from sunlight—has been harvested from space and used for life support of the astronauts and equipment in space. Every other material utilized in space for sustainability of humans in space has been brought from Earth. If astronauts are to stay for prolonged periods in space, in situ-based resource generation and utilization would have to be employed.

[3]UNCTAD, *World Investment Report 2014: Investing in the SDGs: An Action Plan* (2014) http://unctad.org/en/docs/wir2010_presentation_en.pdf.

[4]Percival Lowell, *Mars as the Abode of Life* (Macmillan 1908).

[5]Geoffrey a Landis, 'Colonization of Venus' (*Conference on Human Space Exploration, Space Technology & Applications International Forum, Albuquerque, NM, Feb. 2–6 2003*, 2003) 1193 https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20030022668.pdf, accessed 22 January 2018.

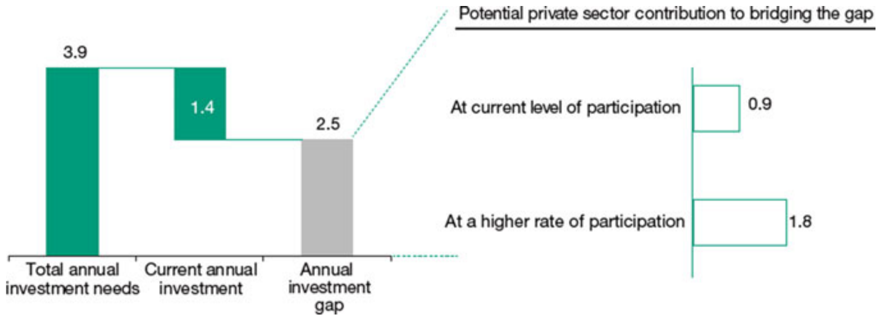

Fig. 3 Estimated annual investment needs and potential private sector contribution, 2015–2030 in trillions of dollars. (ibid)

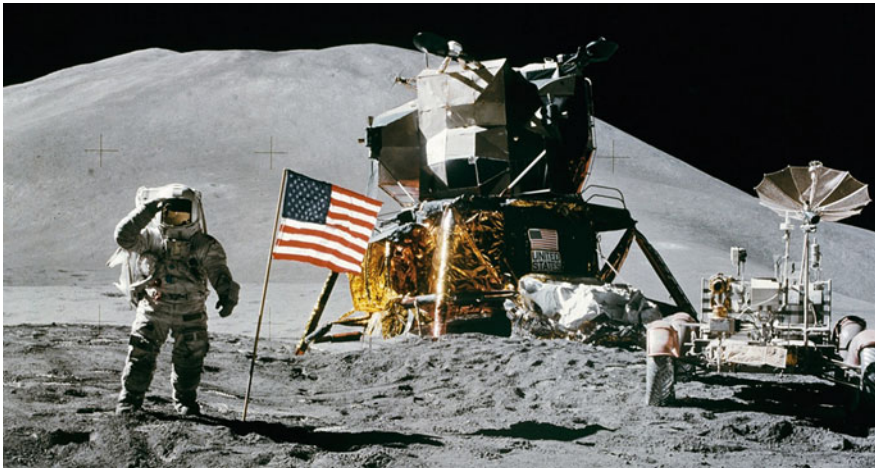

Fig. 4 Astronauts Jim Irwin of Apollo 15 on the Moon. Limited resources and consumables constrained the number of days the astronauts could spend on the lunar surface (NASA, 'Astronauts Jim Irwin of Apollo 15 on the Moon.' (2018) https://www.nasa.gov/centers/marshall/history/this-week-in-nasa-history-apollo-15-astronauts-deploy-first-lunar-roving-vehicle-July.html, accessed 10 January 2018.)

2.2 *Projected Space Arena of the Future*

Future presence in space would encompass missions to Moon, Mars and asteroids; these would require different mission architecture depending on mission objectives. Each of the target destinations has different requirement in terms of launch vehicle and spacecraft. Locations and duration of mission would determine the type of life support, habitats and support equipment such as pressurized vehicles, field equipment that are needed for mission-related extra-vehicular activities.

Though two companies have been identified to date, Planet and Deep Space Industries, more are expected to make inroads into the space mining domain in coming years. The extraction and processing methods to be adopted for these resources by the companies are not yet detailed but it is expected to start with sample return and subsequently full-scale missions and operations.

2.3 Regulations Issues of Future Space

Regulations of exploration and exploitation of resources from outer space have implications both for the prospectors and the Earth in general. The availability of useful resources in outer space such as the platinum group metals (PGMs) in asteroids has spurred several companies to invest in the future mining and processing of the resources. The implication is that several space vehicles with appropriate machineries would have to be launched with subsequent overarching effect on competition among the prospecting entities. Even though the Earth has witnessed certain level of disregard for proper mining procedure most especially in developing countries where most of the related regulations have not been enforced it is still possible to regulate the activities due to historical antecedents and societal norms and laws as they pertain to a group of people usually concentrated on certain geographical regions. These have matured over hundreds of years as they are being enforced. In space, however, the modus operandi of activities would require a different approach that would be coherent enough for missions and extra-terrestrial settlement participants comprising humans from different geographical and cultural backgrounds.

In future Earth and space scenario, a different approach may be adopted that would cater for Earth inhabitants and the environment while taking note of those on missions to space and their environment as well. In Article 11 7(a)–7(d) of the Outer Space Treaty in Agreement governing the Activities of States on the Moon and Other Celestial Bodies proposed (a) safe and efficient use of the Moons resources, (b) management of those resources in, (c) expansion of opportunities in those resources, (d) equitable sharing by all states parties in the benefits derived from those resources considering economic and social aspects of developing countries and the efforts of the states extracting the resources.[6] New developments in technology and entry of private entities in the space arena will require regulations that would accommodate the dynamism in the sector both on Earth and in future settlements in space.

[6]United Nations, 'Agreement Governing the Activities of States on the Moon and Other Celestial Bodies' (1979) https://treaties.un.org/doc/Treaties/1984/07/1984071101–51AM/Ch_XXIV_02p.pdf, accessed 12 January 2018.

3 The Future and Sustainability

Focus on the sustainability of future activities in space with regard to exploration and exploitation of resources as well as the likely impact on Earth and space environment. The section also discusses possible ways to confront and mitigate these challenges. It also suggests the possibility of drawing from lessons learnt from MDGs and SDGs and applying them in future public and private extra-terrestrial missions.

3.1 Post-2030 Space Exploration, Exploitation and Sustainability

Human presence beyond low Earth orbit since the beginning of human spaceflight as demonstrated by the Apollo missions has been that of exploration. Moon and Mars landings as well as mining of materials from the Moon and the asteroids have been proposed for the nearest future. While Mars landing has been the focus of future missions by various agencies, the Trump administration in 2017 directed the Americans towards the Moon—again[7] though with more opportunities for private entities participation. In the past, only few countries have brought back samples from space—The Apollo missions returned about 360 kg of lunar materials while only limited amount of lunar dust was recovered from the Soviet lunar sample return. Minute amount of materials were also returned from comet Wild 1 and asteroid Itokawa.[8] Mining and recovering materials from celestial bodies would require a larger scale of operations if they are to be profitable in the long run.

The Earth has limited resources that would be depleted at the current rate they are being exploited. However, celestial bodies such as the Moon and asteroids have been identified to have sufficient reserves of resources that can be mined if access to them is made possible in the nearest future. Mining of resources on asteroids could provide avenue for a future sustainable development, as they would provide several of the metals and other useful resources that are needed on Earth—and in space. Not only would this be economically viable if properly executed but also reduce the pressure on Earth's limited resources. This will assist to preserve Earth's environment and allow humankind to maintain and improve their standard of living.[9]

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[7]Calla Cofield, 'President Trump Directs NASA to Return to the Moon, Then Aim for Mars' (2017) https://www.space.com/39050-trump-directs-nasa-humans-to-moon.html, accessed 5 January 2018.

[8]Mike Wall, 'Pieces of Heaven: A Brief History of Sample-Return Missions' (2016) https://www.space.com/34002-sample-return-space-missions-history.html, accessed 24 December 2017.

[9]Tina Hlimi, 'The Next Frontier: An Overview of the Legal and Environmental Implications of Near-Earth Asteroid Mining', (*39 Annals of Air and Space Law 409*, 2014) https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2546924, accessed 15 December 2017.

Although space-based resource mining would be primarily carried out in space, there are implications for the mining destination and the Earth both economically and environmentally. The abundance of precious materials on these celestial bodies might create the influx of companies rushing for the materials without consideration for possible human and environmental consequences. On the extra-terrestrial bodies where the extractions are carried out, the safety of the astronaut–prospectors and that of the environment should be of high priority while care must be taken to ensure that the materials brought back to Earth are safe for human use and the environment as well. This also requires adequate planning before bringing any extra-terrestrial body to Earth orbit for further processing to avoid catastrophic impact in the event of crashing through the Earth atmosphere to the surface or portending any other form of harm to the Earth population.

3.2 Space and the Post-2030s Sustainable Development Goals

The past MDGs and current SDGs are specifically designed to eradicate extreme poverty and improve social and economic development of nations—on Earth. The goals and targets are mostly concerned with the situation on the Earth and its inhabitants.

In the nearest future with new set of Earthlings settling in extra-terrestrial locations, new course has to be set to create something similar to the SGDs that would not only cater for the Earth and people therein but that would include settlers in space and their destinations as well. The termination of the SDGs with its 17 goals and 169 related targets in 2030 would most likely necessitate evaluation period to see the achievement and possible areas that need to be focused on in subsequent development goal campaigns.

However, the 2030 era would be quite different from the period of the MDGs and SDGs due to the contemporary role of space around this period. All things being equal humans would have returned to the Moon and are possibly on Mars. Mining of asteroids as well as materials from the Moon would have commenced at a full scale (Fig. 5).

As mentioned earlier, the MDGs were designed to represent a global partnership to address growing poverty and basic needs for the world's poorest, particularly those living in Sub-Saharan Africa while the SDGs on the other hand is more inclusive as an international development efforts with 17 major goals to be achieved over the course of 15 years (2030) adopted by the United Nations on 25 September 2015.

The new role of space in the post-2030s would require new kind of sustainable development regime that would cater not only for the Earth-based sustainable development but also accommodate space-based sustainable development issues too.

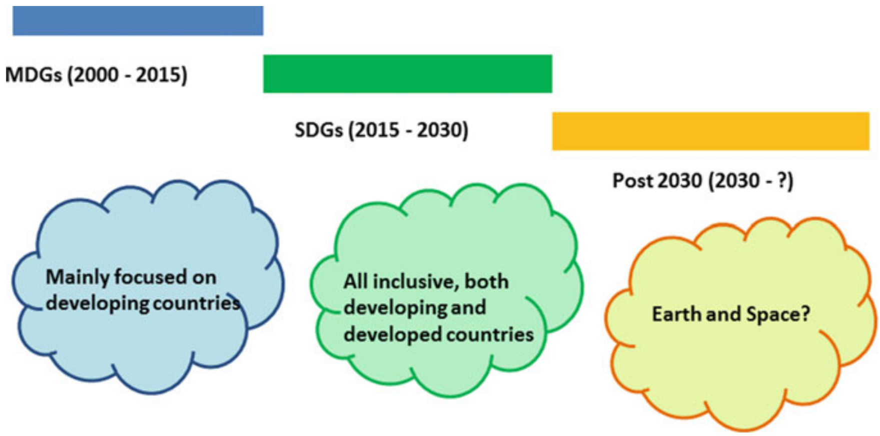

Fig. 5 Timelines and focus of past, present and future development goals

Scenarios of post-2030 are depicted in Table 1 highlighting likely prevailing Earth and space-based conditions, issues and possible interventions to ensure appropriate sustainable development regime.

3.3 Way Forward: Sustainable Development, Production, Consumption and the Future

SDGs are universal set of goals, targets and indicators that UN member states are expected to use to frame their agendas and political policies. The SDGs were designed as a hallmark for economic growth and help herald conditions to improve the well-being of the people by creating quality environment-friendly jobs that improves the economy of nations. Since SDGs adoption, it has served as a reference point for the international community from inception in 2015 up to its conclusion in 2030. The present Goal 12 of the Sustainable Development Goals focuses on “responsible consumption and production” which is designed to promote resource and energy efficiency, sustainable infrastructure, and providing access to basic services, decent jobs and a better quality of life for all. The objective is to help achieve overall development plans, reduce future economic, environmental and social costs, strengthen economic competitiveness and reduce poverty.[10] Aspects of the current SDGs could therefore be adapted for the post-2030 s scenarios.

[10]United Nations, ‘Goal 12: Ensure Sustainable Consumption and Production Patterns’ (2015) http://www.un.org/sustainabledevelopment/sustainable-consumption-production/#, accessed 14 January 2018.

Table 1 Post-2030s and sustainability interventions

Post-2030 Earth-space regime	Interventions
Lessons from SDGs (2015–2030) with focus on Earth—space sustainability	Extraction of appropriate lessons learned from SGD and inclusion of how to promote Earth- and space-based economy without bringing harm to Earth and space environment
Material quarantine and safety of astronauts/spaceflight participants, in their habitats and during EVAs throughout missions	Combination of suitable guidelines to ensure mission success and safety of astronauts/spaceflight participants and Earth inhabitants during and after each mission
Earth-space resource exploitation access and use	Adoption and implementation of appropriate regulations in line with exploration and exploitation of resources during the period and adaptation of heritage technologies from Earth that is compatible with the mission objectives

It is proposed and expected that humans would have moved further into the solar system in the 2030s, by then production as well as consumption of resources would have to be adequately managed to ensure sustainable development both on Earth and in space. Issues of safety of both Earth inhabitants and those in space also need to be addressed in order to achieve comparable sustainable development programmes. Earth and space-based infrastructure by then should have the elements of sustainability from the planning to execution period to ensure and promote the overall progress of the human race both on Earth and in space.

Although there have been some discussions about sustainability within space agencies, focus has been varied, Vedda[11] discusses sustainability for NASA from a perspective of programme sustenance while ESA[12] highlighted programmes designed to achieve SDGs for humanity. However, future space exploration would most definitely impact the Earth and various destinations. Materials mined from asteroid would have to be processed on site or within cis-Earth domain. This has huge implication with respect to sustainability within the environments in question and safety of people involved in the process.

While all the current SDGs are somehow interrelated a focus on extra-terrestrial settlement, exploration and exploitation and their related impact on sustainability should also be addressed.

[11]James A Vedda, 'Challenges to the Sustainability of Space Exploration' (2008) 6 Astropolitics 22.

[12]ESA, 'ESA and Sustainable Development Goals' (2017) http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/ESA_and_the_Sustainable_Development_Goals, accessed 10 January 2018.

Post-2030 sustainable development programmes should be designed for both the Earth and space in mind so that instead of just transforming our world, it would also contribute to sustainable development wherever humans find themselves in the vastness of space.

The Keys to Rule Them All: Sustainable Development of Orbital Resources

J. Claire Wilhelm

Abstract Space is getting crowded. Since the launch of Sputnik 1957, some 4600 space missions have launched from the Earth's surface, less than 40% of which are still operational. The ever-increasing amount of orbital debris poses a threat to valuable space assets. New space situational awareness capabilities due to come online in the near future will appear to increase the number of orbiting objects by an order of magnitude. The apparent increase has the potential to bring greater public attention to the orbital debris problem, which makes now the ideal time for action. The solution proposed in this paper is an 'International Clean Up Station.' It would require the active participation of major space powers in order to mollify anti-satellite weapon concerns.

Protecting the Earth's delicate natural balances in its water, air, and soil will be absolutely vital to humanity's survival on this planet. The importance of these balances serves as the foundation of the United Nations' 2030 Agenda for Sustainable Development. However, the preservation of a major global resource was overlooked: Earth's orbits. While distances between planets and solar systems are so great as to defy description, only a small part of the space around our planet is at all useful to us. That small part is rapidly being filled with operational satellites and useless 'space junk.'

Since the launch of Sputnik 1957, some 4600 space missions have launched from the Earth's surface. Less than half of the satellites contained on those missions are currently in orbit, around 3000, and even fewer still are operational—1738 according to the Union of Concerned Scientists.[1] Those 1738 pieces of space hardware represent billions, if not trillions of dollars' worth of investment from governments and private companies worldwide. The owners and operators of these

[1]Union of Concerned Scientists, 'UCS Satellite Database' (November 7, 2017) www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.Wh3_0kqnGM8.

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satellites understandably wish to protect their investments from collision risks posed by the thousands of other satellites which are no longer operational, some as large as a school bus.

Defunct satellites actually only make up a fraction of all orbital debris. The US Air Force currently tracks around 20,000 pieces of space debris larger than a softball and estimates the total number of debris items is somewhere around half a million.[2] The vast majority of this debris is of natural or unknown origin, but we will mostly consider artificial debris for the purposes of this paper. So, how does this space minefield affect orbital assets? Satellites are built to withstand the harsh environment of space, after all. However, they cannot be built to withstand hypervelocity collisions on orbit. Anything orbiting the Earth is traveling approximately 17,000 miles per hour relative to the surface. Even a percentage point or two of variance in speed between two colliding orbital objects add up to many times the forces imparted by a head-on collision with a semitruck at highway speeds. At those speeds, something as small as a marble could have devastating effects on a spacecraft. In fact, paint flecks caused severe damage to Space Shuttle windows on multiple occasions, requiring them to be replaced.

The astronauts on the International Space Station (ISS) have had more than one orbital debris collision scare. When this occurs, NASA and Roscosmos mission control work together to either move the station out of the debris' path (an orbital debris maneuver) or order the astronauts to take shelter in the Soyuz 'lifeboat.' In the event of a life-threatening hit, the astronauts would flee the station in their lifeboat and return to Earth.[3] Such collisions pose an unacceptable risk to life and to the mission of the ISS.

Somewhat surprisingly, (perhaps because we are still in the infancy of the space age), there have been few damaging accidental orbital debris collisions. In 2009, a dead Cosmos satellite owned by Russia collided with an operational Iridium communications satellite, destroying it. The Aerospace Corporation estimated that the collision created approximately 200,000 pieces debris, which spread through the parent orbits of the two satellites, with 18% still remaining a decade after the incident.[4] The Iridium–Cosmos collision turned the possibility of a collision in space from science fiction into just plain science.

