Acta Astronautica 140 (2017) 59–65

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Global risk & global challenges – Space as a game changer for socioeconomic sustainable development

Christopher Lehnert [a,*], Evelina Karlsson [b], Christina Giannopapa [c]

[a] German Aerospace Centre, DLR Space Administration, Königswinterer Str. 522-524, 53227 Bonn, Germany
[b] University of Gothenburg, Sweden
[c] European Space Agency, France

ARTICLE INFO

Keywords:
Societal challenges
Risk management
Strategy
Policy analyses
Space activities
ESA

ABSTRACT

The world's societies at the beginning of the 21st century are better off than ever before. (Gapminder, 2015) At the same time, the world is also threatened by global challenges where space as a tool has and can play a pivotal role in meeting those challenges. The challenges range from climate change, over mass unemployment, to terrorism or migration – to name but a few. Space activities have started to respond to this changing world, not only by providing a deeper understanding of our universe, but by using space as an additional sphere and sector, through which humankind can increase and secure its wealth – it is thus game changing in the way we sustain humanity's existence. This paper is meant to capture this development. In the first part, an overview is given on the risks that humankind is facing. The second part describes the way that space can be used as a tool to prevent and manage these risks. The overview in the first part is based on the examination of the most recent reports and overall strategies of key International Governmental Organisations and Non-Governmental Organisations that are involved in agenda-setting, policy formulation and implementation. The second part includes an overview on current activities of the European Space Agency (ESA) that play a role in responding to these risks. To better understand ESA's activities that contain humanity's risks, a standard classification for risks management is used, which distinguishes between four components: Identification, Assessment, Management and Communication (Renn, 2005). The analysis reveals how space activities already today play a pivotal role in all four types of risk management. Space activities contribute very tangible to the management of risks through its space mission, but also in a more indirect way, as providing the technical backbone for stable and reliable cooperation in the international governance arena, and serve as crucial economic stimulator. The overall results show that space activities touch upon every aspect of responding to the humanity's risks. Especially in the identification and the preventive management of humanity's risks, space systems are a crucial enabler. They are also an important part in dealing with risks related to scarcity of resources. It is thus important that current levels of investments into space infrastructure are maintained, as the benefits of space activities is essential to humankind's existence and that upon further programmatic decisions, stakeholders involved with the management of risks are being consulted.

1. Introduction

Today's societies are characterised by an unprecedented high degree of wealth around the world, most impressively indicated by all-time highs in the global life expectancy and income per capita [1]. The developments show that all regions of the world, also those suffering by ongoing crisis, are better off than two hundred years ago, and in particular in the last two decades wealth as indicated by income per capita and life expectancy, has risen starkly in most regions of the world. In 2015, the span of life expectancy ranged from 47.1 years on average in Lesotho to 84.8 years in Andorra, vis-à-vis a range from 23.4 years in Yemen to 42.9 years in Iceland in 1800. Even more recent data shows drastic differences: 24 in Yemen to 72.6 Norway in 1950. Nevertheless, the world is also threatened by a series of global challenges where space activities as a tool can play a pivotal role in mitigating the humanity's risks. Those challenges range from climate change, over mass unemployment, to terrorism or migration. Space activities have started to respond to this changing world, not only by providing a deeper

* Corresponding author.
E-mail addresses: christopher.lehnert@dlr.de (C. Lehnert), annaevelina@live.se (E. Karlsson), christina.giannopapa@esa.int (C. Giannopapa).

http://dx.doi.org/10.1016/j.actaastro.2017.08.005
Received 5 January 2017; Received in revised form 21 June 2017; Accepted 4 August 2017
Available online 9 August 2017

Table 1
Overview on risk reports.

Global Challenges Foundation	"Global Challenges – 12 risks that threatens the society" [4]
World Economic Forum	"Global Risks 2015" [5]
United Nations	"Sustainable Development Goals" [6]
European Commission	"Europe 2020" [7]
Organisation for Economic Cooperation and Development	"Space 2030 – tackling society's challenges" [2]

understanding of our universe, but by using space as an additional sphere and sector, through which humankind can increase and secure its wealth. This paper seeks to given an overview on these space activities and classify them. This is important as space activities are rarely seen in the context of risk management at large. One effort was made by the OECD, which is also considered in this report [2]. Efforts to determine the impact of space activities on the economy and the society are lead at ESA, national agencies and international Organisation [3]. Those studies often focus on a specific space programmes and general added value that space brings to the economy, largely by putting a price tag on the activities. What is missing is an overview of the plethora of activities that relate to the fundamental risks to humanity's existence, and an understanding how space activities contribute to the risk mitigation process. For this objective it is relevant to first understand what these risks are. An objective classification of risks in the sense that one risk is more crucial than the other one is very difficult to achieve as it often relates to the views of an epistemic community. The classification provided here takes this into consideration and thus looks at the risks outlined by major political institutions. By counting the issues that are shared by the different actors, an aggregated list of risks is provided that outlines the most important risks to humanity – as provided by political institutions. The first part thus gives an overview on the most crucial risks. The second part examines the activities of ESA and thus reveals how space is and can be used as a tool to mitigate these risks.

