Sustainable development and stakeholder theory: the case of public-private partnerships as a solution to space-debris removal

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Summary
Exploration of the space has reached a point in which there is a challenging question whether further space activities will be viable in the long term. That is mainly because of the growing number of space-debris that may detrimentally impact existing space infrastructure. This research paper concentrates on measures that can be taken in order to mitigate the problem of orbital debris. Firstly, the concept of space debris is investigated with regard to its sources, kinds and existing debris-removal solutions. Within the academic framework, both the stakeholder theory and the concept of sustainable development are introduced. In turn, the connections between the theoretical concepts and numerous stakeholders within the space industry as well as the importance of sustainability in terms of space debris are proposed, based on the aforementioned theories. Subsequently, space-debris removal is presented as a method that can be adopted and executed by public-private partnerships (PPP). To underline the feasibility of such PPPs, the approach of NASA towards PPPs is presented along with the case study of the Swiss PPP project on active debris removal (ADR). The research paper is concluded by indicating the magnitude of the efforts that have to be undertaken by various stakeholders in order to successfully implement ADR solutions through public-private partnerships.

Key words: space debris, active debris removal, stakeholder theory, sustainable development, public-private partnership

Développement durable et théorie des parties prenantes:
le cas des partenariats public-privés comme solution au retrait des débris spatiaux

Résumé
L'exploration de l'espace a atteint un moment où il est difficile de savoir si d'autres activités spatiales seront viables à long terme. Cela s'explique principalement par le nombre croissant de débris spatiaux susceptibles d'avoir un impact négatif sur l'infrastructure spatiale existante. Ce mémoire de recherche se concentre sur les mesures qui peuvent être prises afin d'atténuer le problème des débris orbitaux.Tout d'abord, le concept de débris spatiaux est étudié en ce qui concerne ses sources, types et les solutions existantes d'élimination des débris. Dans le cadre académique, la théorie des parties prenantes et le concept de développement durable sont introduits. Successivement, les liens entre les concepts théoriques et de nombreux acteurs au sein de l'industrie spatiale ainsi que l'importance du développement durable en termes de débris spatiaux sont proposés, sur la base des théories susmentionnées. Par la suite, l'enlèvement des débris spatiaux est présenté comme une méthode qui peut être adoptée et exécutée par des partenariats public-privé (PPP). Pour souligner la faisabilité de tels PPPs, l'approche de la NASA vis-à-vis des PPPs est présentée accompagnée d'une étude de cas du projet PPP suisse sur le retrait actif des débris (ADR). Le mémoire de recherche est conclu en indiquant l'ampleur des efforts qui doivent être entrepris par les différentes parties prenantes afin de mettre en œuvre avec succès des solutions ADR grâce aux partenariats public-privé.

Mots clés: débris spatiaux, actif retrait des débris spatiaux , théorie des parties prenantes, développement durable, partenariat public-privé

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1. Introduction

Space industry is constantly evolving with more and more actors having access to the space activities. That is due to decreasing costs, more accessible technology and declining infrastructural barriers. However, the current space environment is operating under the international legal framework and business imperatives related to the bygone challenges. Inevitably, the organisational aspects will have to change and adapt to support advancements in space exploration, but also to preserve the existing space infrastructure for the future generations.

One of the most perplexing factors that might have major implications for space activities in the nearest future is the issue of space debris. At present, there are already millions of orbiting space-debris items polluting the outer space. In addition, these objects moving with enormous relative velocities may collide with functioning space infrastructure, causing not only serious damage or destruction, but also generate even more debris.

The urge to investigate the space sector and, in particular, the issue of space debris was brought up by the compelling revelation that space industry provides crucial infrastructure for postindustrial economies, namely: telephone, radio and television transmissions, operations related to banking and stock market, weather forecasting, aircraft and maritime global navigation systems are among many others. All above mentioned services fully rely on the proper and reliable functioning of space satellites (Dos Santos Paulino et al., 2016). To put it in simple terms, the technology derived from space programs considerably influences our daily life. Anticipating the future, in the upcoming years the developing technology will substantially transform the way people work, manage existing resources and proceed with new business opportunities, not only exclusively related to space exploration as such.

The problem of space debris calls for global attention as it requires close cooperation between a variety of international space-related stakeholders. Scientists and engineers should strive for presenting dedicated technological solutions and policymakers should be working on the legal framework that will support the suggested space-debris removal activities.

The present paper aims at applying the academic frameworks of stakeholder theory and the concept of sustainable development in the context of the space-debris issue. It seems relevant to examine: the way the space business activities are organized among numerous actors, who is responsible for what and who has the superior capacity needed to implement space projects.