Even before the accidental 2009 collision, China tested an anti-satellite (ASAT) weapon by destroying one of its own defunct satellites, in a relatively high orbit, creating many thousands of pieces of space debris, a large number of which will remain in orbit for many lifetimes. While the Chinese scientists determined the test

[2]Brian Weeden, 'Space Situational Awareness Fact Sheet' (*The Secure World Foundation*, May 2017) https://swfound.org/media/205874/swf_ssa_fact_sheet.pdf.

[3]Mark Garcia, 'Space Debris and Human Spacecraft' (*National Aeronautics and Space Administration*, September 26, 2013) https://www.nasa.gov/mission_pages/station/news/orbital_debris.html.

[4]Ted Muelhaupt, 'The Collision of Iridium 33 and Cosmos 2251' (*Aerospace Corporation Crosslink Magazine*, December 10, 2015) http://www.aerospace.org/crosslinkmag/fall-2015/the-collision-of-iridium-33-and-cosmos-2251/.

a success, the debris it created was cause for international outrage in the space community.

Large-scale collisions such as Iridium–Cosmos or the Chinese ASAT test could potentially accelerate the destruction of other objects and the creation of more and more debris. The Kessler Syndrome, named for one of the first NASA orbital debris scientists, is defined as 'self-sustaining cascading collision of space debris,'[5] even with no additional space launches at all. Kessler theorized that once the amount of space debris in a certain orbit reached a 'critical mass,' debris pieces would continue to collide with one another or operational satellites, creating cascading pieces of debris, until the orbit was so clogged it would be effectively useless for human space activities. Some experts believe we have already reached that crucial tipping point. In fact, Donald Kessler himself co-authored a report for the Institute of Electrical and Electronics Engineers (IEEE) in 2012 entitled: 'We've Already Passed the Tipping Point for Orbital Debris.'[6]

Kessler's IEEE article holds faint echoes of Al Gore's attempts to bring the dangers of global warming to the fore in the late twentieth century, and had about as much impact, as in almost none at all. There have been some efforts by governments to limit the creation of more debris in orbit (addressed later in this paper) but no efforts to actually remove any of it. If Kessler was correct in 2012 and we have passed the fatal tipping point, LEO and GEO are now unable to repair themselves through orbital decay. And each launch, no matter how careful we are, creates more and more debris. Now is the time for action.

Now that we have sufficiently wrung our hands over the space debris issue, and it is time to explore how it is tracked and mitigated. The first step to solving any problem is fully understanding it. In the case of space debris, this begins with space situational awareness (SSA). SSA as defined by the Secure World Foundation 'is the ability to accurately characterize the space environment and activities in space.'[7] Considering the size of space and sheer number of pieces of debris, this is a monumental task.

Space is, by definition, universal. Whether or not a nation is spacefaring, it shares 'ownership' of orbital space with all other nations in the world. Space is a global environment like air or water, which must be protected by the nations of Earth. Therefore, SSA must be achieved through international partnerships and collaboration.

There are currently three main components utilized to paint a reasonably accurate picture of the space environment: ground-based radars, optical telescopes, and space-based systems (to a somewhat lesser extent).

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[5]Michelle La Vone 'Kessler Syndrome' *Space Safety Magazine* (2014) http://www.spacesafetymagazine.com/space-debris/kessler-syndrome/.

[6]Darren McKnight and Donald Kessler, 'We've Already Passed the Tipping Point for Orbital Debris' (*IEEE Spectrum*, September 26, 2012) https://spectrum.ieee.org/aerospace/satellites/weve-already-passed-the-tipping-point-for-orbital-debris.

[7]Weeden (n 1).

Ground-based radars are familiar objects. They have been used for decades in both the civilian and military worlds to track aircraft and other airborne entities, and more recently to track objects in orbit. Radar is helpful for determining a relatively accurate location of an object in space, assuming it is large enough to detect (>10 cm). Optical telescopes could theoretically 'see' in more detail, but common sense shows it is quite difficult to pinpoint a blackened piece of debris against the blackness of space. Infrared telescopes are also used, but again, the universal cold of space makes any temperature differential between the background and an inactive satellite very difficult to trace. Space-based surveillance systems are more accurate, but are stuck in one orbit for their entire lifetime and could therefore be unavailable to assess emerging space debris threats on the opposite side of the globe.

Twenty-five radars and optical telescopes make up the Space Surveillance Network (SSN), run by US Strategic Command (STRATCOM), although some are owned and operated by international partners. Varied types of surveillance (e.g., optical and radar) work together to create a better picture of where an orbital object might be located at any given. As the distances involved are very large, it is really only possible to *estimate* the location of orbital objects, even with the supercomputers at Vandenberg Air Force base, the home of the Joint Space Operations Center (JSpOC). Figure 1 illustrates such an estimate. Each 'error ball' represents where an object *might* be in space at any given time.

When two of these 'error balls' come into contact with each other, there is a possibility that the two corresponding objects may collide in orbit in what is called a conjunction. If the probability is low, the JSpOC sends a conjunction data message to the satellite's operator, informing him or her that there may be a close pass with another satellite or a piece of debris. Generally, the endangered satellite does not correct course, as the accuracy of the data is so low it could well be moving into the path of the debris instead of away from it. If the probability of a collision is high, the JSpOC sends the operator a close approach notification (CAN). This message serves as a warning to the operator that a conjunction may occur and a suggestion that he or she should take corrective action if possible.

How is it possible that such seemingly sensitive information can be shared by the US military to a possibly foreign government or corporation? A large amount of SSA data are available for free to anyone via spacetrack.org. Of course, this Web site does not include any classified assets, but it is still useful. Additionally, USSTRATCOM has SSA data sharing agreements with many national partners, which allow the free flow of more accurate information. This is a relatively new development, having come about as a result of 2009 Congressional action following the Iridium–Cosmos collision. Before that, the USA operated a limited SSA network basically on its own.

As of a 2010 USSTRATCOM report, JSpOC had 16 SSA data sharing agreements. Since then, many other countries have signed similar agreements with the USA, including Belgium, Norway, Spain, and the United Arab Emirates. Dozens of private companies the world over have also signed onto data sharing agreements. This is certainly a positive trend considering the enormity of the task as outlined

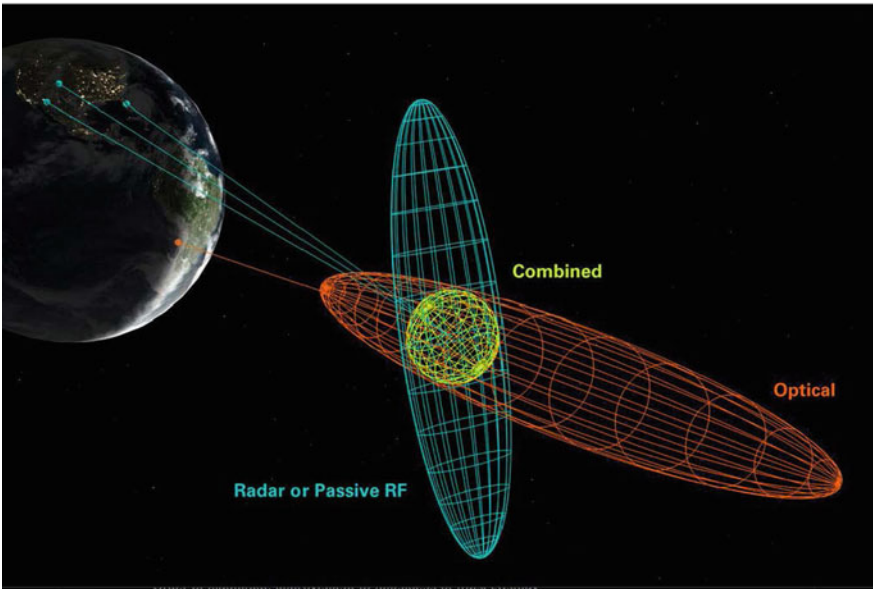

Fig. 1 SSA error balls (image credit STRATCOM)

above. Notably, the USA does not have an SSA data sharing agreement with Russia, who have independent SSA capabilities of their own.

There are criteria which, when met, trigger an emergency notification of an imminent potential collision, regardless of whether an agreement has been signed or not. After all, limiting the creation of more space debris and preventing collisions is in everyone's best interest. The criteria are as follows:

> For an active satellite above low-Earth orbit, we currently notify the o/o if we predict their satellite will approach within 5 kilometers (km) of another orbiting object in the next 72 h. For an active satellite in low-Earth orbit, we will notify the o/o if we predict it will approach within 1 km (overall miss distance) of another orbiting object AND within 200 m in the radial direction in the next 72 h.[8]

There are of course satellites which are not included in SSN's catalogue of orbital objects and debris—classified national security programs. However, for the same reasons that it is difficult to track cold, dark-colored degree against the blackness of space, it is difficult to hide anything which is emitting light or heat. So while the USA certainly does have 'classified' satellites in orbit, amateur organizations take delight in pointing them out, bright against the heavens. These satellites' exact purpose and functions are still secret, but they can be easily spotted in the night sky with a reasonably powerful telescope.

[8]Duane Bird, 'Sharing Space Situational Awareness Data' (Advanced Maui Optical and Space Surveillance Technologies Conference, Maui HI, September 2010).

It is reasonable to assume that the JSpOC reports CANs to satellite operators who are in the vicinity of a classified satellite. STRATCOM has been tightlipped on this issue. We can safely assume that they must warn the other party in a potential collision, but we do not know how much or what information is exchanged. If the JSpOC did not warn the other party, the operator of the national security satellite would be required to make any required avoidance maneuver, at great expense to the onboard fuel stores. Presumably other international SSA networks (i.e., Russia's Space Surveillance System) are aware of the existence and location of the so-called classified satellites as well. Considering that most parties involved in any potential conjunction between a non-USG and a classified satellite are already aware of the 'secret' location of the classified system, it would be quite silly for pertinent information not to be shared.

In early 2019, a new piece will be added to the SSN—the Space Fence. It is not a fence in the sense that it keeps anything in or out; it is more descriptive of the shape. Multi-phased S-band radar will create a fan-shaped 'fence' of radar, through which many if not all satellites will fly. The Space Fence will be based in the Marshall Islands in an attempt to increase the fidelity and amount of SSA data captured in the southern hemisphere. It is expected that after this system comes online, the number of tracked debris pieces will increase by nearly an order of magnitude, from 23,000 to 200,000.[9]

To a layperson, an order of magnitude increases in the number of pieces of tracked debris may look like a catastrophe. Something terrible has clearly happened in space and created all this flying junk! Of course, it will only appear this way to the untrained eye, when in fact the new system is just more accurate and can track object invisible to legacy systems. However, the apparent enormous increase in tracked debris makes for a flashy headline and may cause more attention to be drawn to the issue.

With the dawn of Space Fence on the horizon, now is the perfect time to prepare for political action. The inherently global nature of space debris and SSA means that an international body is necessary to coordinate and share information. Currently, the main international body in charge of this work is the Inter-Agency Space Debris Coordination (IADC).[10] It consists of 13 civilian space agencies, including NASA, ESA, and Roscosmos. According to the group's Web site, its main goals are to: 'exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options.'[11] Importantly, this description does not include any actual commitment to physically mitigate debris—only to think about it.

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[9]Roger Mola, 'How Things Work: Space Fence' *Smithsonian Air & Space Magazine* (Washington DC, February 2016) https://www.airspacemag.com/space/how-things-work-space-fence-180957776/.

[10]*Inter-Agency Space Debris Coordination Committee*. www.iadc-online.org/.

[11]ibid.

IADC is not the only international body concerned with space debris. The UN Committee for the Peaceful Uses of Outer Space (COPUOS) has noted the issue of space debris in its meetings and published reports relating to the subject. In the committee's own words, they have 'paid particular attention to the issue of preventing and minimizing the creation of space debris.'[12] Again, there is no mention of any removal efforts. Remember, according to space debris expert Kessler, even if there is not another single space launch from now until the end of time, the number of debris objects would still continue to grow due to propagating collisions.

From a pure engineering perspective, there are viable methods of conducting active debris removal (ADR). These solutions vary from the intriguing to the fantastical. One way to mitigate debris which has been proven (slightly accidentally), is damaging solar arrays with a ground-based laser. In 1997, American scientists took advantage of a legal loophole at the expiration of a Congressional ban to plan a test of the extraordinarily powerful Mid-Infrared Advanced Chemical Laser (MIRACL). Their goal was to evaluate the laser's ASAT capabilities by firing it at an American satellite reaching the end of its life. Then, MIRACL failed to fire its megawatt beam on command. Somewhat ironically, the comparatively feeble laser used for targeting managed to incapacitate the target satellite on its own.[13] It is not a short leap from there to imagine what the MIRACL would have done to its target had it succeeded in firing.

Even though the Pentagon considered it a failure, the MIRACL test provoked international fear and outrage. 'Brussels's independent Le Soir noted: "The Americans virtually have the power to blind or to destroy satellites in flight, and thereby to paralyze armies at war by depriving them of their eyes and of their ears. A frightening lead".'[14] American defense officials continually insisted the test was for defensive purposes only, but the international community was not buying what they were selling.

Various space-based methods of ADR have also been proposed. Two of the most viable, according to research conducted at the Aerospace Corporation, are a 'space tug' and drag enhancing devices.[15] A space tug would consist of an attachment mechanism built to latch onto large pieces of orbiting debris such as intact defunct satellites. The space tug would then use some type of propellant (picking an effective propellant for this mission would be very tricky) to drag the offending piece of debris to a 'junkyard orbit,' where it would eventually burn up in the atmosphere.

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[12]United Nations, Committee on the Peaceful Uses of Outer Space. 'Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space' (2010).

[13]Lecture from Pete Hays to author (September 2017).

[14]Federation of American Scientists, 'Early Report 10/22: U.S. LASER WEAPON TEST' (October 22, 1997) www.fas.org/spp/military/program/asat/971022-miracl-mr.htm.

[15]Marlon Sorge and Glenn Peterson, 'How to Clean Space: Disposal and Active Debris Removal' (*Aerospace Corporation Crosslink Magazine,* December 10, 2015) http://www.aerospace.org/crosslinkmag/fall-2015/how-to-clean-space-disposal-and-active-debris-removal/.

In September of 2017, Airbus Defense and Space announced that it would pursue development of such a vehicle, whose 'main missions [would be] maintenance, logistics and the cleaning up of Space debris' (as quoted in Henry 2017). Of course, it is important to remember that one man's ADR system is another man's ASAT. If Airbus' space tug is truly capable of towing around satellites in space, there would be no reason to believe it could not also be used to tow enemy satellites to their demise.

A drag enhancement device would be somewhat simpler to implement, as no active propulsion would be required to move the debris into a junkyard orbit. Instead, a drag enhancer would merely attach to a piece of debris and act as a sail, increasing atmospheric drag. Over time, physics would help the old satellite or empty upper stage into lower and lower orbits, and eventually into the atmosphere to be destroyed. Again, note that this device could also be attached to an unwilling satellite. The owner of that satellite would have no way to remove it and would be doomed to watch his or her satellite die a slow, fiery death.

Like any space mission, ADR would be very expensive and fraught with technical difficulties. The solution the aforementioned Aerospace Corporation report favors is post-mission disposal (PMD), as it would be much more cost-effective than ADR. The idea is to equip new satellites with built-in disposal mechanisms (perhaps a deployable drag enhancement device).[16] The IADC has published international PMD guidelines which give mission developers three options[17]:

1. Placement in a disposal orbit with a lifetime less than 25 years.
2. Placement in a storage orbit above GEO (at least 235 km above GEO, typically on the order of 300 km).
3. Placement in a storage orbit between LEO and GEO (lower boundary at 2000 km, upper boundary at 200 km below GEO).

It is understandable that satellite operators and the governments who fund them are not anxious to jump onboard with these guidelines. Changing the orbit of a satellite requires a huge change in inertia, which in turn costs fuel. This fuel has to be carried along on the initial launch. And bringing anything additional into space, especially heavy extra fuel, adds significant cost to a satellite program.

Nonetheless, NASA and the DoD have implemented policies aimed at reducing the amount of space debris created by their missions. This is certainly to be commended, but there are two key drawbacks to keep in mind. One, the American government's adherence to any sort of debris mitigation guideline is entirely voluntary. Neither the IADC nor the COPUOS, nor any other international body has the ability to implement policy changes. They have only the power to suggest. Two, minimizing debris resulting from new missions will not be enough to reverse the Kessler Syndrome. Active debris removal is the only viable path forward.

[16]ibid.

[17]IADC (n 8).

ADR is not without its own drawbacks. It is very expensive. It rankles satellite owners and operators the world over. It could very well be seen as a cover for an illegal space-based ASAT weapon program. If history is to be any sort of guide, Moscow would rankle at the mere suggestion of an American ADR system deployment. Nothing in space is ever easy, but that does not mean it cannot or should not be accomplished.

An international problem requires an international solution. This solution could come from the top down or from the bottom up. In a top-down approach, the echoes of climate change begin to reappear. The Kyoto Protocol and the Paris Agreement have become common household names since the emergence of global climate change into the national consciousness. Drafted in 1997, the Kyoto Protocol was at the time a ground-breaking international agreement on climate change. It was a legal commitment by participating countries to adhere to certain greenhouse gas emission reduction goals specified by the UN.[18] Enforcement mechanisms were weak, however. This resulted in the USA, among other countries, withdrawing from the agreement in 2001.

More recently, the USA has also promised to withdraw from the Paris Agreement, a new international climate change mitigation agreement. The Paris Agreement (or Paris Climate Accord) aims to keep the global temperature from rising more than 2 °C from pre-industrial level. It has attracted some criticism for having no legally binding power or enforcement mechanisms. And again, the USA began the process of removing itself from the agreement with no consequences.