The first part of this overview is based on the examination of the most recent reports and overall strategies of key International Governmental Organisations (IGO) and International Non-Governmental Organisations (INGO), which are leading in the global and regional agenda-setting, policy formulation and implementation. The former include the European Union (EU), the Organisation for Economic Cooperation and Development (OECD) and the United Nations (UN), while the latter include the World Economic Forum (WEF) and the Global Challenges Foundation.[1] This research also considered the World Bank and the International Monetary Fund IMF) as actors, but no relevant reports could be identified to be included in this research. Approaching the exercise of mapping risks in such a manner, poses two crucial challenges. First, given the inherent nature of the actors, the INGOs are taking a proactive approach vis-à-vis risks, outlining and identifying them, while the IGOs take a reactive approach, outlining the mitigation actions. Here risks are rather latent in the policy goals and targets. Second, there are different levels of depth and the reports are often more complimentary than conflicting. The results shown in section two of this paper took these issues into consideration. The analysis is based on five reports (Table 1). Following the analyses of the reports, the identified risks have been organised into their common areas to easier distinguish patterns and see which risks are predominant in the on-going discussions.

The second part of the analysis looks at the activities in space. ESA, as an end-to-end space agency that is involved in the full spectrum of space activities together with its Member States and partners, was chosen as the space agency for this research. ESA's activities relate to all space missions that are carried out and planned as well as projects related to technology development or business support, as well as other activities. The term

[1] The Global Challenges Foundation is commonly not considered a global leader in agenda setting, policy formulation and implementation. It is considered here, because it has led an extensive effort in identifying global risks.

Table 2
Table 2 Categorisation of risks.

Known Knowns
Unknown Knowns
Unknown Unknowns

space activities used here spans a wide area and thus serves to show the range of activities that relate to humanity's risks. All activities were considered that have a direct relation to the outlined risks such as missions to observe changing forests or Asteroid detections missions. In addition, activities that indirect relate to the risks were considered, e.g. where possible findings of ESA's Advanced Concept Teams in future technology developments for computer systems might have spin off effects that mitigate or yield the possibility to mitigate risks related to Artificial Intelligence. While this method enables a very comprehensive picture, a qualitative assessment on the impact of these activities on risk mitigation goes beyond the scope of this paper. Thus a qualitative assessment of the specific activities, their actual impact and the relation between investment and impact should be pursued in a further study. This research nevertheless shows the range of risk areas affected by space and classifies them under a standard concept for risks management introduced by Ortwin Renn [8]. This helps to better understand the role that space as a tools has. Renn's concept explains four stages of risks management: identification, assessment, management and communication [8]. The overall theme of communication is present in all stages when handling and addressing risks. The management of risks further has two components, preventing and reactive management.

In Renn's concept, the objective of the first stage identification is to make risks known. Elements of the identification of risks include monitoring the environment, issues that are brought forward by stakeholders and through early warning systems. This is especially crucial, as a large part of risks are unknown unknowns, a term typically enough coined by former NASA Administrator William Graham and famously used by former US Secretary of Defence, D. Rumsfeld. Unknown Unknowns are part of a categorisation of risks (Table 2).

Known knowns refers to the knowledge about the existence of a risk and its properties. It is in contrast to known unknowns that describe the situation, where there is knowledge about the existence of a risk, without knowing more about its properties. Unknown unknowns then are the most critical risks, as one neither knows about their existences nor their properties. These risks often come sudden and leave little room for assessment and management. Identification of risks and making unknown unknowns known is thus a very critical part of risk management.

The second stage, assessment, provides knowledge of the risk, evaluates its impact and the possibility of reducing or containing its consequences. The third stage is management, where preventive and reactive measures can reduce, avoid or retain risks. The fourth stage is communication, which is also an important element for the other first three stages. It refers to the responsibility of both experts and civil society to inform on risks. For experts that are part of the risk management process there is responsibility to inform the different fields of stakeholders, from private management, science and public management. For the civil society, it pertains to the responsibility to inform about the experience of actual risks. An open and inclusive communication is essential in all stages and key to engage both civil society and stakeholders in the reasons behind the risk governance.

The analysis of space activities under this risk-management classification shows how relevant space activities are in all stages of risk management – especially in preventive management. At the same time, many space activities contribute to risk mitigation in the fields of *Resources, Unknown Unknowns* and *Climate Change*, but also in the areas of *Technology* and *Transport/Mobility*. As mentioned, previous studies as well as decisions makers have rarely considered space activities as a contribution to contain humanities risks, and the impact that space activities have had is most often a by-product of the stated mission purpose. That they do

play a pivotal role is shown here. It is thus important to keep funding for space activities at least at current levels and carefully consider risk-related aspects when making programmatic decisions. The involvement of experts from the field of risk management should be considered.