Looking from this angle, it is advisable to consider the synergy between private and public entities that can be used in order to jointly cooperate towards the preservation of the long-term sustainable exploration of space. Owing to the above, a practical suggestion would be to consider the public-private partnerships as a solution to the pressing issue of space debris.

2. Framework

The paper’s objective is to determine the potential framework for space-debris removal in the context of the sustainable development and stakeholder theory.

2.1. Empirical framework

The following chapter provides the necessary insights into the nature of space debris, its origin and impacts.

2.1.1. Definition, types and sources of debris

Taking into consideration the origin, there are two existing types of debris that can be found in space. The first one being naturally occurring meteoroids naturally passing through the Earth's orbit. The other type of debris called “orbital debris” includes man-made objects in orbit which no longer serve a useful purpose. (Mirmina, 2005). However, the very term *space debris* is frequently used with the reference to the latter: “Space debris are all man-made objects, including their fragments and parts, whether their owners can be identified or not, in Earth orbit or re-entering the dense layers of the atmosphere that are non-functional with no reasonable expectation of their being able to assume or resume their intended functions or any other functions for which they are or can be authorized” (United Nations, 1999).

There are also other names such as: *space junk*, *space waste*, *space trash*, *space litter,* or *space garbage*. These can include such objects as: spent rocket stages, old satellites, unspent propellant, bolts, lost equipment, and other materials including pecks of paint resulting from the degradation and corrosion processes of other man-made objects in the space. Some of these result from either the usual space activities or accidents occurred during these activities, caused either by malfunctions of propulsion systems or by the ignition of residual propellant. Additionally, another source of the space debris is intentional generation thereof by testing anti-satellite weapons (ASAT).

Space debris can be divided into three categories talking into consideration their size, potential risks and possibility of detection. While analyzing the table (Fig. 1) it is noticeable that even though there are far more small space-debris items than large space-debris items, large debris items account for over 95% of the total mass of the all space-debris items. Moreover, in the long run, large objects are bigger threats because, in the event of a collision among themselves, they can generate even more space-debris items (Emanuelii, 2014).

Debris with size less than 1 cm are less likely to damage a satellite, unless it hits an area that is vulnerable. Some shields can be applied as protection against this type of debris. However, shields increase the total costs of satellites and their launch. Debris with size ranging from 1 to 10 cm can considerably damage or even destroy a satellite. There are no shields available. Moreover, the tracking of such particles from Earth is not always possible or reliable, so the warning against a collision may not be given in time, if at all. Debris with size more than 10 cm, apart from completely destroying a satellite, can generate large number of space-debris items when collided with a satellite, but also with another large space-debris item (Wright, 2009).

Space debris is observed predominantly in highly congested communication satellite orbits between the altitudes ranging from 750 to 800 km. At the same time, almost all the space-debris items are within 2 000 km of the Earth (Fig. 2). This is because of the fact that the Low Earth Orbit (LEO) is preferred by space-faring countries due to the lower costs of launch and minimized atmospheric drag that both allow satellites in LEO to stay there for a long period of time with minimal fuel consumption. Since the orbit provides also optimal viewing of the Earth, satellites for astronomical observation, meteorology, navigation, and military surveillance are put there (Fig. 3). On the other hand, the LEO conditions are equally favourable for the space debris. The life time of the artificial space debris depends on the atmospheric drag affecting it and is also influenced by mass, size, shape of a space-debris item and the atmospheric density at its orbital altitude. Taking into account that at high altitudes the atmospheric drag is rather small, space debris can stay in orbit for decades accumulating, as more and more space objects are launched (Bennet et al., 2012).

According to Kessler (1978), as the orbits are more congested, the probability of collisions increases exponentially. In turn, these collisions produce a large number of new space-debris items creating a cascading growth of space-debris items. When these conditions are met, the number of space-debris items will increase exponentially with time, even though new objects are not put into orbits.

2.1.2. Consequences of space debris

The presence of space debris can have the following consequences (Hall, 2014 / Wright, 2007):

-damage to the satellites or, at least, decrease in their performance depending on the size of the space-debris item and the systems affected by it;
- fatal danger to the people working in space;
- shortened lifetime of satellites caused by manoeuvres performed to avoid tracked space-debris items;
- steady generation of new space-debris items (The Kessler syndrome);
- steady increase in the mission costs due to shielding, higher launch costs (more fuel and delays), and more expensive insurance policies;
- threat to the operational activity of various systems on Earth depending on the data obtained by satellites;
- pollution of the space environment;
- pollution of the environment on the Earth caused by the space debris that has not burn during the re-entry;
- accidents on the Earth caused by the space debris that has not burn during the re-entry.