One lesson which could be learned from the United States' flighty attitude toward international climate change agreements is that a diplomatic solution on its own is not enough to solve a problem on such a monumental scale. The only way it could work would be for the UN to institute a punishment for withdrawal or noncompliance, such as sanctions. This seems highly unlikely in the current political atmosphere. In order to really be effective, an international agreement framework should be coupled with an international bottom-up *technical solution*.

As stated previously, ADR technologies are a delicate topic in international space politics, since any such system could be used against a rival nation's space assets. The dual-use nature of all space hardware and ADR in particular means that any technical solution must be at the behest of the international space community at large and not of one single nation or agency. Imagine for a moment if Roscosmos developed an ADR system for the purpose of cleaning up LEO or GEO. The national security space community would understandably be quite nervous about this development. This dynamic applies mostly to the two space superpowers, but still affects other spacefaring nations. As demonstrated by the international reaction to the MIRACL test, the US ability to take down any satellite they choose does not sit well with anyone. Perhaps if the international space community were invited to participate in such projects, they might be more comfortable.

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[18] Kyoto Protocol, United Nations Framework Convention on Climate Change, 2014 www.unfccc.int/kyoto_protocol/items/2830.php.

To find an exemplary model of international cooperation in high technology space projects, one has to look no further than the International Space Station (ISS). Like proposed ADR systems, the ISS was shockingly expensive to build, launch, and maintain—around $150 billion.[19] A cost this high could not have been borne by one space agency alone; although the USA did provide around two-thirds of the funds. Beyond the enormous amounts of money involved, the ISS is truly a physical manifestation of scientific diplomacy.

This is not to say that developing the necessary agreements was easy. After a lengthy debate, the USA signed the first Intergovernmental Agreement (IGA) with Canada, Europe (represented by the European Space Agency), and Japan in 1988. The collapse of the Soviet Union in 1991 threw a wrench into NASA's plans to play top dog in the development of the station.

In an effort to mend fences with post-Soviet Russia, the US government requested that the ISS partner nations consider the addition of Russia to the effort. However, this meant that NASA had to learn to share the leadership role with Roscosmos, which in turn meant a major rework of the IGA governing the program. After a great deal of fraught discussion, Russia and the USA worked out an agreeable mechanism for sharing the leadership role, and the final IGA was signed in 1997. The first segment of the station, a Russian capsule called Zarya, was launched the next year.

During the infancy of the space station, the Cold War was still very fresh in everyone's minds. In particular, the USA and Russia were not keen to get too friendly with one another. Through careful negotiation, a sufficient 'firewall' was implemented to prevent militarily sensitive data from being inadvertently transferred between the two former Cold War rivals. Through its modular design, much of the engineering data generated by each national space agency could be kept relatively closed off from others. The only pieces which required more in-depth exchanges of information were the interfaces. The type of data associated with the interfaces and operation of the station is commonly referred to as 'form, fit, and function.' During the 1994–1997 renegotiation of the space station agreements, 'the provision on exchange of data and goods was revised to state that transfer of technical data for "interface, integration and safety" (form, fit and function) purposes will normally be made without restriction.'[20] Other than that, the details of the Russian and American ISS modules could remain essentially 'black boxes' to one another.

In the event any classified data must be transferred in pursuit of form, fit, or function, the 1998 IGA provides: 'A transfer need not be conducted if the receiving Partner State does not provide for the protection of the secrecy of patent applications containing information that is classified or otherwise held in secrecy for

[19]Brad Plumer, 'NASA wants to keep the International Space Station going until 2024. Is that a good idea?' *Wonkblog*, The Washington Post, January 9, 2014.

[20]Lynn Cline and Graham Gibbs 'Re-negotiation of the International Space Station Agreements—1993–1997' (1997) 51(11) Acta Astronautica https://www.sciencedirect.com/science/article/pii/S0094576502002102.

national security purposes.'[21] In other words, no nation is obligated to hand over classified or sensitive data unless it feels that it will be treated correctly and not disseminated.

Even after the ISS became operational, the USA and Russia have operated relatively peacefully side by side. They have accomplished this by keeping their data separated: 'The USA and Russia, through their Cooperating Agencies, shall provide the two primary data relay satellite system space and ground communications networks for command, control, and operations of Space Station elements and payloads, and other Space Station communication purposes.'[22]

The moral of the story: it *is* possible to work on space, an inherently dual-use technology area, with a political rival without compromising national security. So take heart; if something as technically and politically challenging as the ISS can be accomplished by so many partner nations, so can ADR. Lessons learned from the two rounds of IGA negotiations which created the legal foundation for the ISS should be leveraged on this new era of international cooperation in space.

What might this new International Clean Up Station (ICUS), as we will call it, look like? First, the main goal ought to be removal of large piece of artificial space debris. While objects as small as 1 cm in diameter could cause damage to a spacecraft, they are much harder to see, track, and capture. It is collisions between large objects which contribute most heavily to the acceleration of Kessler Syndrome. By removing the largest objects, ICUS can drastically reduce the creation of new debris over time. At this point, the technical means of ADR do not matter too much. But, as stated earlier, there are viable technical solutions which can be implemented, whether that is drag enhancement, a space tug, or something else entirely. We will leave that up to the engineers to decide.

The development and operation of ICUS should be conducted by an international consortium, led by the USA and Russia. These two nations have the most active space assets, and therefore the most to lose when it comes to space debris. NASA and Roscosmos have worked together successfully in the past and can do so in the future if both of their best interests are at stake. The consortium should also include emerging space powers such as China and any other interested parties.

In order to ensure that ICUS is not used to destroy operational satellites, the operations team should be made up of representatives from each of the world's main space agencies: NASA, Roscosmos, ESA, Japan Aerospace Exploration Agency (JAXA), and the Chinese National Space Administration (CNSA). Before a piece of space debris is targeting for cleanup, each member of the operations team must turn their metaphorical 'key,' much like on the UN Security Council. As more of the world's nations become spacefaring, they can be added to the operations team with the agreement of the other members.

[21]ibid.

[22]US State Department. Space Station. Treaties and Other International Acts Series 12927. January 29, 1998. https://www.state.gov/documents/organization/107683.pdf.

The main goal of this concept of operations is to keep political disagreements from leaking into space. Although relations between the USA and Russia are not at their best at the moment (see invasion of Crimea and alleged election interference), the two nations have managed to remain peaceful and cooperative partners aboard the ISS. The same would hopefully be true in the development and operation of ICUS.

A black box architecture such as the one used on the station would allow multiple parties to participate in ICUS operation without compromising sensitive information. Current ISS partners have already negotiated data sharing agreements in the 1998 IGA, which could be useful as a starting point for ICUS negotiations.

All spacefaring nations can agree that the form, fit, and function of a notional ICUS concept would be broadly beneficial. After all, if nothing is done to actively remediate space debris, orbits that many nations depend on will soon become unusable. It will no doubt be expensive and challenging, but must be done nonetheless. Here we see again the parallel with global climate change. If something is not done soon to combat the rising temperatures, the Earth itself will soon also become unusable. But that is a topic for another paper.

Unlike climate change, all nations agree that there is a problem and that it is certainly not naturally occurring. It seems it is a much easier line to draw between human actions and Kessler Syndrome than between human actions and climate change. Again unlike the fight against climate change, there are no corporations (otherwise known as big polluters) who stand to benefit from a lack of action on the issue. No one benefits from space debris.

We know exactly what must be done to preserve the space environment for future use. There are clear technical answers which can and should be implemented once the initial political and legal hurdles have been cleared. There is already broad international cooperation in the sharing of SSA data. This shows space debris has been recognized as a global issue and requires a global solution. International cooperation in complex space systems is no longer a nascent idea. It has been realized in the fullest by the International Space Station and other projects. We, the international community of spacefaring nations, can reach the height of international technical diplomacy and preserve the space environment for use by future generations. Not only can we—we must.

The Probable Contribution of the Post-2030 Space Industry to Global Economic Development

Anton de Waal Alberts

Abstract The economic crisis that arose during 2008 (often termed as the Great Recession) emphasised the systemic deficiencies of the global economy and its financial subsystem. It also once again highlighted the chaotic, and therefore unpredictable, nature of markets and the lack of foresight and strategic management of the markets (and thus the economic and financial system). It is trite that an equitable, efficient, environment-friendly and robust economic and financial system that can withstand rare events is of the utmost importance for the sustainable development of the human race and the ecology as a whole on planet earth. Therefore, future consciousness that will bring about this idealised state is an important endeavour (the idealised state or preferred future). The Sustainable Development Goals (SDGs) adopted on 25 September 2015 is an endeavour to implement a future consciousness and plan to build a better future. In the event that the SDGs are wholly or even partially achieved, the question is what is next? This enquiry specifically focuses on what the world economy may look like and what role the global space industry may play in the further development of the global economy. Given the technological drivers that have given rise to previous market developments and upswings, like the sail ships with which new physical spaces were colonised or the more recent information revolution that is still colonising digital space, this enquiry interrogates the probability of the modern global space industry serving as a techno-economic driver in the establishment of an advanced global economy with systems in space feeding into the planet's sustainable development and management.

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1 Introduction

Humankind has historically been able to harness technology for their use, but as far as is historically known, the acceleration, globalisation and democratisation of technology only truly started during the Industrial Revolution with its intellectual scaffolding embedded in the Renaissance. Since this event technology has become part and parcel of the socio-economic landscape on the Earth.

Economic activity has since been linked to the stage of technological advancement that allowed and facilitated enhanced travel and communication that in return dictated the level of exploitation, value-creation and distribution of products. Economic awareness and poverty resulted in the development of second-generation human rights focused on socio-economic matters and the establishment of economic development goals by the United Nations (UN), to oversee and coordinate a global effort to eradicate poverty, amongst others. This has led to the adoption of the UN Millennium Development Goals (MDGs)—eight goals in total adopted in 2000 by all 191 UN member states and 22 international organisations—whereby first of the goals was to globally eradicate extreme global poverty and hunger by 2015. This goal naturally implied economic growth and the democratisation of that growth into the space of the "have-nots" and the balancing of this goal against the achievement of the other seven goals, especially the seventh goal of ensuring environmental sustainability. Sub-goal 1A, namely halving the population living on less than $1, 25 a day, was incredibly achieved by 2015 with a 70% drop rate. Despite this success, many other goals are still problematic with global unevenness in achievement.

The MDGs were replaced by the Sustainable Development Goals (SDGs) consisting of 17 goals and 169 targets on socio-economic issues. These goals and targets must stimulate action up to 2030. The SDGs are ambitious, cross-cutting and global. The question remains whether the economic system can deliver the desired outcomes without compromising the planet's already fragile ecosystem. Further questions orbiting the SDG's are what is to be expected post-2030? If the targets are materially met, what would be humankind's next set of goals. Given the restricted ability to achieve the outcomes by 2030, what will humankind's goals be given its failures to meet its own standards?

Pre-2015 the Internet facilitated the communication explosion that created the current globalised electronic services industries and increased the efficiencies in older industries to aggressively enhance and accelerate the process of globalisation and the process of creating global economic prosperity. While the Internet-industry is going through new iterations of growth and innovation, the question to be addressed is whether another technology-driven industry, namely the space industry, can be the next economic accelerator given the grand scale of plans to develop next-generation rockets, space vehicles, satellites, applications and business plans for extra-celestial mining (asteroid) mining and exploitation of the celestial bodies like the Moon and Mars.

2 Predicting the Future

"The future predicted? An impossible task be it" Yoda from Star Wars-lore would say.

An impossible task (for now?) is predicting the future and therefore also the possibility to gauge the future growth of the space industry and its effect on the global economy. In effect, it means this query is invalid and cannot be continued.

However, over the course of the twentieth century a new field of study has developed, namely Futures Studies (FS). According to De Jouvenel, FS is not supposed to predict the future (1967: 15) as per the term "*clairvoyance*" (supernatural ability), but to develop foresight ("*prevoyance*") in possible, probable and lastly preferable futures on which decisions can be made to create an idealised state. This also entails the discovery of past and existing patterns from the domain of knowable facts, namely the past or *facta*, the possible or probable continuance of those patterns and any possible and probable discontinuities, bifurcations and establishment of new patterns in the future, and which possibilities may be translated as images of the future or *futuribles*. De Jouvenel explains further that the future, though it is inherently uncertain, is also a field of liberty as humans can conceive a future situation or object that does not yet exist. It is also a field of power as humans can actively create and therefore validate any given conception about the future. De Jouvenel concludes that forecasting is basically forming an opinion about the future, but a carefully formed one.

Depending on the type of future one intends to identify, specific tools have been developed to "open up" that future. These tools, importantly, are qualitative and quantitative in nature and still in development and are thus constantly being refined. Futures are mainly divided into possible, probable and preferable futures that can be illustrated as per the following Futures Fan devised by the Institute for Futures Research at the University of Stellenbosch (Fig. 1).

The Futures Fan illustrates that probable futures are limited and based on current patterns, but subject to foreseen and unforeseen bifurcations. Probable futures are the ones likely to develop. The current limit of probability forecasting is a 20-year horizon. Beyond this one enters the realm of possible futures that can or could exist, are numerous and can consist of contradicting images. At the far end sits the preferable future that is an idealised state and must be created by strategic planning, management and perseverance.

This enquiry extends to the world beyond 2030. However, the investigation will be limited to exploring the probable future of the space industry and its impact on the global economy against the background of the SDGs on a maximum 20-year horizon leading up to 2038 (from 2018).

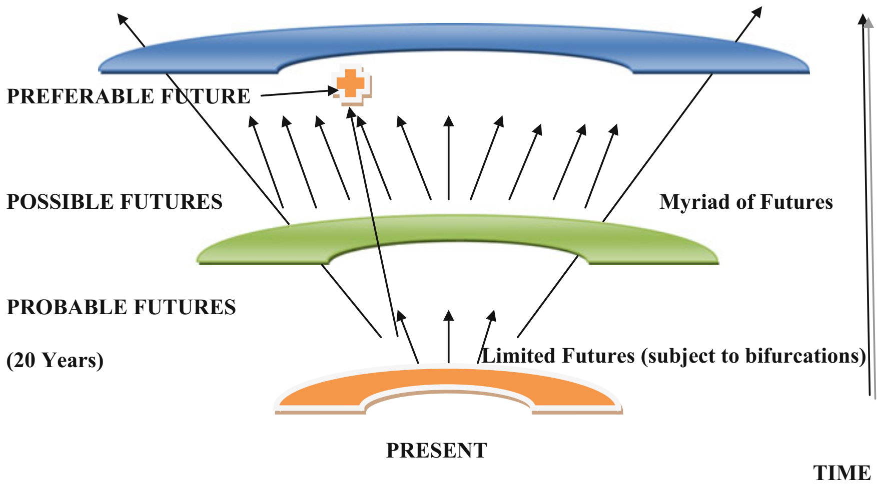

Fig. 1 The Futures Fan (Stellenbosch Business School. 2009. Global Issues—DVD. M.Phil Futures Studies. University of Stellenbosch)

3 The Nature of the Global Economic System

Chang and Baek argue that the advancement of human civilisation is predicated on the human ability to devise and use technology to change and improve their environment.[1] Perez explains, furthermore by virtue of what she titles a techno-economic paradigm, that one of the most profound historical drivers of the economic environment since the Industrial Revolution is technology and its accompanied process of innovation.[2] The latest age, namely the Information Age with its substantial and still unfolding impact on the planetary system, was brought about by information technology. Thus, the profound influence that technology has on the economic system and even the unfolding of human history allows for the reasonable inference that the future of the global economy will to a large degree predicated on technological drivers. The question is what technology driver[s] will prove to be relevant?

Planet Earth currently faces several substantial and interrelated challenges that can be divided into two major categories: global poverty and inequality (social, economic and political justice issues) on the one hand, and environmental decay (environmental justice issues) on the other hand. At the core of these two challenges vests the current global economic system with its subsystems (e.g. the financial system) and other related systems that act as drivers and/or inhibitors, e.g. the

[1]Chang, Y.S, & Baek, S.J. 2010. Limit to improvement: Myth or reality? *Technological Forecasting & Social Change*.

[2]Perez, C. 2002. Technological revolutions and techno-economic paradigms. Working Papers in Technology Governance and Economic Dynamics.

global socio-political and technological systems and their subsystems. It is indeed against this background that the UN created the MDGs followed by the later SDGs to facilitate economic development in a sustainable manner.

A lack of equitable economic development can lead to global instability due to uprisings and war. On the other hand, economic development that does not dovetail and interact harmoniously with the environmental system can lead to irreparable environmental damage. This is illustrated in Fig. 2, also devised by the Institute for Futures Research at the University of Stellenbosch.

Figure 2 illustrates the contradictory movements of a declining Life Sustaining Resources System (LSRS) against the pressures of a growing population and global economy that draws on the LSRS. At the point where demand is set to exceed capability, a canyon opens up that presents a small window where humanity can move through subject to adopting and implementing sustainable and equitable policies.

In his work, "Welcome to postnormal times", Ziauddin Sardar postulates that humankind has "entered postnormal times, the in-between period where old orthodoxies are dying, new ones have not yet emerged, and nothing really makes sense".[3] He states that this period is characterised by the three c's: complexity, chaos and contradictions as witnessed by the litany of events taking place, such as the Great Recession, terrorism, climate change, dwindling natural resources and biodiversity, amongst others. Sardar postulates further decision-making is thus difficult due to increased risks to individuals, society and the planet.

In planning and setting out goals like the MDGs and SDGs, one must take cognisance of the nature of the current global economic system. The economic system today is a complex adaptive system that exhibits periods of chaotic behaviour, whether on a meta-level or within the nested subsystems, like the global financial system. The global economic system, being planetary and international in nature, also consists of subsystems based on territoriality in accordance with the logic of the current nation-state political system, regional subsystems as well as territorial industry sets, with global connections facilitated by multinational companies that contribute and interact with each other horizontally [mostly based on the international law rule of the equality of nation states and the rules of institutions like the UN and the World Trade Organisation (WTO)]. Interaction, of course also takes place across levels, thus multiplying the complexity.