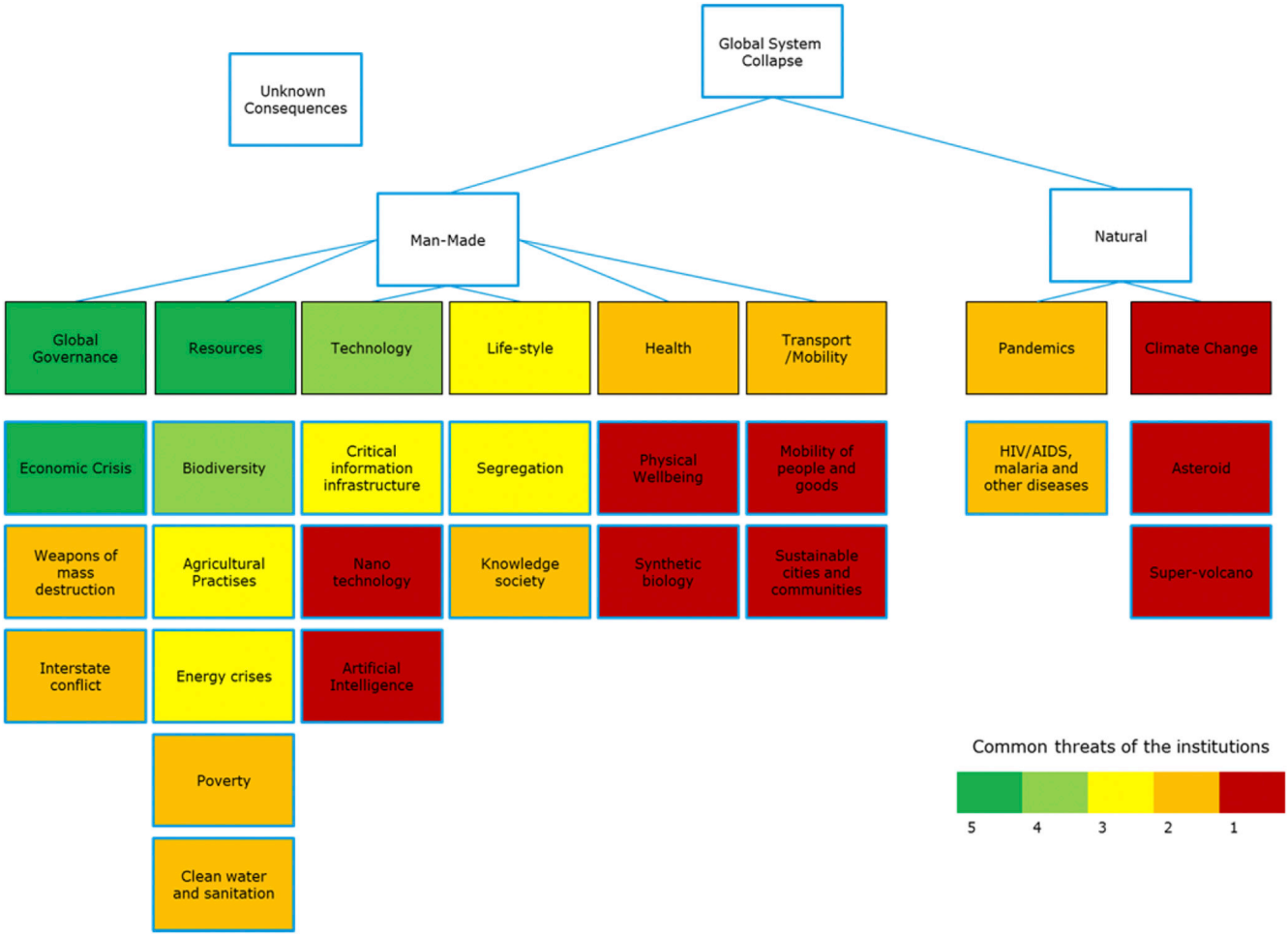
2. Risks for human civilisation

The risks that have been identified in the reports cover a broad range of topics that are also interconnected. Therefore it is always difficult to find a coherent categorisation of risks that clearly separates one risks from the other, and in addition prioritises these risks. Nevertheless, the following Table 3 depicts the result of such an endeavour that was conducted here. It shows three levels of risks that all are based on the understanding that the ultimate consequence of not managing the risks, can lead to a global system collapse, in which human civilisation would end. The first level distinguishes between man-made risks and natural risks. The second level shows the overall themes that are included in man-made and natural risks. There are six man-made risks: global governance, resources, life-style, technology, health and transport/mobility. There are only two natural risks, pandemics and climate change. For climate change it is important to note, that in this study, climate change is understood literally, as the changing of the climate e.g. as a consequence of an asteroid impact or the eruption of a super volcano. Commonly, climate change entails other elements, such as energy consumption or biodiversity. Here, those elements are being attributed to the category of resources. The reason is that humans have the capacity to influence these elements through their own behaviour. The third level breaks down the themes and shows their elements.