The probability of the collision between a satellite and space-debris items is influenced by different factors: the satellite's trajectory, the flux of space debris present along this trajectory, the satellite’s residence time in orbit, and the satellite’s projected area to the debris flux (Fig. 4). In turn, the possible consequences of the impact depend on the specific characteristics of the met space-debris flux such as its size, velocity, material and the design of the concerned spacecraft itself (Science Magazine, 2002).

The viability of satellite presence depends heavily on finding a new space environment management strategy that would allow to avoid potential collisions.

2.1.3. Current policy regarding space debris

A turning point in the context of the discussions concerning the space debris issues was a hypervelocity collision that occurred between two artificial satellites *Iridium 33* and *Cosmos-2251* on 10 February 2009. As a result of the event, numerous pieces of space debris were created and became a threat for the existing and future operating equipment.

Although the threat posed by space debris has become evident, not enough measures have been taken to remedy the situation and most of them involve issuing guidelines (e.g. the guidelines of The Inter-Agency Space Debris Coordination Committee (IADC)) on minimizing the generation of space debris including ideas such as: a limited debris release during regular operations, reduction of the potential for on-orbit break-ups, post mission disposal and prevention of on-orbit collisions. Although these guidelines are supported by most of the space-faring nations, they are not legally binding (Mirmina, 2005).

There are three strategies concerning post-mission disposal (PMD) of the space equipment. The first one involves controlled re-entry. The method requires a significant amount of fuel and is usually used for launch vehicle upper stages due to their short mission time frames and sufficient amount of remaining propellant to perform the required maneuvers. The second strategy is about leaving spent stages in lower orbits in order to accelerate their re-entry into the Earth's atmosphere and, subsequent, burning which is possible thanks to natural perturbations. However, it may take years to happen. The third strategy involves putting satellites in a higher orbit which, in turn, serves as a graveyard. The described strategies can be very effective when it comes to reduction of the space-debris growth in space. However, in order to be truly effective, they should be employed by all space users. Even though these strategies can be effective while controlling the future deposition of space-debris items, they will not solve the existing space-debris related issues (Aerospace, 2015).

From the legal point of view, the removal of the space-debris items can be also difficult to carry out. According to *The Outer Space Treaty* (1967), the launching state is liable for its space objects and retains jurisdiction while in outer space. Therefore, no third party shall be allowed to remove an object without a consent from the launching state. Should the object be retrieved by another state, there is also a question of a national security and intellectual property rights that could be violated as objects put in the orbit are distinguished by their state-of-the-art technology and purpose (e.g. military).

Nevertheless, mitigation and monitoring constitute passive measure to face the debris challenge and, in the long-run, space-debris removal solutions will be necessary to preserve the sustainable space environment (Fig. 5).

2.1.4. New technology

While dealing with space debris, one of the most important issues is its tracking. Therefore, *The Space Environment Management Research Center* (*SEMCRC*) has been created in order to develop Australian and international expertise in measurement, monitoring, analysis and management of space debris and, as a result, to develop technologies aimed at preserving the space environment.

Objects in LEO are usually tracked using Radio Detection and Ranging (RADAR) which includes, a radio transmitter and receiver, together with signal processing electronics used to amplify and interpret received signals. Light Detection and Ranging (LIDAR) combines optical and RADAR techniques in order to illuminate a specific target with a laser beam and, then, measure the range to the specific target by precisely timing the round trip of a single laser signal. The detection of space debris allows the operating satellites to omit the given space-debris item.

Active debris removal (ADR) is a set of methods aiming at cleaning up the space. There are two main differences between ADR and PMD methods. First of all, ADR is performed by an external vehicle that is used for supplying the device performing the removal. Secondly, ADR can be applied to any item floating in space, whereas PMD can be performed only during the missions that either have a built-in capability that was foreseen during the planning stage or have available a residual capacity to complete them (Aerospace, 2015).

The ADR techniques can be divided into two basic groups: active removal (large debris) and passive removal (medium and small debris). Active removal consists in a spacecraft approaching the orbital debris and either capturing it in order to descend together or attaching another device that descends only the orbital debris. Passive removal involves the orbital debris colliding with the removal spacecraft and either capturing it with special density materials (e.g. polyimide foam, foil stacks) or decelerating it during the passage through the removal spacecraft (Ariyioshi et al., 2011).