This means that forecasting the probable state of the global economic system is difficult, if not impossible. This also impacts on any forecasts regarding the fulfilment of the SDGs by 2030 or beyond. Many FS tools exist whereby the probable future of the global economic system can be forecast and many more are in development, but it still does not make the task simpler and many forecasts will turn out to be wrong, if not all of them.

This does not mean that one should not endeavour to create forecasts, as they allow one to plan strategically for eventualities. However, the purpose herein is to

[3]Sardar, Z. 2010. Welcome to postnormal times. *Futures*.

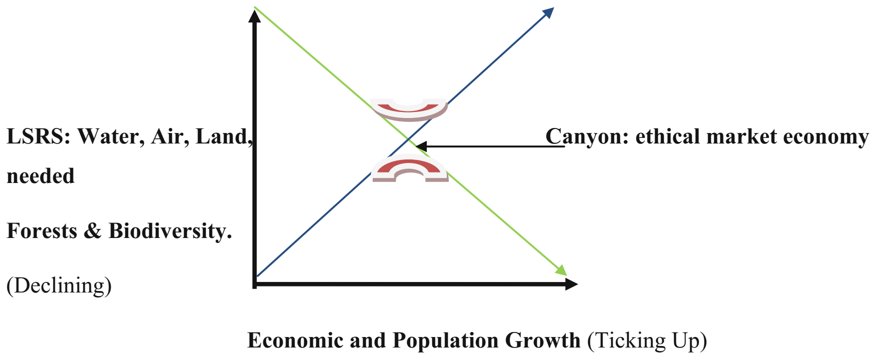

Fig. 2 Life Sustaining Resources Systems (LSRS) Projection (Spies, P. 2009. Module: Introduction to Futures Studies. *Futures Studies*. University of Stellenbosch)

forecast the probable future of the global space industry and economic system and its concomitant impact on the global economic system and the SDGs. It is not an easier task and can turn out to be completely wrong, but still one that might provide insight into the industry for strategic planning purposes.

4 The Nature of the Space Industry Economic System

Technology is regarded as a key driver of change within the current macro-environment, consisting of the social, technological, economic, environmental and political environments. "The evolution of civilisation appears to have primarily resulted from continuous improvement made possible by technological advances". This statement by Chang and Baek is broadly accepted as truth.[4] Papenhausen further argues that one of the main indicators of economic growth is the long wave of economic growth that occurs as a result of innovation based on the economist, Schumpeter's work.[5] Long waves describe long-term economic growth as a process and indicate crucial changes in the mode of production in capitalist economies. Therefore, the development of technology is inextricably linked to economic development, and by implication the unfolding of history itself.

As technology is a tool that can for the most part be controlled it also allows humankind to influence their environment with a rippling effect into the future. Therefore, technological forecasting (TF) is an important subset of FS whereby insight for planning and action towards a better future for humankind can be

[4]See note 3. Chang and Baek mention that various economists and social evolutionists regard, amongst others, energy, transport and information and communication as the most influential technologies.

[5]Papenhausen, C. 2008. Causal mechanisms of long waves. *Futures*.

established. The global space industry and economic system (Space Economy) is a technologically based system and, therefore, TF can be used as a tool to discern the probable development of the system.

As for the current nature of the global space industry and economic system, an apt definition can be discerned from the 2011 OECD Handbook: "The Space Economy is the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilising space. Hence, it includes all public and private actors involved in developing, providing and using space-related products and services, ranging from research and development, the manufacture and use of space infrastructure (ground stations, launch vehicles and satellites) to space-enabled applications (navigation equipment, satellite phones, meteorological services etc.) and the scientific knowledge generated by such activities. It follows that the Space Economy goes well beyond the space sector itself, since it also comprises the increasingly pervasive and continually changing impacts (both quantitative and qualitative) of space-derived products, services and knowledge on economy and society".[6]

The Space Economy currently exhibits, amongst others, the following important characteristics: (i) The space sector plays an increasingly important role in the efficient functioning of modern societies via satellite technology, etc., and its economic development and is a source of economic growth; (ii) Telecommunication still is the main commercial market; (iii) Since the late 1980s the number of states (especially smaller states like South Africa) and private players (e.g. Virgin Galactic, SpaceX, Blue Origin) in the commercial space market has increased markedly. Commercial actors as systems providers and investment sources are playing an increasingly important role.

Interestingly, a ten-year-old (2008) economic report produced by Oxford Analytica for NASA entitled "Understanding the Space Economy", the drivers of the Space Economy was identified as being "emerging technologies, and combinations of technologies, coupled with new ways of doing business. In particular, the fusion of space-based services with information technology and terrestrial networks is creating novel "systems of systems" that have the potential to combine the nineteenth-century impact of railway development with the world-altering effect of telecommunications and computing in the twentieth century". The report continues to state that the centre of twenty-first century economic power will be found at the heart of space activity.[7]

However, the Oxford Analytica Report provides for a logical prerequisite to the development of the Space Economy. The Space Economy was born out of military necessity (the Second World War and thereafter the Cold War) and was exclusively

[6]OECD. 2011. *Handbook to Measuring the Space Economy*. [Online] Available: http://www.oecd.org/futures/oecdhandbookonmeasuringthespaceeconomy.htm.

[7]Oxford Analytica. 2008. *Understanding the Space Economy*. [Online] Available: http://isulibrary.isunet.edu/opac/doc_num.php?explnum_id=290.

state-run until fairly recently. Private industry, at least in the West during the Cold War, did and still is providing goods and services to government-run projects. Accordingly, the Space Economy has evolved into a hybrid economy with public and private actors and interests, but still weighted towards state involvement. It, therefore, follows that the Space Economy will need further state involvement to develop it into a fully fledged commercial sector. In this respect the Oxford Analytica Report compares the global space industry with that of the commercial aviation industry that was first driven mostly due to military necessity before and during the Second World War (hardware was developed on the back of military research) up until the 1950s when the civil-military linkage became less direct with airliner design becoming driven by commercial interests instead. This resulted at that stage in a hybrid aviation industry as is the case with the current Space Economy.

The Oxford Analytica Report interestingly highlights that the turning point of the aviation industry into a fully fledged commercial one was caused by the introduction of a unique technological innovation, namely the jet engine. The resultant increase of conveyance speeds and cost efficiencies thereafter democratised and propelled the use of aviation into a mass activity. Accordingly, the global space industry must look for its own "jet engine" to jump into a completely new phase of commercialism.

It is thus clear that space transport technology is the key to the future development of the Space Economy and the growth of the Space Economy that may catapult the global economic system into a new phase of growth as was the case with ships, trains, cars and aeroplanes. Accordingly, a closer investigation of space transport technology, especially launch technology, and its probable future is warranted.

4.1 Technology Futures

A well-used TF tool of foresight is the S-Curve that will also be applied herein to ascertain the probable future state of space transport technology as prerequisite to the growth of the Space Economy and the condition upon which that growth will positively impact the global economic growth and the fulfilment of the SDGs whether by 2030 or thereafter.

4.1.1 S-Curve Application

The S-Curve indicates the performance progress of a particular technology over time by marking its stages of infancy, explosion and later gradual maturation, thus setting out the industry life cycle. This method is also useful in ascertaining when a technology will be replaced by another. Modus accepts the S-Curve as a good indicator of a cumulative rate of growth. He calls it "a remarkably simple and fundamental law”.[8] According to Modus the S-Curve “is derived from the law that which states that the rate of growth is proportional to both the amount of growth already accomplished and the amount of growth remaining to be accomplished”.

The S-Curve is illustrated in Fig. 3.

The phases indicated by the S-Curve are as follows:

- The introduction and incubation period, where the technology is seen as having potential, but there are still significant problems to overcome before the technology can become mainstream;
- The next phase is one of rapid improvement in the technology as incremental performance improvements and cost-efficiency take place. The technology normally finds application in higher volume markets during this phase;
- The last phase is one of the maturities as the technology proximates a natural or physical limitation that cannot be breached.

In applying the S-Curve, the effectiveness of transport/launch vehicles over time will be used to ascertain the probable time when newer effective technologies will become available to expedite the growth of the Space Economy (Fig. 4).

This S-Curve represents a connected multiple technology S-Curve where the suborbital launch technologies are seen to evolve into the orbital technologies used since 1957. In this case, the S-Curve to the left from 1900 until 1957 represents the precursor rocket technologies, like the V2-suborbital rockets of World War II. The following S-Curve represents the substitutive technology of the orbital launch systems to date.

As it took approximately 60 years for orbital technology to reach effectiveness (since 1900), it is arguably also the period it would take for more effective substitutive technology to become useful or effective which is set to take place around 2020. This substitutive technology may be the scramjet technology or others in development, but must in essence replace disposable rocket technology with more effective and reusable launch technology as noted in the Oxford Analytica Report *supra*. SpaceX has successfully developed reusable rocket technology on the back of legacy technology, but the question remains when new technology based on new science might arise that will change the landscape to one where space transport is affordable, widely accessible, and sustainable.

This S-Curve indicates that it is probable that 2020 will be the high-point of the effective use of the current rocket technology after which the new technological paradigm can be phased in. It is important to note that older technology in many instances remains in use after a successor technology has emerged, e.g. suborbital launch systems are still used for terrestrial military purposes. Accordingly, it is possible that orbital rockets remain in use as the new technology reaches for maturity as trains remain in use after the motor car revolution.

[8]Modis, T. 1992. *Predictions: Society’s telltale signature reveals the past and forecasts the future*. New York: Simon & Shuster.

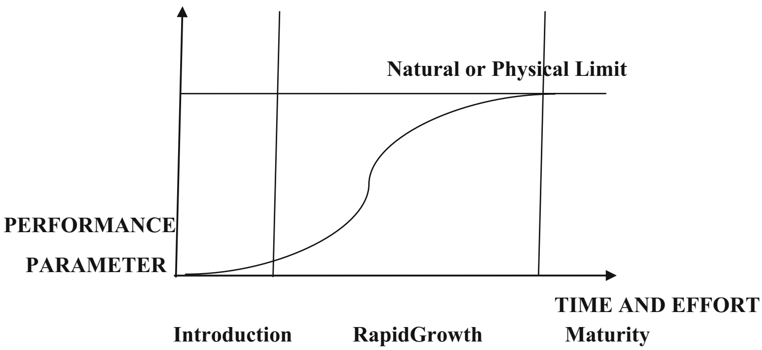

Fig. 3 S-Curve

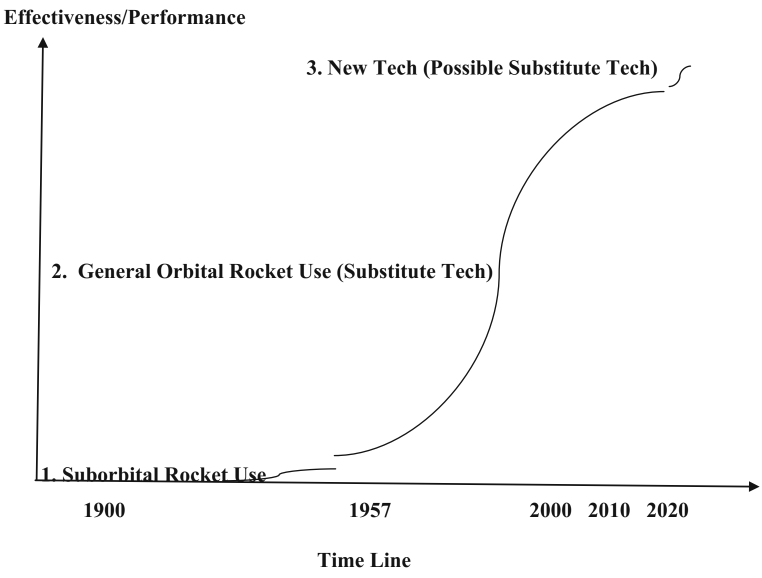

Fig. 4 S-Curve application

5 The Future of the Space Industry Economic System

Having regard to the above investigation, the following summary about the probable future of the Space Economy can be made:

- The Space Economy's future growth is dependent on the technology to transport objects and humans into space, thus allowing more space and economic activity;

- The current state of transport technology is one where legacy technology is made more effective like SpaceX's reusable rockets and stronger rocker engines used by the Falcon Heavy Rocket;
- An inflection point is likely around 2020 when a new scientific paradigm or paradigms will probably be introduced that will increase the effectiveness of space transport and allow for wider and increased cost-effective use;
- Should this come to pass the ten-year period from 2020 to 2030 will be an important incubation period for the new technology;
- The combination of the increased use of better legacy technology to build and implement business cases together with the experimental use of new technology from 2020 onwards will contribute more to the global economy and may make Earth-based business models more effective, e.g. the growth of the Internet of Things, thereby indirectly creating a multiplier economic effect;
- This will allow the Space Economy to contribute more to the global economic system that may enable the fulfilment of some of the SDGs by 2030;
- Given the probable higher growth of the Space Economy after 2030 as the new transport technologies advance and democratise space activity across the planet, the impact on the global economic system should be greater and result in the further meeting of the SDGs.

6 Conclusion

Predicting the future rationally is difficult, actually impossible. Having said this, the relatively new emerging field of Future Studies with its tools in development can provide one with probabilities, possibilities and preferable futures that allows for strategic planning for eventualities and ultimately the ability to build a future. These tools are not perfect, but are increasingly being refined.

The probable future of the global economic system and the fulfilment or not of the SDGs by 2030 can be achieved by implementing a variety of probability tools, but no certainty exists as to whether the outcome will be in accordance with the foresight achieved.

Technology Futures, as a subsidiary field to Futures Studies, also carry an arsenal of tools that can gauge the probable future. In using the well-respected foresight S-Curve tool—ideal in domains where technological advancement dictates the future, like the Space Economy—it is possible to make predictions on the nature of technology to be used in the near-future, the inflection point of a paradigm shift and the effect that this will have on the Space Economy, and ultimately on the global economic system and the SDGs. In this regard, the transport systems of the space industry are of the utmost importance as it forms the basis for space and economic activity in the Space Economy.

Without having any certainty that this will unfold, the S-Curve informs that the technological limit of the current transport technology, namely rockets, will be reached by 2020 after which the incubation period of the new technological paradigm and its technologies will start. The Space Economy will continue to grow between 2020 and 2030 adding more to the global economic system and assisting with the meeting of the SDGs. However, it is only after 2030 that the new technologies will feature strongly enough to democratise space activity to the point where it plays a larger role in the global economic system.

Space as Engine for Growth

A European and Italian Analysis

Rosa Maria Lucia Parrella

Abstract Space industry is worldwide a high-growth sector, that, despite the economic crisis, remained strategic for many countries. The European space industry is currently facing big challenges due to the new production of small and low-cost satellites, the recent exploitation of Big Data coming from space, and to the rise of private actors. This is a very exciting period, with the advent of new investors. In this framework, a more structured funding system, besides more pervasive international relations, could transform space industry, and more in general Space Economy, in a global driver for development. This paper analyses the recent available economic and employment data in Europe, with a focus on Italy, and shows, through several examples, the main beneficial impacts that space programmes can bring to the whole economic system, in terms of growth and high-quality job creation. The aim of the author is to demonstrate that space industry can be a useful tool to exploit in order to create economic growth and to achieve by 2030 the 8th SDG "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all".

1 Introduction—Space Industry in the Development Agenda

The discussion about the Post-2015 Agenda,[1] through the objective number 8, brought out the employment and decent work importance as well as the need to make them one of the central development objectives, along with inclusive growth and sustainable development. Jobs were considered not only as a tool to way out of poverty, but also as a good strategy to reduce inequalities. An inclusive growth

[1]United Nations Development Group (UNDG), *Growth and Employment in the Post-2015 Agenda*, 2013.

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generates good jobs and reduces inequalities, and it is economically, socially and environmentally sustainable.

A key aspect is "decent work" that, according to the International Labour Organization's definition, involves opportunities for productive work and delivers a fair income, security in the workplace as well as social protection for families and better prospects for personal development and social integration. Further, (recognized) benefits are the freedom for people to express their concerns, organize and participate in the decisions that affect their lives and equality of opportunity and treatment for everyone.

Inequality, indeed, and the lack of decent jobs in general, is particularly suffered in less developed countries, where especially women and young people are disadvantaged in the labour markets. They are more likely to be employed in informal or low-skilled jobs and, even when they work on par with men, their pay is 10–30% lower. Jobs, instead, give women and men a sense of self-esteem and respect by society.

The Post-2015 discussion is relevant to the space sector because participants, among the others, brought back to the agenda the theme of the industrial sectors development, which have the potential to stimulate growth, increase employment and sustain improvement in standards of living. Industries, realizing the economies of scale, are likely to achieve higher productivity and wages. Industrial sectors tend to have high capacity for employment generation, for both direct and indirect job creation. In particular, the discussants focused the attention on higher value-added production, upgrading to higher-skill production, building linkages between capital-intensive industries and the rest of the economy, and incentivising industries with more resource-efficient technologies.

Another connecting point with the space industry that can be pulled out from the consultations is the need to create a favourable environment for technology transfer[2] and knowledge exchange among countries in order to enable a freer and easier exchange of technology. The need to intensify the processes of technology transfer is particularly felt in the space sector, since even space agencies are attempting to increase the returns on their investments in space missions by encouraging the commercial use of advanced technologies. The aerospace industry,[3] indeed, is characterized by very high-value products, derived from an "archipelago-like" system of technologies, largely originating from other sectors, and that can be transferred again. Among all the technologies, the space's ones can be adopted in many fields: from health care, telecommunications, broadcasting, to weather monitoring, earth observation and natural resources management, as well as

[2]Technology Transfer, by definition, is the process of transferring technology from the places and in-groups of its origination to wider distribution among other people and places. In this context, t.t. is generally referred to transferring space technologies to non-space sectors (spin-off mechanism). It is worth to mention that, recently, the system is moving to an inverse innovative process (spin-in mechanism), which foresees transferring technologies created in other industrial sectors to space.

[3]G. Petroni et al., *Strategies and determinants for successful space technology transfer*, Elsevier, 2013.

manufacturing. Furthermore, technology transfer is important to the creation of new markets and jobs because it is able, through the innovation process, to create a demand for new technology and, consequentially, new investment opportunities and request for new job profiles.