Additionally, the table gives an indication on the priority of these risks, by showing the count of these risks that were mentioned in the reports in colour coding. The priority stems from the understanding, that risks are more important when they various political actors share them. The colour coding ranges from five (green) to one (red). Overall, the table shows that the actors consider more man-made activities than natural ones that can lead to the end of civilisation. Global governance and resources constitute the prime risks to humanity, as all the actors share it. It is followed by technology, which is shared by all the actors with the exception of the OECD, and life-style, that is shared by the EU, the OECD and the United Nations. The Global Challenges Foundation and the United Nations share risks associated with health. Together with the OECD, the Global Challenges Foundation and the United Nation see risks of transport/mobility as an issue. Natural risks have only been mentioned by two organisations. Climate change in fact, only by the Global Challenges Foundation. The Global Challenges Foundation as well as the World Economic Forum mentions pandemics.

In the third level that breaks down the eight themes there are twenty elements in total. Global governance is the primary concern that all actors share. It is understood as the efforts of the national and international political system to ensure implementation of their political mandates. It thereby contains the ability to prevent economic crisis, prevent the use of weapons of mass destruction such as nuclear bombs, and interstate conflicts that lead to war. Economic crisis is shared by all the actors, and

Table 3
Risks bearing the potential to end humanity.



refers mainly to crisis in the financial markets, fiscal and monetary crisis. It is thus directly linked to the overall global governance system. The Global Challenges Foundation and the World Economic Forum share the risks associated with weapons of mass destruction. The OECD and the World Economic Forum both highlight interstate conflicts.

Risks associated with resources are the second most mentioned and are the ones that actors most often refer to when speaking about climate change. The risks identified include the disruption of biodiversity, with reference to species on land and in the oceans, agricultural practises that lead to soil erosion and degradation or the problem of monoculture plantations, which increase the impact of crop failure. Further risks include energy crisis, poverty, as well as lack of clean water and sanitation. It is understood that a failure in provision of these services, can trigger other challenges such as interstate conflicts or pandemics.

Technology is the third highest concern as all actors except for the OECD identify its elements. In particular, the EU and the UN, along with the WEF consider the mismanagement of critical information infrastructure as a prominent risk. On the contrary, the Global Challenges Foundation highlights two different risk factors, namely unforeseeable threats derived from the use of nanotechnology and the development of artificial intelligence.

Lifestyle is the fourth highest concern. It refers to the change of societies with regards to their own self-understanding and individual's action-guiding principles. A failure to adapt to a cultural self-understanding, can lead to rebellion, revolution and system crisis. Lifestyle contains risks of the knowledge society, as well as social issues of discrimination and exclusion (segregation). While the former ones includes the need for more education on all aspects of life, the latter ones especially refer to gender issues as well as issues of income inequalities. These risks are mainly a concern of the IGOs, as the World Economic Forum and the Global Challenges Foundation do not regard them as threats for humankind. The OECD, the UN and the EU are all highlighting segregation in lifestyle conditions, but only the latter, the UN and the EU consider additionally the risks born in the framework of knowledge society.

Man-made risks, namely those associated to health or transport and mobility are not widely accepted as potential threats. The Global Challenge Foundation and the UN are addressing physical well-being and synthetic biology respectively. Synthetic biology refers to the creation of pathogens in laboratory conditions that, accidently released, are resistant to traditional methods of cure. At the same time, OECD and the UN are focusing mostly on the financially related factors of transport and mobility, reflecting concerns over sustainability and the freedom of movement of people and goods.

The natural risks are split into two categories: pandemics and climate change. Pandemic diseases are not found among the high-risk factors. It is only international non-governmental organisations that draw attention to pandemic diseases, despite the wide spread of HIV/AIDS. One can find natural disasters that lead to a changing climate to be at the lowest end of the risk scale, as only the Global Challenge Foundation mentions those risks, considering possible scenarios of an asteroid impact or volcano eruptions for the end of human civilisation.

The analysis of the risks that are being considered by international governmental and non-governmental organisations has shown that there are eight areas that pose threats to the existence of humanity. Two of those risks are natural risks, while six areas stem solely from human activities. Moreover it shows that global governance issues around economic crisis, but also risks stemming from a destruction of biodiversity, disruption of food supply as well as energy crisis and ICT related risks are among the top concern related to humanity's existence. Space as a tool has a crucial role to play in mitigating these risks.

3. Space as a tool for risk mitigating

In the efforts to prevent and mitigate the risks outlined above, the role that space as a tool can play and already has is essential. This has already been highlighted by an effort ESA has taken in identifying ESA's contribution to societal challenges with regards to the United Nations New Sustainable Development goals, where it is depicted how ESA executes several activities virtually all in supporting to reach the UN goals [9–14]. For a better understanding on how space can be used to mitigate these risks, ESA's activities can be examined according to Renn's risk management approach outlined in the first section of this paper.