The last remarkable recommendation coming out from the consultations is the special support to micro- and small enterprises, through a better access to finance, networking opportunities, business development services, streamlining regulatory processes, encouragement for forming associations and cooperatives and linking these enterprises to large firms. This aspect is relevant to the space sector, very fragmented, made of very few big firms and a constellation of small enterprises.

I think that, even though these themes were central years ago, they will be more likely to be achieved by 2030 and beyond, and the space sector with its myriads of applications could be a crucial tool to exploit. Space industry is living a period of great excitement and changes, due to its shifting to small and low-cost satellites and the recent great opportunities offered by the exploitation and analysis of Big Data coming from space. These phenomena, besides the rise of private actors, who are bringing new and more aggressive innovative business models, represent a great challenge for the industry (especially European), and also a new area of opportunities for entrepreneurs.

2 Space Sector

The global space sector[4] is a high-technology niche with a complex ecosystem. In 2013, it employed about 900,000 people around the world, considering both public authorities (space agencies, space departments in civil and defence-related organizations) and private actors, like the space manufacturing industry and the space services suppliers. In the same year, the space economy represented $256.2 billion in revenues, divided between the space manufacturing supply chain (33%), satellite operations (8.4%) and consumer services (58%), including actors who rely on some satellite capacity for part of their revenues, even if their core business was different from space activities.

Despite the economic crisis, institutional and private funding remained globally stable; the space sector remained strategic for many countries, and, furthermore, it has attracted even more attention by investors, seeking new market opportunities.

Recent available data (2017) affirm that the space industry workforce, instead, counts about 700,000 people worldwide. The figure below shows the workforce distribution among the groups of main actors; it highlights that ex-URSS and USA still are the two greatest world powers, sharing more than the 60% of the industrial workforce. These two colossi are followed by the rising China, which is recently

[4]OECD, *The Space economy at a glance 2014.*

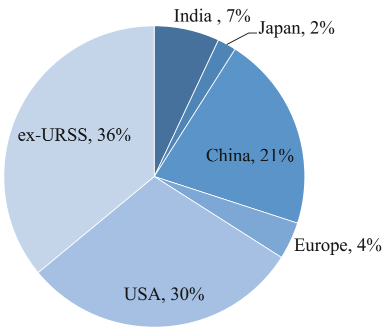

Fig. 1 Space industry workforce worldwide distribution. *Source* Elaborated on Eurospace data (2017)

earning more and more market portions, India and then Europe, which employs the 4% of the total (Fig. 1).

2.1 The European Space Industry

The European space industry is distributed across all Europe, and it is highly fragmented, particularly in the smallest contributors to ESA. On the other hand, the six major ESA member states (France, Germany, Italy, UK, Spain and Belgium) provide 90% of European space industry employment.

The industry, then, is composed of few large aerospace and defence groups (such as EADS, Thales, Finmeccanica, Airbus and Safran). With a view to securing the supply of critical equipment, large groups also tend to extend their control in the space supply chain with the absorption of suppliers and competitors. Thus, the space sector counts a large number of small units, but a limited number of independent small and medium enterprises (SMEs), that count the 5–13% of total employment.[5]

In Europe, the total direct employment of the space manufacturers has reached a historic level slightly above 38,000 in 2014,[6] and confirming that despite the economic downturn, the European space manufacturing segment has been able to maintain the creation of highly qualified jobs.[7] Recent estimates,[8] then, affirm that in 2016, the direct industry employment reached 40,419 workers; women represented about 21% of space industry employees.

The graph below shows the global employment trend in the European space manufacturing industry. It is clearly positive and particularly significant after 2013,

[5]ASD-Eurospace, *Facts & figures 2014*.

[6]OECD, *The Space Economy at a Glance 2014*.

[7]It is worth to underline that these estimates do not capture the downstream space industry (e.g. services, applications).

[8]ASD-Eurospace, *Facts & figures 2017*.

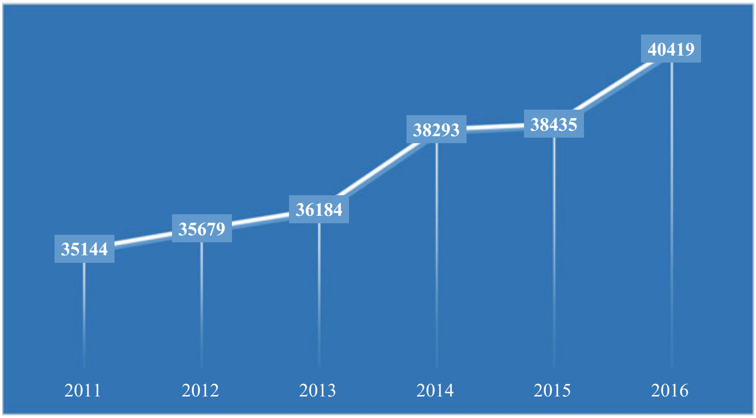

Fig. 2 Employment trend in the European space manufacturing industry (2011–2016). *Source* Elaborated on Eurospace data (2017). (Eurospace collects data through the annual update of its Facts & figures statistical series. The data collection is supported by companies with space activities operating in Europe (not limited to Eurospace membership). Companies answer a questionnaire providing detailed information on their sales and employment relevant to space systems design, development and manufacturing. The quality of the survey is as good as the data provided by participating companies)

thanks to an increase of more than 2000 units, and between 2015 and 2016, when other 2000 units were added (Fig. 2).

Figure 3, instead, decomposes the employment trend among the six major ESA contributors. France has clearly had the highest number of employees over time, followed by Germany and Italy but almost doubling the second. Furthermore, it is interesting to notice that the other countries, considered all together, have the same level of employment performed by UK alone; this highlights how residual they are in comparison.

The European space industry is quite specific in terms of age and qualification structures. The industry maintains a rather stable age structure. The employment distribution by age shows a larger portion of employees in the 49–58 age group, with an average age of employees around 44. About a fifth of space industry, employees are women.

Due to the engineering complexity of space programmes, the space sector attracts a large share of highly skilled workers. The majority of space industry workers have a scientific and/or engineering background and hold high-level degrees (Ph.D. or masters). According to the Eurospace's estimation, indeed, the 60% of the space industry employees has a university degree, and the 41% has studied for more than 3 years, that in the majority of European countries involves

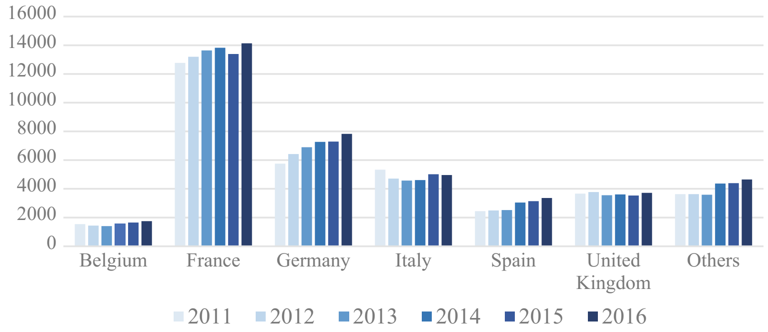

Fig. 3 Employment trend in the European space manufacturing industry by country (2011–2016). *Source* Elaborated on Eurospace data (2017)

Table 1 Space industry employees' qualification and gender characteristics

Qualification profile	All (%)	Men (%)	Women (%)
University (4–5 years and up)	41	44	29
University (up to 3 years)	19	19	20
Apprenticeship	10	9	11
High school/vocational	31	27	40

Source Elaborated on Eurospace data (2017)

Ph.D. and/or post-graduate masters. The qualification structure of females, then, is quite similar to that of males, whereas women in the space sector are not limited to clerical and low-level positions.[9] As shown in the table below, 49% of women employed is graduated (Table 1).

According to Eurospace, within the sector of space systems manufacturing and development, the portion of SMEs is comprised between 6 and 21% of total employment.

2.2 *The European Earth Observation Services Industry*

Earth Observation Services industry is a sector very fragmented (in small players). According to the EARSC data, gathered in its 2017 Industry Survey,[10] 66% of companies are micro-sized, 30% are small, 3% medium, and only the residual 1% is made of large companies.

[9]ASD-Eurospace, *Facts & figures 2017*.

[10]EARSC, *A survey into the State & Health of the European EO Services Industry*, 2017.

Companies are distributed throughout Europe with 13 countries having 20 or more enterprises in the sector. The number of companies has grown from less than 200–510 during the last 10 years (2006–2016); this growth mostly concerns small- and micro-sized enterprises. The ownership is a peculiar characteristic; 80% of the companies are private owned, this means that the sector is dominated by start-ups with the founder owing the company.

The survey shows a total sector employment of 7877 persons in 2017 for Europe and Canada (Canada is an ESA member), with a 16% increase from 2014. Employees are mainly distributed in SMEs,[11] just the 15% is employed in large companies (Fig. 4).

Employees in EO services companies are highly qualified, with 90% of them holding a university degree level and over 60% having a post-graduate degree or higher. The 33% of workers is female.

3 Examples of Benefit for Employment and Economic Growth

In this section, three examples of the benefits for growth and employment coming from space are proposed, in order to demonstrate that space can be considered as an engine for economic growth and development, with beneficial effects on employment. These examples have to be considered within the limits of the European framework; they consist in a national employment survey conducted by the Italian Space Agency and two studies committed by ESA about the members' participation respectively to the International Space Station and to the launchers programmes.

Analysing the European space system is particularly interesting because Europe, through the European Commission, has recently recognized space as strategic sector for the growth and investment agenda, in which it should maintain its global leadership. In 2016,[12] indeed, the Commission decided to present a Space Strategy for Europe, with the purpose to set out the overall strategic vision for the Union's activities in space while ensuring proper coordination and complementarity with the activities pursued by the member states and ESA.

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[11]Accorded to ESA definitions:

1. Micro-enterprise: fewer than 10 employees and an annual turnover (the amount of money taken in a particular period) or balance sheet (a statement of a company's assets and liabilities) below €2 million.
2. Small enterprise: fewer than 50 employees and an annual turnover or balance sheet below €10 million.
3. Medium-sized enterprise: fewer than 250 employees and annual turnover below €50 million or balance sheet below €43 million.

[12]Previously, the Treaty of Lisbon (signed on December 2007) created a juridical base (Treaty of the Functioning of the European Union, art. 189), which allowed European Union countries to establish a common European Space Policy.

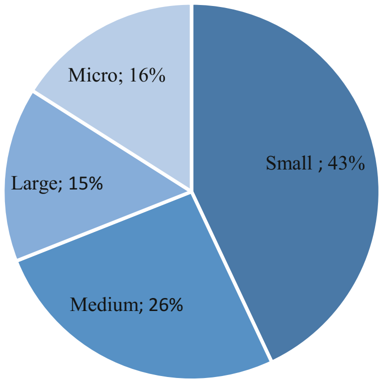

Fig. 4 Distribution of employees among company classes. *Source* Elaborated on EARSC data (2017)

It is worth mentioning that, as it will emerge from the examples, the main indicators currently used to assess the socio-economic impact of space activities are not homogeneous, have limits in terms of precision and representativeness, and do not allow a full valorisation of the added value of space activities. Anyway, during last years, numerous progresses in defining common methodologies and taxonomies have been awarded thanks to the cooperation among ESA, its member states and OECD, actors active in socio-economic assessments.

3.1 Employment in the Italian Space Sector

In 2016, Italy, having at disposal a civil institutional budget of about 642 M€, realized an industrial product value of 1.6 billion €. The Italian space industry covers the entire value chain; more specifically around 66% of the companies operate in the manufacturing sector, while around 34% operate in the downstream sector. The industry is made up of around 200 companies, represented for 80% by small and medium companies, with a high incidence of micro-companies.

During the first semester of 2017, the Strategies and Industrial Policy Unit of the Italian Space Agency[13] conducted a survey focused on measuring the employment impact of the Italian space industry in the previous three years. This reference period (2014–2016) is particularly interesting because it came immediately after a long and global economic crisis that seriously affected the Italian system.

The data collection was supported by companies with space activities operating in Italy and which answered a questionnaire providing detailed information on

[13]Authors: Silvia Ciccarelli, Rosa Maria Lucia Parrella, Osvaldo Piperno, Strategies and Industrial Policy Unit, Italian Space Agency. The survey analysis was not published, but utilised for internal use.

their employment levels. The questionnaire was sent to a sample of 30 private companies, representative of the Italian space industry universe, corresponding to the 95% of the total employment of the sector. The sample is composed of 30 enterprises, 40% large and 60% SMEs (12 large, 1 medium, 11 small and 6-micro).

Considering the year 2013 as baseline, at a first sight, the collected data underline a quasi-stationary trend. However, a more detailed analysis reveals that there was an inflexion in 2014 and a global increase of employment of almost 200 units until 2016, overcoming the historical data of 6000 employees (Table 2).

By decomposing, instead, the global trend, it is possible to differentiate between the large and the SMEs performance, and to notice that the observed growth is mainly caused by SMEs, that show an increase of units every year, whereas large companies have a less clear trend, growing until 2015 and then decreasing again in 2016.

Only the 10% of the companies declared not to have had new hirings during the considered three years. The other enterprises totally hired 675 units; the 65% of them was absorbed by large enterprises, and among the 25.9% of the newcomers were women.

In most cases (81%), permanent contracts[14] were stipulated, and they were largely used by big companies. In the 19% of cases, instead, different kinds of permanent contracts were agreed, and they were more suitable to be employed by SMEs, more likely to prefer flexible contracts (Table 3).

Another interesting aspect coming out from the questionnaire is that the 52% of new hired people belongs to the 26–35 age class that, combined with the data about education (66% of new entrants is graduated and the 10% holds a Ph.D. or a post-graduate master), points out that the space industry mainly hires young and highly educated people (Table 4).

Furthermore, another interesting result is that the most educated people are hired by SMEs, which, in the last years, are strongly boosting their specialization activity, utilizing very high level of technology.

Several aspects came out in this analysis which fit for the purpose of demonstrating that the space industry is an engine for growth: firstly, despite the crisis the space sector employment continued to grow leaded by SMEs, particularly active and high technologies oriented; secondly, Space industry attracts young and high educated people mainly employed with permanent contracts.

[14]This result is probably affected by a State recruitment incentive given to enterprises, addressed to young people, included in the Jobs Act (the Italian job's market reform—2014–2015).

Table 2 Employment trend in the Italian space sector

	2013-baseline	2014	2015	2016
Large	5718	5604	5718	5692
SMEs	460	476	543	578
TOT	6178	6080	6261	6270

Source Elaborated on ASI data (2017)

Table 3 Employment by contract classes

2014–2016	Permanent	Fixed–Term	Other
Large	387	51	2
SMEs	157	67	11
Total	544	118	13

Source Elaborated on ASI data (2017)

Table 4 Employment by age classes

2014–2106	18–25	26–35	36–50	51 and more
Large	11	233	164	32
SMEs	32	120	65	18
Total	43	353	229	50

Source Elaborated on ASI data (2017)

3.2 *Socio-economic Impact of the ESA Participation to the International Space Station Programme*

In 2016, ESA conducted an assessment study[15] about the socio-economic impact of the participation to the International Space Station (ISS) Programme, showing the benefits produced in terms of gross domestic product (GDP) and employment.

The GDP impact is expressed in terms of estimated value added (direct + indirect + induced) generated over the entire period (1995–2016), where the value added is the contribution of the ISS programme to member states' GDP.

Firstly, the impact for all member states is analysed, and secondly, the effect on the Italian system is showed.

For all member states, the value added is equal to €14.6 billion for a total ESA funding of €8 billion. This represents a GDP multiplier of 1.8, which is at the upper end of the range of equivalent multipliers for manufacturing industries in Europe.

The €8 billion invested in ISS over 1995–2016 are estimated to have boosted total employment[16] by around 209,250 person years, with additional employment in the space sector equivalent to 110,320 person years and additional employment in

[15]PWC, Cambridge Econometrics, Airbus Defense&Space, Thales Alenia Space, *Assessment of the socioeconomic impact of the ESA participation to the International Space Station (ISS) Programme*, 2016.

[16]The GDP employment impact is calculated as the increase in employment deriving from the increased economic activity (GVA) associated with the direct, indirect and induced economic impacts of the ISS programme. The Person years equivalent is cumulative across the whole period, it is not the annual average number of jobs over that period.

non-space sectors equivalent to 98,930 person years. As a result, the model performed an employment multiplier of 1.9 across ESA member states, with every 100 additional jobs created in the space sector supporting 90 additional jobs in the wider economy. The incremental government revenues[17] originating from the ISS programme amounted to €7 billion in total over 1995–2016.

Considering now Italy, its contribution to the ISS programme is of €1388.9 million. The national share as destination of the total ISS spending over 1995–2016 equals 17.4%, meaning that 17.4% of total spending was directed to suppliers in Italy. The total value added of the programme resulted to be equal to €2077.4 million, with a 1.5 GDP multiplier.

The employment impact was also positive. Jobs generated by Italy's spending in ISS within the Italian space sector were 22,474; the total employment generated, considering also non-space sectors, counts 33,374 units, with a 1.5 multiplier. Italy had almost twice as large a share of space jobs created than non-space jobs. This suggests that the wider supply chains effects are more concentrated in low labour intensity/high wage sectors, such as high-value manufacturing or professional services, rather than consumer services.

Finally, the national Government revenues derived from ESA spending on the ISS programme was equal to €1064.2 million, corresponding to the 14.8% of the total.

3.3 Socio-economic Impact of ESA Launcher Programmes

In 2014, ESA conducted a study[18] to assess the socio-economic impact of the two ESA launcher programmes Ariane 5 and Vega. The assessments revealed positive impacts and, above all, a significant direct spending from ESA payments flowing to non-core aerospace companies, outlining the transversal reach of space activities, and the high potential for wider economic impacts to non-space sectors.