Taking a look at the risks outlined in section three and considering the stages of risk management, as well as ESA's activities, it becomes clear that there is more than meets the eye. ESA is a crucial partner in the effort of mitigating risks. The following overview in Table 4 shows this as it reveals that ESA virtually contributes to tackle all of humanities challenges. Table 4 is based on the analyses of all the current activities that ESA is carrying out as reported on their website. This includes the Science, Navigation, Earth Observation, Launchers, Space Engineering & Technology, Telecommunication & Integrated Applications as well as Human and Robotic Exploration programmes. The research looked closely at the purpose of each activity and grouped them accordingly into the cycle of the Renn's risk management.

A first important highlight is that most of ESA's activities also support mitigating humanity's risks and that most of ESA activities pertain to the two latter stages assessment and management. One reason for this is of course, that all of humanity's risks listed here, have already been identified and can therefore only be assessed and managed. Nevertheless, past space activities have contributed greatly to the identification of risks. It is thus not surprising that as the term also originate from a space context, a substantial number of ESA activities, mainly from the science program, have the potential to identify risks, the *unknown unknowns*. Many current missions, in particular with regard to Climate Change and Resources, are thus a result of identification of unknown unknowns, as the famous example of the exploration of Venus which led to the detection of Climate Change illustrates.

3.1. Identification

The potential to identify risks have 25 ESA activities. In particular, with regard to the *unknown unknowns* (19) ESA's current and future science's missions play an important role: JUICE, Athena, Solar Orbiter, Euclid, Plato, Cheops, JWST, Bepi Colombo, Gaia, Planck, Herschel, Venus Express, Rosetta, Mars Express, Cluster, XMM-Newton, Integral and Hubble. Some of these mission like Venus Express have ended their mission life-time, but the analyses of the data still continues and thus might lead to new knowledge, that will change the understanding of processes and bear the potential to identify risks. Also in the risk area technology for *Critical Information Infrastructure (4),* the Solar Orbiter, Cluster, Double Star and SOHO missions, which examine the effect of the son or the magnetic field on the Earth and thus also on our Critical Information Infrastructure Furthermore, for the identification of risks related to Clean Water and Sanitation, data from the Earth Observation Programme - (SMOS) further understanding of the Earth's water cycle -, supports in identifying risks. ESA's - SSA-NEO - programme supports in identifying asteroids.

3.2. Assessment

For the assessment of known risks, 17 ESA activities play a role, especially in the areas of natural risks *Climate Change* (11), and man-made risks *Resources* (6).

In *Climate change*, understood here as the changing of the climate as a natural process without man's interference, several missions contribute to a better understanding of this risk: ADM-Aeolus, Cryosat, Earth Clouds Aerosols and Radiation Explorer, Earth Explorer 8, EarthCARE, Meteosat Third Generation, Metop-sg, Sentinel 4, Sentinel 5, and Swarm. These missions use a variety of sensors to provide unique images, and a better understanding of planet Earth and assessment of the changing environment.

Table 4
ESA activities in relations to humanity's risks.

	Identification	Assessment	Preventive Management	Reactive Management	∑
Climate Change	**1**	**11**	**2**	**3**	**17**
Asteroid	1	1	1	1	4
Climate Change		10		2	12
Super-Volcano			1		1
Global Governance			**4**	**2**	**6**
Economic crisis			1	1	2
Interstate Conflict			2	1	3
Weapons of Mass Destruction			1		1
Health			**3**	**4**	**7**
Physicall Well-being			3	3	6
Synthetic Biology				1	1
Life-Style			**4**		**4**
Knowledge Society			2		2
Segregation			2		2
Pandemics			**1**	**3**	**4**
HIV?AIDS, malaria and other diseases			1	3	4
Resources	**1**	**6**	**9**	**8**	**24**
Biodiversity		4	3	1	8
Clean water and sanitation	1	1	2	3	7
Energy Crises			1	2	3
Poverty		1	1	1	3
Sustainable Agricultural Practises			2	1	3
Technology	**4**		**9**		**13**
Artificial Intelligence			2		2
Critical Information infrastructure	4		6		10
Nano Technology			1		1
Transport/Mobility			**9**	**4**	**13**
Mobility of people and goods			7	1	8
Sustainable Cities and communities			2	3	5
Unknown Unknowns	**19**				
Unknown Unknowns	19				
Total	**25**	**17**	**41**	**24**	**107**

The risk *Resource* relates to man-made changes in the environment that also lead to the change in the climate and thus bear the risks of a global system collapse. Here, 2020 Biomass, Sentinel-2, Sentinel-3 and Sentinel-6 provide assessments for the state of *Biodiversity*. The - (SMOS) Further understanding of the Earth's water cycle - project, also plays a critical role in the assessment of *Clean water and sanitation* risk and ACT-Earth System Sciences, with their on-going project on harmful algal blooms, has direct implications for fisheries and thus supports in the fight against *Poverty*.