The GDP impact of the Ariane 5 programmes is significant for all member states, with several countries exhibiting a total gross value added (GVA) exceeding 200% of their original ESA spending. The associated Type II GDP multipliers[19] for each ESA member state are in line with high-technology sector multipliers; most countries, indeed, fall into the 1.5–3 range, and the ESA participating member states total multiplier is of 2.2. Exploitation by Arianespace shows Type II GDP

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[17]Government revenues are not part of the total value added itself; they represent a distribution out of value added and can be interpreted as that part of the total spending that goes back to the government, i.e. that goes out the macroeconomic flow.

[18]PWC, Stratey&, *Socio-Economic Impact Assessment of Access to Space in Europe: an Ex-Post Analysis of the Ariane 5 and Vega Programme*, 2014.

[19] $$\text{GDP Type II Multiplier} = \frac{(\text{Direct Impact} + \text{Indirect Impact} + \text{Induced Impact})}{\textit{Arianespace Spending in the upstream}}.$$

Table 5 Launcher programmes' employment and GDP multipliers

Context	Employment multiplier	GDP multiplier
Ariane 5 programmes (development and exploitation) (ESA spending)	2.0	2.2
Ariane 5 exploitation (Arianespace spending)	2.4	1.6
Vega programmes (ESA spending)	1.2	1.4
Total launchers (Ariane 5 programmes + Vega programmes + Ariane 5 exploitation)	2.0	3.2

Source ESA data (2014)

multiplier of 1.6 for all ESA member states, and the development of Vega leads to a GDP multiplier of 1.4.

Ariane and Vega contributed to employment of nearly 400,000 people in Europe over the period. The employment impact is positive, and it can be summarized that each job supported by the launcher space programmes within Europe supported one additional job in the rest of the economy, or an employment multiplier[20] of 2 (Table 5).

Ariane 5 programme enabled €51.5 billion of revenues in the space and non-space industry. Revenues associated with Ariane 5 amount to €110.4 billion over 2000–2012.

Furthermore, to give an idea of the effects spread worldwide, Arianespace exported 60% of its services to non-European customers, leading to a positive impact on the trade balance, although modest in absolute terms, especially in a context where Europe was experiencing a constant lack of growth and unemployment. In addition, the gross value added (GVA) return multiplier, meaning the total GVA achieved in the European economy through Ariane 5 and Ariane 5 exploitation to the original ESA spending, was 3.2. This means that, each euro spent in the Ariane 5 launcher programmes by ESA produced a total of 3.2 euro of value added in the economy.

4 The Post-2020 SDG 8 Perspective

This report shows the distinctive aspects of the space industry and various examples of socio-economic benefits in terms of employment and economic growth. The European space industry, analysed more in detail, is a high-growth sector, increasingly export-orientated, with consistently outgrowing domestic output at

[20] $\text{Employment Type II Multiplier} = \frac{(\text{Direct Employment Impact} + \text{Indirect and Induced Employment Impacts})}{\text{Direct Employment Impact}}$.

both global and European level. The space value chain affects every European country. Space industry is highly research intensive, space employees are highly skilled and productive, scientific profiles are preferred, and consequentially, the uptake of science, technology, engineering and mathematics (STEM) education and careers is promoted.

The analysis conducted in this document tries to demonstrate that space sector, despite its modest size, is not to be left out in the development discussion. The case of Europe provides good food for thoughts, showing that it continued growing although the crisis, bringing benefits to the whole economy, and promoting the increase of high-quality jobs.

Although this analysis is limited to Europe and Italy, thinking that this argument could be extended to other countries in the world does not sound unrealistic.

The theme of sustainable development in and through space sector needs to be faced and spread out in a more structured way at international level in space conferences, workshops and meetings with the participation of the main space actors, especially the institutional and industrial representatives. The aim should be to create a space culture and awareness about the sector potentialities and related benefits. To achieve this objective, several space education measures should be implemented, like the promotion of dedicated scholarships for students and mobility grants for researchers to allow access to space technology knowledge to everyone. To do this, space agency should reach new agreements with universities worldwide, as well as bridging the gap with the industry, encouraging the creation of more joint job-oriented projects.

In order to make space central for growth, the main space actors should promote a more pervasive dialogue and cooperation at both international and national level. Indeed, a larger cooperation among Space agencies, UNOOSA and the main space actors could foster the negotiation of new political and industrial agreements, besides promoting the conduction of pre-competitive R&D work in order to reduce the cost of access to space. Instead, at national level, it could help to promote a greater direct involvement of space national industries with national space agencies and aid communities.

In this context ESA,[21] with its extensive expertise in space technologies, project management and international cooperation, is presumed to play a crucial role in promoting sustainable development and dealing with developing countries. ESA has a long record of being involved in various initiatives of this nature and has a powerful ‘Integrated Applications Programme’ also serving this kind of purposes. ESA’s expertise could be an asset to create industrial programmes for less developed countries, exploiting space technologies.

More in general, space agencies worldwide could cooperate and promote international programmes in order to expand the national scientific and technological knowledge in a sort of “open innovation” approach. By promoting technology transfer programmes, space innovative technology could be applied also to

[21]S.Ferretti et al., *Space for Sustainable Development*, Report 59, ESPI, June 2016.

other industrial sectors, supporting and stimulating the national industrial system. In this perspective, the space agencies' role would change; they would play a role not only as promoter and organiser of space programmes, but also as a technical-scientific leader able to require high challenging technical specifications to space companies and suppliers, incited to create innovation.

Cooperation among national agencies, then, could include also the search for new sources for funding. To become a key for development, space sector should establish a stronger and global funding system. An international fund for space activities, coordinated by UNOOSA and financed by member states contributions, could be the optimum. It could cooperate with NGO's and private sector donors. They should nominate a joint committee in charge of evaluating project proposals presented by companies looking for funding. This opportunity would be extremely useful especially for SMEs and start-ups worldwide, which often owe a high-quality projects creation capability, but lack large financing opportunities. An important rule for the fund's activity, to guarantee the attention to the less developed countries and the coherence to the aim of reducing the technology gap, could be the destination of a certain percentage of allocated funding to projects presented by developing countries. The fund would be useful, indeed, to both developed and poor countries; to the formers, it could help to create new business opportunities, and to the latter, it would offer new development tools. Furthermore, this fund institution would be better associated with training programmes offered to the supported companies, in order to make industries more competitive and allow them to grow, in terms of both economic system and employment.

A more structured funding system, besides a more pervasive international relations context, promoting space culture and cooperation in space activities, could transform space industry in a global driver for development.

Satellite Data as Evidences Before the Mechanisms of International Courts

Anne-Sophie Martin

Abstract This paper deals with the importance of the use of satellite data as evidence before international courts. The paper analyses applicable law and provides an overview of international case law so far. It shows that in the future and for the purposes of Post 2030-Agenda of the United Nations, it can be envisaged that these data will be more and more widespread. Satellite data will be significant not only for the traditional issues such as environmental protection or borders delimitation, but also in other domains, like human rights protection.

1 Introduction

The United Nations 2030 Agenda for Sustainable Development "argues" for stronger space governance and supporting structures at all levels, including improved space-based data and space infrastructure.[1] It calls for strengthening space cooperation and coordination mechanisms at the international, regional, interregional and national levels. The promotion of international cooperation in the peaceful uses of outer space is the core international effort to harness the benefits of outer space for global sustainable development.[2]

The aim of the 2030 Agenda is to reinforce the role of space science, technology and applications in areas of critical importance for humanity, namely people, planet, prosperity, peace and partnership, and the role of space-derived information in measuring and monitoring the goals and targets to the latter.[3] Regarding the notions of peace and sustainable development, the Agenda recognizes their cyclical rela-

[1] *UN Doc A/AC. 105/1115* "Coordination of space-related activities within the United Nations system: directions and anticipated results for the period 2016–2017—meeting the 2030 Agenda for Sustainable Development", *28 April 2016.*
[2] Ibidem.
[3] Ibidem.

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Studies in Space Policy 17, https://doi.org/10.1007/978-3-319-78954-5_8

tionships: there cannot be sustainable development without peace, and there can be no lasting peace without sustainable development. Therefore, it is necessary to foster peaceful, just and inclusive societies that are free from fear and violence; increasing and streamlining the use of data and information derived from space systems, in particular to provide an access to justice for all and to prevent and prosecute human rights violations.

The 17 Sustainable Development Goals (SDGs) are integrated, indivisible and balance the three dimensions of sustainable development: the economic, social and environmental. In this context, two of the SDG are particularly relevant in terms of peace, justice and human rights.

Indeed, the Goal 16 (Peace, Justice and Strong Institutions) addresses the promotion of peaceful and inclusive societies for sustainable development, providing access to justice for all and building effective, accountable and inclusive institutions at all levels. More specifically, it ensures public access to information and protects fundamental freedoms in accordance with national legislation and international agreements by strengthening relevant national institutions, through international cooperation, capacity building (particularly in developing countries), preventing violence and combating terrorism and crime.[4] Moreover, the goal deals with the promotion of the rule of law at the national and international levels and ensuring equal access to justice for all. Lastly, it guarantees the promotion and the enforcement of non-discriminatory laws and policies for the sustainable development.

The Goal 17 (Partnerships for the Goals) promotes the strengthening of the various means of implementation and revitalization of the global partnership for sustainable development. Notably, space applications, such as Earth observation (EO) and Positioning, Navigation and Timing (PNT), can bring a great level of transparency to any political, economic and social system. Indeed, more transparency helps to build just, equitable and more inclusive institutions. Data from Earth observation satellites can help in gathering evidence of international crimes, especially areas where access may otherwise be difficult, if not impossible.

Furthermore, sustainable development cannot be realized without peace and security, and peace and security will be at risk without sustainable development. It is necessary to build peaceful, just and inclusive societies that provide equal access to justice and that are based on respect for human rights, on effective rule of law and good governance at all levels and on transparent, effective and accountable institutions.[5] It is of utmost importance to redouble our efforts to resolve or prevent conflict and to support post-conflict countries.

The Post 2030-Agenda calls for strengthened space cooperation and coordination mechanisms at the international, regional, interregional and national levels.[6]

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[4]UN Resolution A/RES/70/1 "*Transforming our world: the 2030 Agenda for Sustainable Development*" adopted by the General Assembly on 25 September 2015.

[5]Ibidem.

[6]UN Doc A/AC. 105/1115 of 28 April 2016.

The use of space data can make more efficient trials and certainly reflect the new horizon of international justice. This is a new target which takes into account the needs and interests of the whole international community in that sense that international crime deeply shock the conscience of humanity and there is a need of accountability and justice.

This paper underlines the specific value of satellite evidence and how satellite data respond to the new challenges presented in the Agenda by gathering evidence of international crimes, especially in areas where access may otherwise be difficult (or impossible). It is important to evolve further satellite data before international courts to take into account the needs and interests of the vulnerable populations and to support effective humanitarian response. Indeed, the international courts confirm the valid means of proof of satellite data as evidence. Lastly, the paper examines some challenges remaining, namely the probative value of satellite data as evidence, their interpretation and their availability.

2 The Use of Satellite Data as Evidence

In international judgment, evidence embraces “information submitted to an international court or tribunal by parties to case or from other sources with the view of establishing or disproving alleged facts. The production, collection and evaluation of evidence serve a particular purpose: they are meant to enable the adjudicative body in question to decide a legal dispute or to deliver an advisory legal opinion. The collection and assessment of evidence are essential elements of the judicial function of international courts or tribunals”.[7]

Taking this definition into consideration, it can be admitted that the use of satellite data is a part of documentary evidence, and more particularly, it belongs to the category of digital or electronic evidence.[8] Hence, this kind of evidence can take two different forms, namely the data from earth observation, and from GNSS systems *(Global Navigation Satellite System).*

2.1 Data from Earth Observation

Satellite images are obtained by remote sensing which consists of the observation of the Earth by satellite from outer space (EOSS—*Earth Observation Satellite System*). Traditionally, the term is understood as the sensing of the Earth’s surface

[7]Rudiger Wolfrum, Mirka Moldner, *International Courts and Tribunal, Evidence*, Max Planck Encyclopedia of Public International Law, August 2013.

[8]Marco Roscini, *Digital Evidence as a Means of Proof before the International Court of Justice*, Journal of Conflicts and Security Law, Vol. 21, Issue 3, December 2016, pp. 541–554.

from space by making use of the properties of electromagnetic waves emitted, reflected, or diffracted by the sensed objects.[9] Nowadays, the images' quality and resolution are more precise, and higher as a result of the technological development.[10]

In order to acquire remote sensing information, a complex infrastructure is needed. Indeed, the images are transmitted to the ground stations where experts analyse and interpret the data because the latter are not immediately useful in practice. As it is explained in the *Principles Relating to Remote Sensing of the Earth from Outer Space*, information arrives on Earth as "primary data",[11] and then through the use of sophisticated processes, it becomes "processed data"[12] and finally, after interpretation, "analysed information".[13]

2.2 Data from GNSS Systems

The currently two main active GNSS systems are the United States' *Global Positioning System* (GPS), and the Russian Federation's *Global Orbiting Navigation Satellite System* (GLONASS). It must be mentioned also the European Galileo, and the Chinese Beidou (Compass). Concerning Galileo, it is the Europe's Global Satellite Navigation System carried out under the supervision of the European Union (EU) and the European Space Agency (ESA). With 22 Galileo satellites in orbit (4 IOV—*In-Orbit Validation* plus 18 in FOC—*Full Operational*

[9]Mahulena Hofmann, *Remote Sensing*, Max Planck Encyclopedia of Public International Law, March 2011. See also the *Principles Relating to Remote Sensing of the Earth from Outer Space* (adopted in 1986), Principle 1 (a) The term "remote sensing" means the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment.

[10]Sergio Marchisio, *Le Régime Juridique de la Télédétection*, in Philippe Achilleas, *Droit de l'Espace*, Larcier, 2009, pp. 143–163.

[11]*Principles Relating to Remote Sensing of the Earth from Outer Space* (adopted in 1986), Principle 1 (b), The term "primary data" means those raw data that are required by remote sensors borne by a space object and that are transmitted or delivered to the ground from space by telemetry in the form of electromagnetic signals, by photographic film, magnetic tape or any other means.

[12]*Principles Relating to Remote Sensing of the Earth from Outer Space* (adopted in 1986), Principle 1 (c), The term "processed data" means the products resulting from the processing of the primary data, needed to make such data usable.

[13]*Principles Relating to Remote Sensing of the Earth from Outer Space* (adopted in 1986), Principle 1 (d), The term "analysed information" means the information resulting from the interpretation of processed data, inputs of data and knowledge from other sources. The UN Remote Sensing Principles refers to three type of data: primary data, processed data, and analysed information. In practice, remote sensing operators utilize many other terms: for instance, "raw data" for primary data, or "derived products" for analysed information. See also: Fabio Tronchetti, *Legal aspects of satellite remote sensing*, in Frans Von Der Dunk and Fabio Tronchetti (eds.), *Handbook of Space Law*, Cheltenham: Edward Elgar Publishing, 2015, pp. 501–533.

Capability), the constellation is on track to reach completion in 2020.[14] On 15 December 2016, Galileo has started delivering its initial services to public authorities, businesses and citizens.[15]

These GNSS systems provide highly precise positioning and timing information of people or objects around the world.[16] Every GNSS is composed of three main segments, the space, the ground and the user segments. The satellite emits the signal, which contains the PNT, to the earth and the receiving stations.[17] Each user is equipped with a GNSS receiver.

3 The Application of the International Law Due to the International Character of Both EOSS and GNSS

International Space Law generally refers to the *corpus iuris spatialis* as the five United Nations Treaties[18] adopted between 1960 and 1970.[19] They establish general norms applicable to space activities and have a binding character for the ratifying States.

Along with the above-mentioned mandatory instruments, international space law is composed of the declarations of principles, relating to specific fields of space activities.[20] One of them, particularly relevant for data produced by EO satellites because it expressly refers to remote sensing, it is the 1986 *Principles Relating to*

[14]European Global Navigation Satellite Systems Agency: https://www.gsa.europa.eu/galileo/programme.

[15]European Commission—Press release "Galileo goes live!". http://europa.eu/rapid/press-release_IP-16-4366en.htm.

[16]Lesley Jane Smith, *Legal aspects of satellite navigation*, in Frans Von Der Dunk and Fabio Tronchetti (eds.), *Handbook of Space Law*, Cheltenham: Edward Elgar Publishing, 2015, pp. 554–617.

[17]Ibidem.

[18]Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, *27 January 1967, 610 UNTS 205 (entered into force 10 October 1967). The other four treaties:* Agreement on the rescue of astronauts, the return of astronauts and the return of objects launched into outer space, *22 April 1968, 672 UNTS 119 (entered into force 3 December 1968);* Convention in International Liability for Damage Caused by Space Objects, *29 March 1972, 961 UNTS 187 (entered into force 1 September 1972);* Convention on the Registration of Space Objects Launched into Outer Space, *14 January 1975, 1023 UNTS 15 (entered into force 15 September 1976);* Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, *18 December 1979, 1363 UNTS 3 (entered into force 11 July 1984).*

[19]F. Durante, *Lezioni di Diritto Aerospaziale*, La Sapienza Editrice, Roma, 1997, p. 13.

[20]Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, *adopted in 1963;* Principles Governing the Use by States of Artificial Earth Satellites for International Direct Broadcasting, *adopted in 1982;* Principles Relating to Remote Sensing of the Earth from Outer Space, *adopted in 1986;* Principles Relevant to the Use of Nuclear Power Sources in Outer Space, *adopted in 1992;* Declaration on International Cooperation in the

Remote Sensing of the Earth from Outer Space, adopted by the United Nations General Assembly (UNGA). It establishes essential principles concerning the applicability of international law and the UN Charter, the international cooperation with a due consideration for developing States and the international responsibility. Moreover, it refers to the accessibility of data by the sensed State as well as the freedom of using and disseminates data gathered by the sensing State.[21] It promotes the role of remote sensing for the protection of mankind from natural disaster. Nevertheless, it does not mention the possibility to use satellite imagery during lawsuits and does not provide any specific rule on this matter.

Concerning the use of GNSS, neither space law treaties nor resolutions of principles provide any specific rule.[22] Therefore, the absence of specific references to the use of these data during a legal proceeding has to be emphasized.