3.3. Management - preventive

The largest contribution that ESA's activities make, is in the field of Preventive Management with 41 activities. In particular for *Resources (9), Technology (9)* and *Transport/Mobility (9)* there are several benefits coming from space.

Within the area of *Resources* for *Biodiversity*, the ARTES missions VGTropics and Proba-V contribute to the management of animal health as well as agricultural monitoring and the Sentinel-3 missions gives precise information on land and sea data, that support to prevent forest fires and improve maritime conditions. Sentinel-1 and ARTES KORE support in *sustainable agricultural practises*. ESA's Kore project provides cost effective crop management advisory tools. For the risks associated to *Clean Water and Sanitation*, Proba-V and the ARTES-EOAPP fulfil a preventive management role. Proba-V, was also designed to target water resource management, and food security estimates. Furthermore, ACT-Energy Systems, which researches on innovative energy system, bears the potential to increase *Energy Security* on Earth.

In the area of *Technology* risks, ESA's activities especially relate to risks in C*ritical Information Infrastructure*, with ACT-Bioengineering, ACT-Biomimetic, ARTES - 7 EDRS, ARTES - e2E, Hylas-1 and Informatics and applied mathematics. ESA's activities are here at the forefront of technology, and for Bioengineering ESA's Advanced Concept Teams exploit "new developments in neurosciences, molecular biology, biochemistry, microbiology, and as well as sensing, electronics, and imaging, to encompass any situation where technology must interface with a living system" [9–14]. With the ARTES - 7 EDRS project, ESA offers solutions at the edge of technology and contributes to a stable C*ritical Information Infrastructure*, making optical communication between satellites in orbit possible, and allow real-time data processing. ARTES – e2E also offers services in communication to promote stable and reliable communication systems. ARTES Hylas-1, developed a series of innovative technologies to offer broadband data services to European users. It thus directly contributed to a stable ICT system. For risks related to *Artificial Intelligence* ESA's Advanced Concept Teams (ACT-Artificial Intelligence, ACT-Computational Management Sciences), and *nanotechnology* (ACT-Nanotech), aim at incorporating innovation in their respective fields to the space sector, contributing to the generation of knowledge in these sectors and to a reliable handing of these technologies [9–14].

The important risk of *Transport/Mobility* also includes a variety of activities. Therein, mainly for *Mobility for People and Goods*, ESA's Advanced Propulsion Systems, ARTES – SENSA, ARTES - Electric Propulsion, ARTES - 10 IRIS, ARTES - 21 SAT-AIS, IXV, ATV are able to provide solutions. These include in particular the possibility to find new solutions for innovations in the propulsion and vehicle manufacturing sector (Advanced Propulsion Systems, ARTES - Electric Propulsion, IXV and ATV). With ARTES-SENSA, a responsible way of eco-tourism is enabled, where protected natural areas become accessible, with the guarantee that they remain protected from pollution. Furthermore, ARTES - 10 IRIS, ARTES - 21 SAT-AIS enable safer and more efficient ways of air and ship traffic management, with which the increasing demands for transport and mobility will be met. For *Sustainable Cities and Communities*, the MELiSSA project and the ARTES – UTRAQ mission provide innovative concept on how to achieve a self-reliable and sustainable closed ecosystem (MELiSSA), as well as ways to increase the mobility through smart-traffic in the cities (UTRAQ). This holds the potential for new perspectives in architecture, urban planning and holds mitigation solutions for the effect of climate change.

For other risks, such as *Global Governance* (4), *Life-Style* (4) and *Health* (3), space activities from ESA yield vital potential. As *economic crisis* is part of risks associated to global governance, Sentinel-1 supports a stable economic framework and is sought to boost the economy. Sentinel-1 "generate timely maps of sea ice for ship routing, offer information on wind and waves for safe passage, and can be used to track oil spills" [15–17]; p. 4). It will also be "used for precision farming and to track land-use change. Offering insight into subsidence and uplift, Sentinel-1 is suited for urban planning" [15–17]; p. 4). Similar, Sentinel-2 and Sentinel-5, provide imagery for decision-makers that increase the awareness of potential conflict zones, and thus directly contribute to reduce the likelihood of interstate conflict [15–17]. The HELIOS SatCen mission with its surveillance and tracking solutions, reduces the risks of conflicts with weapons of mass destruction.

For the adoption to changing societies, a risk named as *Life-Style,* ARTES - Sway4edu2 and Space Girls Space Women contribute to reduce *Segregation* and contribute to the *Knowledge Society* as does ESA Space for Educators.

In the area of *Health* contributing to *Physical Wellbeing*, Sentinel-4 provides Telemedicine solutions, as do ESA's ARTES-B-Life and ARTES KosmoMed mission.

Additionally, ESA's forthcoming Asteroid Impact Mission (AIM)[2] and the imagery of Sentinel-2, contribute to risk-prevention of natural *Climate Change*, by providing solutions to avoid an *Asteroid Impact*, and to increase the knowledge about given issues associated with climate change, by generating "land-cover maps, to track changes in the way land is being used and to monitor the world's forests", as well as providing, "information on pollution in lakes and coastal waters" [15–17]. At last, in the area of preventive management, ARTES-B-Life, by "bringing a diagnostic capability as close as possible to crisis area" [9–14], provides solutions to prevent the risk of *Pandemics*.