The lack of precision in international space law on the application of satellite imagery and geolocation information as evidence before the mechanisms of international courts is due to the fact that the space treaties and the UNGA resolutions have been adopted at the beginning of the space age. It was impossible to foresee the development of space technology and applications as we now know it. Criticisms on these instruments are presented by some scholars, especially regarding their inadequacy to deal with the current new challenges, and their revisions are often highlighted, in particular the Resolution on *Principles Relating to Remote Sensing of the Earth from Outer Space.*[23]

Moreover, the awareness of the protection of human rights could be another important objective within the context of the Post 2030-Agenda of the United Nations.

Considering all these aspects, the use of satellite data before the mechanisms of international courts does not seem precluded.[24] Indeed, the following analysis of international practice will show that satellite data are generally handled as other

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Exploration and Use of Outer Space for the Benefits and in the Interests of all States, Taking into Particular Accounts the Needs of Developing Countries, *adopted in 1996.*

[21] *Ram Jakhu,* International Law Regarding the Acquisition and Dissemination of Satellite Imagery, *Journal of Space Law, Vol. 29, N° 1&2, 2003, pp. 65–92.*

[22] Paul Larsen, *International Regulations of Global Navigation Satellite System*, Journal of Air Law and Commerce, 2015, 80, pp. 365–422.

[23] *Tanja Masson-Zwaan;* Some Reflections of the Future of Space Law, *in Stephan Hobe (ed.),* Air Law, Space Law, Cyber Law: the Institute of Air and Space Law at Age 90, *Koln, Carl Heymanns Verlag, 2016, pp. 57–63. See also: Sergio Marchisio,* Le Régime Juridique de la Télédétection, *in Philippe Achilleas,* Droit de I'espace, *Larcier, 2009, pp. 143–163. See also: Federico Tajani,* Il remote sensing tra interessi particolari e benefici globali nella prospettiva giuridica, *in* Spazio. Scenari di collaborazione - Note di Diritto Internazionale*, a cura di Antonello Folco Biagini, Mariano Bizzari, pp. 77–84.*

[24] Maria del Carmen Munoz Rodriguez, *La aplicacion de la teledeteccion como elemento de prueba ante los tribunales*, Instituto Iberoamericano de Derecho Aeronautico y del Espacio y de la Aviacion Comercial, III Seminario sobre actividades espaciales y derecho, Madrid, 2013, pp. 31–46.

documentary evidence. Their acceptance during legal proceedings depends only on certain regulations—who can present and which kind of evidence is permitted—that each court or tribunal has developed in their statutes or procedures.

4 A Glance at Some Contemporary Mechanisms of International Case Law

The use of satellite data during trials is increasingly commonplace. Some selected cases of the International Court of Justice, of the International Tribunal for the Law of the Sea and of the International Criminal Court, analyzed in this section, are clear examples of this trend.

4.1 The International Court of Justice and the Space Data

In 1986, in the case *Burkina Faso/Republic of Mali*,[25] the ICJ used images and data gathered from the sky in order to settle the dispute between these two countries, based in particular on the respect for the principle of the intangibility of frontiers inherited from the colonial period. The ICJ declared that those images, even if more accurate than in the past, do not represent a territorial title by themselves, unless the parties so decided. In addition, the ICJ stated that, in order to decide on the weight to be attributed to those images, many considerations have to be taken into account such as the technical reliability and the interpretation of the information obtained.[26]

In 1998, in *Cameroon v. Nigeria* (Preliminary Objections),[27] satellite images have played an important role during the proceedings, in order to support the decision of the ICJ and to monitor its implementation.[28]

Again, in *Botswana/Namibia* of 1999,[29] the Court had to decide on the status of the Kasili/Sedudu Island, and in this context, the use of satellite images as proofs was admitted.

[25] *Frontier Dispute*, Judgment, I.C.J. Reports 1986, p. 554.

[26] Valentina Nardone, Claudia Candelmo, *Satellite Evidence in Human Rights Cases: Merits and Shortcomings*, Peace Human Rights Governance, 2017, 1(1), pp. 87–113.

[27] *Land and Maritime Boundary between Cameroon and Nigeria*, Preliminary Objections, Judgment, I.C.J. Reports 1998, p. 275.

[28] Annette Froehlich, *The Impact of Satellite Data Used by High International Courts Like the ICJ and ITLOS*, Proceedings of the International Institute of Space Law, The Hague: Eleven International Publishing, 2012, pp. 471–483.

[29] *Kasiki/Sedudu Island* (Botswana v. Namibia), Judgment, I.C.J. Reports, 1999, p. 1045.

We can observed that satellite images have been used also in *Nicaragua v. Honduras*,[30] in *Malaysia/Singapore*,[31] as well as in *Argentina v. Uruguay* case,[32] or in the *Georgia/Russian Federation* case (Preliminary Objections),[33] in which Georgia presented satellite images to demonstrate the presence of Russian forces involved in violations of international law and human rights.[34]

In regards to Post 2030-Agenda, it is of utmost importance to take into consideration the use of satellite imagery as a tool to solve geographical questions such as boundary disputes or environmental issues and also to address the widespread and systematic character of such acts.

4.2 The International Tribunal for the Law of the Sea and the Satellite Images as Proofs in Its Decisions

The ITLOS, for instance, admitted satellite images in the *Bangladesh/Myanmar* case in 2012.[35] The dispute concerned the identification of the maritime boundary, with the objective to delimit the territorial sea, the exclusive economic zone, and the continental shelves of the States overlooking the Bay of Bengal. The controversy focused on the St. Martin's island, and Bangladesh adduced satellite evidence to evaluate the dimension of the disputed territory.[36]

4.3 The International Criminal Court and the Use of Space Data as Evidences

In some specific cases, also the ICC has admitted the use of space data, inter alia, *The Prosecutor v. Thomas Lubanga Dyilo, The Prosecutor v. Germain Katanga and Mathieu Ngudjolo Chui, The Prosecutor v. Bahar Idriss Abu Garda and The*

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[30] Territorial and Maritime Dispute between Nicaragua and Honduras in the Caribbean Sea (Nicaragua v. Honduras), *Judgment, I.C.J. Reports 2007, p. 659.*

[31] Sovereignty over Pedra Branca/Pulau Batu Puteh, Middle Rocks and South Ledge (Malaysia/Singapore), *Judgment, I.C.J. Reports 2008, p. 12.*

[32] Pulp Mills on the River Uruguay (Argentina v. Uruguay), *Judgment, I.C.J. Reports 2012, p. 14.*

[33] Application of the International Convention on the Elimination of All Forms of Racial Discrimination (Georgia v. Russian Federation), *Preliminary Objections, Judgment, I.C.J. Reports 2011, p. 70.*

[34] *Op.cit.*, note 9.

[35] Delimitation of the maritime boundary in the Bay of Bengal (Bengladesh/Myanmar), *Judgment, ITLOS Reports 2012, p. 4.*

[36] *Op.cit.*, note 29.

Prosecutor v. Abdallah Banda Abakaer Nourain and Saleh Mohammed Ferbo Famus.[37]

Following the ICC's jurisprudence, it is important to note that in 2013, an expert in digital evidence has been hired by the Office of the Prosecutor of the ICC for its Scientific Response Unit to improve its ability to collect and analyse the space data.[38] Hence, the analysis and interpretation are carried out in-house and not by external expert, enhancing the judicial institution's independence as well as its reliability.[39]

This is a point to take into consideration for the Post 2030-Agenda in terms of peace, justice and human rights; in that sense, international courts could contribute to the creation of international forensic standards including methodologies for use, and integration with other evidence.

5 Some Considerations and Remaining Challenges

Firstly, the use of satellite images data as evidence is becoming increasingly common. They possess some positive aspects such as their immediate availability and their accuracy due to use of high-resolution technology. But even if they are more accurate than aerial photographs, raw images need to be processed and elaborated. Moreover, for their interpretation, judges need the assistant of experts which means that they have to be educated on the interpretation of these data in order to avoid any error, in particular when they have to verify whether some human rights has been violated or not.[40] In this case, the work of the International Law Association Space Law Committee, on the use of satellite data in courts, is of particular relevance.[41]

Regarding the GNSS data, the receiver is immediately able to decode the signal received on his device, without any processing.

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[37]Eya David Macauley, *The Use of EO Technologies in Court by the Office of the Prosecutor of the International Criminal Court*, in Ray Purdy and Denise Leung (eds.), *Evidence from Earth Observation Satellites. Emerging Legal Issues*, Leiden: M. Nijhoff Publishers, 2013, pp. 217–240.

[38]Mr. Lars Bromley (USA), Expert in Remote Sensing and Satellite Imagery.

[39]*Op.cit*., note 38.

[40]Ana Cristina Nunez, *Admissibility of Remote Sensing Evidence Before International and Regional Tribunals*, Innovations in Human Rights Monitoring-Working Paper, August 2012, Amnesty International USA.

[41]The ILA Space Law Committee is still working on the topic of the use of satellite data in courts. For recent reflections, see ILA Space Law Committee Reports of the Washington Conference (2014) and the Johannesburg Conference (2016). It is important to mention the foundation in the United Kingdom in 2014 of the Air and Space Evidence, a highly-expert consultancy also known as the World's first "Space Detective Agency". The main purpose of its founders is to bridge the gap between law and technology, combining legal knowledge and technical expertise on earth observation. For more information, visit www.space-evidence.net.

In the future and in view of the Post 2030-Agenda, it can be envisaged that these data will be more and more widespread. As already noticed, satellite data will be important not only for the standard issues such as environmental protection or borders delimitation, but also having regard to the human rights protection.[42] The international community has to promote peace from above.

It remains to define the issue of the admissibility of satellite data which will be on case-by-case, and their probative value according to the principle of free assessment of evidence.[43] An harmonization of the legal framework taking into account the treatment of satellite data as evidence before international courts is necessary in respect of current and future challenges, such as the development of remote sensing devices operated not only by States, but also by private entities, and the related technological developments of the space sector.[44]

[42]Satellite data for monitoring war crimes and genocide: Harvard Humanitarian Initiative—Satellite Sentinel Project. See: https://hhi.harvard.edu/sites/default/files/publications/pipeline.pdf.

[43]Military and paramilitary activities in and against Nicaragua (Nicaragua v. United States of America), *Merits, Judgement, I.C.J. Reports 1986, p. 14.*

[44]*Op.Cit.*, note 27.

Evolution of Innovation Mechanisms to Support the Post-2030 Agenda Goals: Case Study on the European Space Exploration Programme

Clelia Iacomino

Abstract At European Union (EU) level, the importance of innovation is a key factor to European competitiveness in the global economy, undergoing deep transformation driven by innovative technologies and new business models. A key objective of the European Commission (EC) is to "foster a globally competitive and innovative European space sector" to maintain and further strengthen a world-class capacity to develop and exploit space systems, opening up new opportunities to develop innovative products and services which can benefit the industry in all Member States. The new business and innovation ecosystem are supported at the European, regional and national levels by creating space hubs with the objective to open space up to non-space entrants. Innovation derived from space exploration, fosters economic growth and delivers high returns on investment. The involvement of space exploration applications to sustain the *innovation and technological advancement goal* could be proposed and achieved in the post-2030 Agenda by government, the private sector, civil society and individuals for a sustainable future. Currently, the European Space Agency (ESA) strategy outlines the long-term planning for Europe's participation in space exploration activities and is looking for innovative cases with a tangible business performance that can be matched with the *innovation and technological advancement goal* after 2030. Directly or indirectly, European space exploration activities could contribute to new knowledge and technical innovations, stimulating the creation of tangible benefits for Earth.

1 Innovation, a Key Component of European Industrial Policies

At the European Union (EU) level, the importance of innovation is a key factor for Europe's competitiveness in the global economy. As highlighted by EU industrial policy, industry is the "*engine of innovation*", and currently EU is developing

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policies and programmes with the aim to support the innovation, increasing investment in R&D to better convert research into improved goods, services and processes for the market.[1]

However, the European industry is undergoing deep transformation driven by innovative technologies and new business models. The "companies that prioritize innovation are also those who experience the highest increase in turnover"[2] and some 70% of private actors that introduced innovative technologies experienced the highest increase in turnover by more than 25% by 2014.

Concerning the industrial policy, Jean-Claude Juncker, President of European Commission, stated: "I want to make our industry stronger and more competitive. The new Industrial Policy Strategy we are presenting today will help our industries to stay or become the world leader in innovation, digitisation and decarbonisation".[3] In this new industrial age framework, the EC is investing in Europe's industry for a modern and fair economy. Important efforts are needed by Member States, EU institutions and industry to reach a high level of economic prosperity in Europe and to maintain and reinforce the industrial leadership in the age of sustainability challenges and rapid technological change.

The current dynamic offers an interesting opportunity for the European space sector as it enters a period of transformation, stemming from internal and external factors. The internal factors include limitation of public budget, and commercialization activities are prioritized more than ever. Fostering the involvement of commercial actors in public programmes has become a dominant consideration of the public sector. The opportunity for space agencies to stimulate new and ambitious partnerships with the commercial actors can contribute to the growth of the sector and the amplification of socio-economic impacts of space activities. External factors include "new forms of innovation external to the space sector (spin-in), broad industrial transformations creating more interconnected industries (Industry 4.0 concept)".[4] Currently, these drivers are transforming European and global space activities and institutions and have been captured in the notion of Space 4.0. In January 2016, ESA Director General Jan Wörner outlined his vision of Space 4.0 as "a diagnosis of the global transformation of the space industry and the challenges and opportunities this poses for ESA's new mission".[5] For this reason, ESA is challenged to support the European space industry in global value chains and to compete with the growth of new players form mostly US firms. ESA's strategy is

[1]European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Space Strategy for Europe*, (2016).

[2]European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Space Strategy for Europe*, (2016).

[3]Ibid.

[4]Marianna Mazzuccato and Douglas K. R. Robinson, *Market creation and the European Space Agency, towards a competitive, sustainable and mission-oriented space eco-system*, (2016).

[5]Ibid.

principally to position the agency in support the space innovation chain and "systems of innovation have been defined as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies".[6]

In the Space Strategy for Europe of 2016, the European Commission highlights its key objective to "foster a globally competitive and innovative European space sector"[7] to maintain and further strengthen a world-class capacity to conceive, develop, launch, operate and exploit space systems and open up new opportunities to develop innovative products, services and processes which can benefit industry in all Member States. To achieve this objective, the Union intends to explore two areas:

- **Supporting research and innovation and development of skills**: based on relationships with private actors and other innovation actors to address their competitiveness needs and strengthen the use of innovative procurement schemes. The objective is to foster and support the demand-side of innovation, and explore new approaches and mechanisms to leverage private sector investments and partnerships with industry[8];
- **Fostering entrepreneurship and new business opportunities**: the objective is to stimulate European space entrepreneurs in starting and scaling up across the European single market, enhancing its support to SMEs, start-ups and young entrepreneurs through business incubators and the use of prizes and competitions.[9]

In addition, the document underlined that the new business and innovation ecosystem are sustained at European and national levels, creating and stimulating space hubs with the objective to open up space to non-space entrants through existing instruments within the Commission, ESA's business incubation centres and initiatives in the Member States.

Regarding ESA, the Resolution on the Evolution of the Agency, approved in 2014 at Ministerial level, gave more emphasis on the evolution of ESA's relations with the private sector. Member States urged ESA director general to make proposals for the ESA Council meeting in 2016, promoting new innovative ways to adapt the relationship between ESA and industry in cooperative endeavours. In 2016, the follow-up Resolution "Towards Space 4.0 for a United Space in Europe", affirmed this demand with a clear intention to open up the agency to new partnerships with commercial actors in both space and non-space sectors and to implement complementary new funding schemes relying on commercial activities.

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[6]Marianna Mazzuccato and Douglas K. R. Robinson, *Market creation and the European Space Agency*: *towards a competitive, sustainable and mission-oriented space eco-system*, (2016).

[7]European Space Agency (ESA), *Resolution on Europe´s space exploration strategy*, (2014).

[8]Organisation for Economic Co-operation and Development (OECD), *Innovation for Development*, (2017).

[9]Ibid.

2 Evolution of the European Framework for Innovation in Space Exploration

The space exploration activities, human spaceflight and robotic exploration have traditionally been handled by ESA in collaboration with national space agencies. The official document presenting ESA strategy in space exploration was endorsed during ESA Council at Ministerial level held in Luxemburg on 2 December 2014. This document is the Resolution on Europe's space exploration strategy.[10]

The ESA strategy outlines the long-term planning for Europe's participation in space exploration activities, focusing on the next ten years but also taking into account longer-term perspective. The document affirmed that the recent European space exploration strategy relies on the ambitions, capabilities and commitments of ESA Member States as well as on opportunities offered by global cooperation with international partners. Europe's general purposes are to support and reinforce the role of Europe as an important and key partner in international space exploration programmes and to maximize the socio-economic return of space exploration activities including through the commercial valorization of related innovative technologies and facilities for applications on Earth.[11]

In line with the European priorities introduced above, the ESA vision is based on four articulated strategic goals highlighting the link between space exploration and its value to society:

- **Science**: strengthening European excellence in scientific research through opportunities for in situ investigations and the development of relevant instrumentation and enabling technologies;
- **Economics**: contributing to the competitiveness and growth of the European industrial sector by pushing the frontiers of knowledge and developing new technologies able to be applied in all fields on economic values;
- **Global Cooperation**: establishing a global cooperative framework to carry out several specific space exploration projects, involving in each case interested partners;
- **Inspirational Dimension**: attracting society, and in particular young generations to expand the limits of our knowledge, to the study of natural sciences and engineering, to the values of global cooperation in space, and to the preparation of sustainable human presence in the solar system beyond Earth.[12]

Regarding destinations to explore, ESA activities and planning focus on Low Earth orbit, the Moon and Mars. Considering that cooperation is a key pillar of ESA engagement in space exploration, the agency, through its flexible LEO–Moon–Mars

[10]Organisation for Economic Co-operation and Development (OECD), *Innovation for Development*, (2017).

[11]European Space Agency (ESA), *Resolution on Europe´s space exploration strategy*, (2014).

[12]Ibid.

strategy, remains open to a variety of possible partnerships with other space agencies active in human spaceflight and robotic exploration.

These destinations are part of a single exploration roadmap, and ESA aims to maximize technology and system synergies among these different destinations.[13] These targets have been selected to pursue different objectives with the ultimate goal to land humans on the Moon and Mars within the next 20–30 years. These three destinations could implement a variety of robotic and/or human missions to build a comprehensive set of technologies capabilities for Europe, each mission building on the achievements of the previous ones, make science progress on priority questions and further build international partnerships.[14]

However, most ESA space exploration activities are implemented in the context of international cooperation on the basis of complementarity and mutual benefits with a view to build long-term strategic partnerships with other space-faring nations. This approach allows ESA to reach more ambitious achievements by benefiting from financial and technical resources from its partners, to develop and share technologies but also to position Europe as a key player in the global space exploration arena. ESA works with a range of international agencies with the objective to be positioned as a key partner, if not a critical one, in these programmes and to find an appropriate role for European technology and science as well as opportunities to develop new capabilities. International cooperation also allows to optimize value for money by pooling resources, complementing each other's capabilities and sharing resulting benefits.

2.1 Space Exploration Programmes at ESA Level

Innovation is increasingly recognized as a key driver in the European space exploration context, in particular regarding innovative public procurement aiming at further involving the private partners in such activities, traditionally fully controlled by public agencies. Of course, space exploration projects will remain driven by governments with private industries acting as contractors for public programmes. However, this *status quo* is being increasingly challenged with new opportunities for a more prominent contribution of commercial actors lying in the so-called New Space ecosystem.

This new trend has been triggered by the successful approach implemented by NASA to extensively rely on private actors for the development and the operations of a new generation of space transportation systems for the servicing of the ISS after the retirement of the Space Shuttle.

[13]European Space Agency (ESA), *Resolution on Europe´s space exploration strategy*, (2014).

[14]Leonard David, *Lunar Leap: Europe Is Reaching for a Moon Base by the 2030s*, https://www.space.com/31488-european-moon-base-2030s.html, accessed 09.12.17.

This prominent example, coupled with multiple initiatives of private investors to tackle space ventures, has raised the interest of governments and agencies who are increasingly eager to explore new mechanisms to take advantage of private contributions in future programmes.

This comes along with clear challenges in order to define and implement new models of ambitious public–private partnerships. As a matter of fact, it can also be said that globally, increasing involvement of private actors in space agencies programmes in a more commercially driven space exploration activities offer promising perspectives to more efficiently address the post-2030 Agenda goals.

ESA has been very active in proposing several space exploration programmes and mechanisms that are meant to stimulate innovation and sustainable development. The agency is in particular investigating new ways to partner with the private sector to facilitate the realization of its ambitions in the space exploration sector. Recently, AZO-Space of Innovation (Anwendungszentrum GmbH Oberpfaffenhofen, an international networking and branding company for the European space programmes) has launched on behalf of the ESA the Space Exploration Masters in line with ESA Space Exploration Strategy.[15] The Space Exploration Masters is an international competition aiming to promote a clearly business-oriented approach to space exploration, identifying the best technology transfer business successes and fostering business innovation activities in LEO orbit, Moon, Mars and beyond.[16] There are two different prize categories "Technology Transfer Success" and "New Business Innovation" in the fields of:

- Human Space and Robotic Missions,
- Resources & Industry,
- Discovery & Space Observation,
- Spacecraft, Rockets,
- Propulsion,
- Space Tourism,
- Deep Space Communication & Navigation,
- Space Habitats
- and Life Sciences.[17]

According to its Managing Director, the main objective of AZO is to seek innovative business ideas providing major benefits for global society and economy, exploring spheres of uncharted areas in space and beyond. In this respect, the baseline of the project is to consider space exploration activities as a "large potential for the creation of future-oriented applications, products and services, benefitting activities on Earth. With new topics and application areas arise countless

[15]Space Exploration Masters, Boost Your Innovative Space Exploration Business Idea Benefitting Earth! https://www.space-exploration-masters.com/details/, accessed 09.01.18.

[16]Ibid.

[17]European Space Agency (ESA), *Exploring together: ESA Space exploration Strategy*, (2015).

possibilities for technology transfer and novel ideas for solutions and their application in non-space industries, as well as new business opportunities and objectives”.[18]

In line with these strategic objectives, ESA launched in 2015 a new mechanism known as Call for Ideas (CFI).[19] This mechanism established a process for launching strategic partnerships with the private sector and positioning the agency as business partner and sponsor of selected private sector initiatives. In addition, such partnerships also represent an opportunity for the private sector to shape and engage in the future global space exploration undertaking. More generally, this initiative also aims at fostering innovation, promoting innovative approaches into ESA space exploration missions, and strengthening the competitiveness of European industry in providing exploration enabling services. In this framework, ESA positions itself as a “business partner in developing new services or products on a non-exchange of funds principle, where the agency provides technical support, and reviews, business development support, co-funds technology development, and grant access to ESA facilities”.[20]

The scope envisaged encompasses the development of applications, products and services related to utilization of the ISS, post-ISS LEO exploitation, lunar exploration and ground analogue tests. As a matter of fact, fully in line with its space exploration strategy, the agency intends to take advantage of this initiative to promote a broader utilization of the ISS and to develop a step-wise approach to partner with private companies that would share risks.[21]

Following the first success of the CFI, a permanent call has been established to continue receiving commercial partnership suggestions. New ideas have already emerged from a successful consultation meeting and will now undergo a thorough evaluation process during a pilot phase comparable to what was implemented in the first call.[22]

Furthermore, commercial partnerships are now an integral part of European Exploration Envelope Programme (E3P).[23] More specifically, the main purposes of commercial exploration partnerships in E3P are to:

- Stimulate private participation in the space exploration framework.
- Foster innovative and inspiring approaches.

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[18]Matthias Engler, *Time to Explore the Unknown with the Space Exploration Masters*, http://www.space-of-innovation.com/time-explore-unknown-space-exploration-masters/, accessed 15.12.17.

[19]European Space Agency (ESA), *Space Exploration as a Driver for Growth and competitiveness: opportunities for the private sector*, (2016).

[20]Ibid.

[21]Bernhard Hufenbacha, Andreas Borggräfeb, Leopold Summererc, Elisabeth Sourgensd, Luca del Montee and Veronica La Reginaf, *Engaging the Private Sector in Space Exploration—An ESA Approach (IAC-16-A3.1.2)*, (2016).

[22]Ibid.

[23]European Space Agency (ESA), *European Exploration Envelope Programme (E3P)*, http://m.esa.int/About_Us/Ministerial_Council_2016/Human_Spaceflight_and_Robotic_Exploration_Programmes, accessed 17.12.17.

- Enhance private sector capabilities and demand for ISS utilization.
- Open perspectives for commercial approaches for exploitation of the ISS and post-ISS infrastructures.

With the adoption of the E3P, the agency has paved the way to the definition of new business models with a commercial partner. Moreover, additional call for proposals has been established by ESA lately, such as in situ resource utilization (ISRU) in the framework of lunar missions and co-funded studies on platforms and facilities in LEO orbit in the framework of Post-ISS.[24]

A complementary objective of the agency is here to explore and test innovative founding sources for space exploration, such as: "crowd funding, sponsorship and prize schemes. Brainstorming activities with space and non-space actors are defining potential ways forward".[25] Regarding this new initiative, an upcoming event called ESA Grand Challenge, and part of ESA's Space 4.0 Strategy was proposed and approved by the ESA Member States at the Council Meeting at Ministerial Level in December 2016.[26] The core purpose of this ESA Grand Challenge is to foster a new European ecosystem of entrepreneurs and start-up "competing to develop solutions that address complex problems be they technical, scientific or societal".[27]

The ESA Grand Challenge thus ambitions to support and create a new European ecosystem based on entrepreneurs and start-up companies, identifying new and innovative ideas, solutions or approaches to particular challenges. The purpose is to support cost-effective R&D, to foster innovation and entrepreneurship in space research and technology sectors, with the purpose of exploiting them for scientific objectives and for operational space applications systems. In the medium term, this new tool may increase the research funds (the prize fund will originate from competitor's own investment) and reduce the risk of public investment (paying only in case of success).

It can also be expected that the emergence of a subsequent Europe-wide innovative space industrial policy helps Europe to better shape and structure its industrial base to face the challenges of Space 4.0 era. This challenge has driven the European Commission (EC) to consider a EU Space Policy based on five priorities that complement existing ESA Industrial Policy[28]:

- Establish a coherent regulatory framework;
- Further develop a competitive, solid, efficient and balanced industrial base in Europe and support SME participation;

[24]European Space Agency (ESA), *Exploring together: ESA Space exploration Strategy*, (2015).

[25]Ibid.

[26]European Space Agency (ESA), *Global space economic forum: community of innovation* http://m.esa.int/About_Us/Business_with_ESA/Global_Space_Economic_Forum/Global_Space_Economic_Forum_Community_of_Innovation, accessed 17.01.18.

[27]Ibid.

[28]Patricia Conti, *ESA industrial policy*, http://www.innovation.public.lu/en/financer/competitivite/esa/politique-industrielle/index.html, accessed 25.01.18.

– Support the worldwide competitiveness of the European space industry and encourage the sector to become more cost-efficient along the value chain;
– Develop markets for space applications and services;
– Ensure the technological non-dependence and independent access to space.[29]

In order to achieve the objectives of this policy in collaboration with ESA and the Member States, the EU could further elaborate on the required framework conditions, making use of the instruments at its disposal, supporting research and innovation and promoting better use of financial instruments. In addition, EC pointed out, in the document *EU space industrial policy*,[30] that Research and Innovation (R&I) are considered not only as key elements for space industrial competitiveness, but also for sustainable economic growth. The budget for space under Horizon 2020 is proposed to be 1737 M€ in current economic conditions, and the programme will cover R&D and innovation to support to the competitiveness of the European space sector, focussing on industrial processes and favouring the emergence of SMEs. It also ambitions to promote European R&D in the context of international space partnerships (e.g. ISS, SSA, global robotic exploration programmes).[31]

3 Support to UN Post-2030 Agenda

In September 2015, with the adoption by the United Nations of the 2030 Agenda for sustainable development, a set of 17 "Sustainable Development Goals" (SDGs) was defined.[32] The current SDGs clearly draw attention of worldwide policymakers on the need for specific actions in meeting the global development challenges of the coming decades.[33] Each goal has clearly identified objectives to be achieved by 2030, transforming the world for the better. Basically, the Agenda "Space 2030" is expected to be an outcome of the UNISPACE+50 initiative proposed by the United Nations Office for Outer Space Affairs (UNOOSA) to take place in May 2018. Four thematic pillars have been set along the overall missions of the UN to further engage with the Member States with a view to strengthening international cooperation in this framework:

[29]Patricia Conti, *ESA industrial policy*, http://www.innovation.public.lu/en/financer/competitivite/esa/politique-industrielle/index.html, accessed 25.01.18.

[30]European Commission, *New Industrial Policy Strategy*, (2017).

[31]European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Space Strategy for Europe*, (2016).

[32]United Nations, *Sustainable development goals*, http://www.un.org/sustainabledevelopment/, accessed 08.01.18.

[33]Stefano Ferretti, Jean-Jacques Tortora, Elisabeth Veit, Alessandra Vernile, *Engaging with Stakeholders in preparation for UNISPACE+50*, (2017).

– Space Economy,
– Space Society,
– Space Accessibility,
– Space Diplomacy.

It is worth mentioning that the SDGs are well in line with ESA's guiding principle, fostering sustainable development on Earth via its programmes, data and services. The agency has even stated that sustainable development requires a structuring approach and "proposes to further enhance its role by funding dedicated activities".[34]

In this respect, the inclusion of space exploration in the 2030 agenda could be relevant to sustain the *innovation and technological advancement goal*. This could be achieved by the coordinated action of governments, private actors, civil society and individuals. Currently, ESA's space exploration programmes include identification of innovative cases with a tangible business performance that can be matched in this perspective by or beyond 2030.

Directly or indirectly, European space exploration activities can thus contribute to the achievement of SDGs and lead to new knowledge and technical innovations, stimulating the reaping of concrete benefits for Earth. The tangible aspect includes investments in programmes such as new devices and services that spin off into marketplace, developing industrial capabilities and the start-ups that are emerging in this new space ecosystem.

Such objectives are also fully in line with the overarching ambition of the European Union to promote a "knowledge-based society", through education and the enabling of understanding in society, which can be considered as an additional notable stakeholder (Fig. 1).[35]

In this framework, the above mentioned innovative concepts of the New Space economy set up an adequate ecosystem providing a favourable ground for the implementation of ambitious public–private partnerships, and we have seen that several Europe-led initiatives are properly addressing the need to foster innovation and to encourage the development of private ventures (ESA' Business Incubator Centers, Calls for Ideas, Grand Challenges and SME instruments). Such steps have been positively assessed by international consultancy companies (JKIC), which stated that through the "initiatives as ESA Technology Transfer Programme (TTP) and Business Incubation Centres (BIC), not only Europe can today boast a large number of start-ups being launched every year, but also an increasingly large networks of brokers, business angels, incubators, mentors and accelerators as well as university, research centres and experts".[36]

[34]International Space Exploration Coordination Group, *Benefits Stemming from Space Exploration*, (2013).

[35]Office of the Deputy Assistant Secretary of the Army (Research & Technology), *Emerging Science and Technology Trends: 2017–2047*, (2017).

[36]ESPI, *11th Autumn Conference: Innovation in the New Space Economy*, (2017).

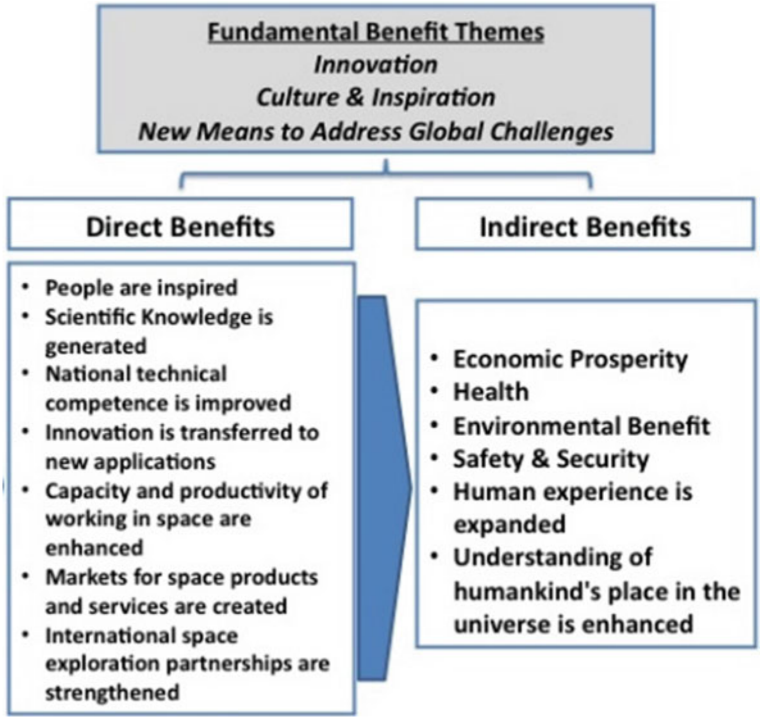

Fig. 1 Benefits of space exploration [International Space Exploration Coordination Group, *Benefits Stemming from Space Exploration*, (2013)]

However, cooperation with investment banks and venture capitalists are important steps towards a renewed European approach and support an innovation ecosystem. Altogether, these stakeholders could positively influence the manner in which space powers support and develop their space exploration strategies and programmes, fostering the emergence of such “New Space ecosystem”.

4 Conclusion

The concept of innovation and technological advancement as a future goal to the post-2030 Agenda, utilizing the space exploration applications, could drive improvements in other space systems and services in higher performance and lower cost, resulting in better services on Earth and better return of investment in institutional and commercial space activities.[37]

[37]Enrico Giovannini, Ingeborg Niestroy, Måns Nilsson, Françoise Roure, Michael Spanos, *The Role of Science, Technology and Innovation Policies to Foster the Implementation of the Sustainable Development Goals*, (2016).

Europe is making substantial efforts in this direction through various initiatives at ESA or EU level with the objective to:

- Further, strengthen innovation for economic growth.
- Promote a more prominent role for private actors in public space programmes.
- Maximize socio-economic impact of innovation, including beyond the space sector.

Within the realm of space exploration activities, effective leveraging of technological innovations is sought so far primarily through technology transfer programmes as well as through a few collaborations with other sectors.

Yet, the ecosystem is changing, bringing new opportunities to enhance the potential contribution of space exploration activities to economic growth way beyond the space sector through a number of groundbreaking applications such as:

- Space mining,
- Microgravity-related processes,
- Commercial exploitation of manned Low Earth orbit space assets,
- In-orbit servicing, …

The fast increasing availability of private sources of funding for such activities is currently favoring the emergence of multiple initiatives, together with the readiness of industry to take a more prominent role in space exploration programmes through new kinds of risk-sharing schemes with institutions and public actors.

In order to reap full benefits of such emerging opportunities, the main challenge for public institutions will be to operate a partial transformation of their best practices. The ultimate objective is to elaborate effective schemes to complementarily achieve scientific objectives of space exploration programmes and maximize innovation impact in terms of business growth and benefits for economy and society at large.

This implies to:

- Rethink R&D programmes so as to include the business dimension as a core component,
- Elaborate appropriate mechanisms to build on two-way synergies with actors outside the space sector,
- Implement a new innovation approach building on a more prominent role of private actors,
- Accept new types of risks and stronger reliance on external stakeholders,

European actors, in particular ESA, already took initial steps to transform its approach to innovation in particular for space exploration programmes.

Continuing and further intensifying this effort will be essential towards the post-2030 agenda, and space exploration could potentially serve as a driver to strengthen coordination between the three UN bodies dealing with space, namely the Scientific and Technical subcommittee, the Legal Subcommittee and COPUOS in order to achieve a comprehensive and effective global approach to space encompassing political, economic, scientific, technical, legal and societal aspects.