3.4. Management – reactive

That space can also offer solutions, in an event of crisis, is supported by the finding that 24 ESA activities support in the field of *Resources (8), Transport/Mobility (4), Health (4), Climate Change (3), Pandemics (3)* and *Global Governance (2)*.

For the risk of *Resources*, and therein *Clean Water and Sanitation,* ESA's ARTES projects offer support, by allowing an efficient water management at dams (Dammings), control of the quality of inlands waters by monitoring special bacteria populations (CYMonS) and by improve the management of water resources to avoid water scarcity in Africa (TIGER). Damming thus also contribute to prevent a stable energy system and avoiding *Energy Crises* as does ARTES-SUMO, a "service for planning and monitoring of marine operations for offshore wind farms" [15–17]. Additionally, ESA's EO Crowd, by allowing a better management of the maritime economy, helps to reduce *Poverty*. Equally so does Proba-V, with its contribution to agricultural monitoring and food security. By allowing a secure and efficient management of dams, ESA's Damming project, also directly supports *Sustainable Farming Practices*. The Sentinel-3 directly supports the preservation of the Earths *Biodiversity*, by "supplying a wealth of data related mainly to the marine environment. Delivering critical data on the height and temperature of the sea surface, it supports ocean forecasting for maritime safety" [15–17].

In the risk area of *Transport/Mobility,* it is ESA's Damming, Concordia and the utilisation of the ISS that brings solutions to *Sustainable Cities and Communities,* by testing new technologies in extreme environments that also find their applications in the common households. Dammings ensures safe urban planning and thus enables new possibilities. For the *Mobility of People and Goods,* the Artes EO Crowd project, enables a better and more efficient management of maritime traffic.

[2] AIM has not received the required level of funding at ESA's Council at Ministerial Level in Lucerne in 2016 and might not be implemented.

Reactive management solutions for *Physical Well-Being,* which constitutes a risks in the category of *Health,* are provided by the ISS programme, Artes B-Life and Artes KosmoMed that offer solutions to human diseases as in the case of diabetes research on the ISS, but also solutions through operational support and tools to doctors in the field and in remote areas with the latter two ESA activities. With risks associated to *Synthetic Biology*, the research on the ISS also provides answers to managing biological risks.

For *Pandemics*, also ESA's Artes B-Life and Artes KosmoMed, as well as ARTES VacMap, a tool to help map infectious disease vectors, contribute greatly to reduce the risks of spreading *HIV/AIDS, malaria and other diseases.*

In the natural category of *Climate Change,* it is the Asteroid Impact Mission (AIM) that can support in the case of an *Asteroid* threat. Also, great contributions are being provided in case of natural disasters from the ARTES programme Eagle Space, which "aims at the integration of space based capabilities in crisis management to support the joint combat of natural flooding and wildfire disasters" [18] and SAPI&NS, that "aims to improve the effectiveness of *Search And Rescue* operations for civil and military operators" [15–17].

To a lesser, but still to some extent, ESA missions also offer capabilities in the management of *Global Governance* issues. With ESA's Satcom Service for Finance, economic growth is being promoted, as it allows customers stable financial services also in remote areas. Furthermore, Sentinel-2 will also provide solutions and greater knowledge in an event of security crisis, which is reducing the impact of interstate conflict.

Overall, the analysis has shown that ESA's and space's contribution to managing risks is great and although it offers transversal solution, its greatest role is in preventive management.

4. Concluding remarks

Although many well-being indicators showed that humanity is on a continuous path of growth, this wealth has also become vulnerable to a series of risks. Many reports and articles outline these risks, but there has been no systematic overview provided, on what the key decision-making institutions outline as such risks. Therefore, based on a this research of international governmental and non-governmental institutional reports, it was shown that humanities main risks for a global system collapse stem from the *Global Governance System*, which mainly highlights risks pertaining to *Economic Crisis*. Equally critical, are risks associated to *Resources,* and here specifically the need to protect a rich *Biodiversity* and achieve *Sustainable Agricultural Practices.* Less often raised but still important risks include *Life-Style,* where a failure of the systems to adapt to societal needs can lead to collapse, or risks coming from *Technological Advancements*, or *Health Issues.* A great risk also stems from the so called *unknown unknowns*, risks we do not know we do not know.

The second part of the research, has then looked at how space activities, with the example of ESA's activities, relate to tackle humanities risks. For this purpose, Ortwin Renn's categorisation of risk management, which distinguishes between identification, assessment, management and communication of risks, was considered, to better understand in what way space activities support risk mitigation. It showed first of all, that ESA's space activities play a major role at all stages of risk management with 107 activities. Especially in the critical risks of *Resources, Unknown Unknowns* and *Climate Change*, space offers a plethora of unique options and means. But also in the area of *Technology* and *Transport/Mobility*, space has a role to play. To a lesser extent, space infrastructure and services support in the crucial risks related to global governance. Nevertheless, single space infrastructure projects such as global positioning systems or communication systems constitute critical infrastructure that enables large parts of today's economies as well as international cooperation through provision of stable and reliable information.

Looking at the way in which space offers support, the analyses revealed that ESA's activities are especially crucial in the field of preventive management. This is mainly driven by the space components of

Copernicus Earth Observation programs with its different Sentinel satellites as well as the ARTES program that have a strong application focus. Also ESA's main missions, the sciences missions bear an important contribution. These cutting edge missions are able to transform the unknown unknowns. Preventive management and unknown, are both areas with a low visibility vis-à-vis the public, but are highly critical in the way they help humanity's well-being.

Thus given that space activities contribute to mitigating all risks to humanity and in all areas of risk management, the exceptional contributions to the critical risks related to *Resources* as well as the often overlooked importance of preventive management and space activities great contribution therein, it is important that investments in space activities continue at current levels despite economic and security crisis. And although risk management is not at the core of ESA's tasks and space in general is not often linked to this important topic, this analysis provided ample evidence that those two fields should be jointly examined. It is advisable to carefully consider risk-related aspects when making programmatic decisions and perhaps the involvement of risks-experts in the consultation process on further space activities should be considered.

References

[1] Gapminder, Global trends, Retrieved December 12, 2015, from Wealth & Health of Nations, http://www.gapminder.org/world/#$majorMode=chart$is;shi=t;ly=2003;lb=f;il=t;fs=11;al=30;stl=t;st=t;nsl=t;se=t$wst;tts=C$ts;sp=6.9341935483871;ti=2015$zpv;v=0$inc_x;mmid=XCOORDS;iid=phAwcNAVuyj1jiMAkmq1iMg;by=ind$inc_y;mmid=YCOORDS;iid=phAwcNAVuyj2tPLxKvvn, 2015.

[2] Organisation for Economic Cooperation and Development, Space 2030. Tackling Society's Challenged. *Paris: Organisation for Economic Cooperation and Development*, 2005.

[3] European Space Agency, Industry portal: space economy: external studies, Retrieved Juni 19, 2017, from, http://www.esa.int/About_Us/Business_with_ESA/Space_economy/External_Studies, 2017.

[4] D. Pamlin, S. Armstrong, Global Challenges 12 Risks that Threaten Human Civilisation. Global Challenges Foundation, Global Challenges Foundation, Oxford, 2015.

[5] World Economic Forum, Global Risks 2015, World Economic Forum, Geneva, 2015.

[6] United Nations, Transforming Our World: the 2030 Agenda for Sustainabile Development, United Nations Development Programme, New York, 2015.

[7] European Commission, COM(2010)/202s0: Europe 2020. A European Strategy for Smart, Sustainable, and Inclusive Growth, European Commission, Brussels, 2010.

[8] O. Renn, Risk Governance: towards an Integrative Approach. *White Paper Nr. 1*, International Risk Governance Council (IRGC), Geneva, 2005.

[9] European Space Agency, Advanced concepts team, Retrieved April 21, 2016, from Bioengineering, http://www.esa.int/gsp/ACT/bng/, 2016a.

[10] European Space Agency, Advanced concepts teams, Retrieved April 21, 2016, from ACT, http://www.esa.int/gsp/ACT/index.html, 2016b.

[11] European Space Agency, Artes applications, Retrieved April 14, 2016, from B-LIFE - Biological light fieldable laboratory for emergencies, https://artes-apps.esa.int/projects/b-life, 2016 February 12c.

[12] European Space Agency, Space for Earth, Retrieved January 29, 2016, from ESA and the Sustainable Development Goals, http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/ESA_and_the_Sustainable_Development_Goals, 2016 January 27d.

[13] European Space Agency. (n.d.). Advanced concepts team. Retrieved April 21, 2016, from Bioengineering.: http://www.esa.int/gsp/ACT/bng/.

[14] European Space Agency. (n.d.). advanced concepts teams. Retrieved April 21, 2016, from ACT.: http://www.esa.int/gsp/ACT/index.html.

[15] European Space Agency, Artes applications, Retrieved April 21, 2016, from Sumo - planning and monitoring support of marine operations in offshore wind farms, https://artes-apps.esa.int/projects/sumo, 2015 July 16a.

[16] European Space Agency, Artes applications, Retrieved April 21, 2016, from Eagle Space, https://artes-apps.esa.int/projects/eagle-space, 2015 May 13b.

[17] European Space Agency, Sentinels. Space for Copernicus, 2nd ed., European Space Agency, 2015c. ESA Brochure (BR-319).

[18] European Space Agency, Artes applications, Retrieved April 21, 2016, from SAPI&NS, https://artes-apps.esa.int/projects/sapins, 2014.