Some examples of the solutions used for the ADR are included in the Appendix: (Fig. 6).

2.2. Theoretical framework

The concepts of the sustainable development and stakeholder theory will be described and, subsequently, analyzed in the context of space debris issues.

2.2.1. Stakeholder theory

The stakeholder theory has been widely discussed by Edward Freeman in his renowned book, *Strategic Management: A Stakeholder Approach*, but lately others developed that concept and provided valuable insights. The outcome of deliberations on that theory resulted in the observation that it is still unclear who actually is to be considered a stakeholder. Certainly, it is reasonable to say that a stakeholder should possess a stake in the enterprise, simultaneously making his input to the firm and sharing the firm’s output. One could say that the nature of the relationship between a stakeholder and a company is the reciprocity (Tullberg, 2013).

Stakeholder theory is aiming at the issue of the interference between critical actors. Since numerous actors may possess divergent interests that may ultimately lead to the conflict which will negatively affect the company. The key is to ensure good cooperation between those actors for the benefit of all. Tullberg (2013) proposes the distinction between stakeholders that are either the *influencers*, having superior power towards the company, or the *claimants*, much weaker and susceptible to unfavourable actions of the firm. In fact, majority of other actors, beyond the scope of interest for particular company, can be at some point and to some extent affected by that company. Notwithstanding, to simplify the understating of the stakeholder concept, the theorists recommend to view a stakeholder as an entity that somehow contributes to the company. Stakeholder has, therefore, “a stake, a claim, or an interest in the operations and decisions of the firm” (Carroll, 1991).

2.2.1.1. Notion of a stakeholder

In fact, as Mitchell et al. suggest, that actual or potential stakeholders can be “persons, groups, neighborhoods, organisations, institutions, societies, and even the natural environment". According to Carroll (1991), the stakeholder theory indicates that five major stakeholder groups can be identified within the company reasoning. These groups are the following: owners (being equally shareholders), employees, local communities, customers and general public. Tullberg (2013) in his paper put the emphasis on an additional actor that should not be disregarded among stakeholders, namely: management group. Since management is one of the stakeholders and, at the same time, the group that should make a decision which of the interests and of whom to fulfil, the concept of stakeholder management appears.

2.2.1.2. The importance of stakeholders' claims and corporate responsibility

Obviously, a company has certain obligations in respect to its stakeholders' groups, which is embedded in the notion such as corporate social responsibility, however, the nature of obligations and the behaviour of the company will differ among above-mentioned groups. It is worth stressing that a film should treat all its stakeholders with equal respect, on the basis of fairness principle and strive to protect their rights.

It is vital to mention that managers have extremely challenging task to determine which stakeholder deserves special consideration in the process of making decisions in the company. Given the number of stakeholders and, usually, their contradictory interests, managers have to evaluate the importance of the stakeholders' claims and which of them should be granted a priority. As Carroll (1991) states, management decisions rely on the criteria of stakeholder legitimacy and power. Legitimacy can be explained as a scope of a justifiable right of a group to proceed with its claim. Power, in turn, refers to the extent to which groups are organized and poses, for example, considerable financial resources. Depending on the point of view, legitimacy and power will have different weight in the decision making. For instance, legitimacy criterion will prevail once the concept of Corporate Social Responsibility (CSR) is taken into account. On the other hand, if superior weight is given to the management efficiency, managers will rather consider the stakeholder's power.

Above-mentioned reasoning is not exhaustive and another contribution to stakeholder theory was presented by theorists claiming that, along with the legitimacy and power, there is also the issue of urgency. That criterion suggests sort of time-sensitivity and high importance for the stakeholder. What is more, theorists put emphasis on the complex and dynamic considerations that are occurring between those three criteria. On the basis of above attributes the concept of stakeholder salience was created. That theory aims at answering the question of the degree that managers give to the stakeholders' competing claims. To put it in simple words, stakeholder salience enables to comprehend to whom and to what managers really pay attention (Mitchell et al., 1997).

The whole art of stakeholder management is, therefore, to fulfil the critical stakeholders' objectives and keep a relatively high satisfaction level of remaining stakeholders. According to Carroll (1991), it seems that this "win-win" scenario is almost impossible to achieve, hence, it constitutes a big, long-term oriented and a worth-pursuing challenge for the company management. Mitchell et al. (1997) indicate that stakeholder theory has to stand at the same time for power, urgency and legitimacy. Only with that, management can act in accordance with legal and moral interests of legitimate stakeholders.

A conclusion from the stakeholder theory is that it may serve as a valuable framework comprised of rules and norms referring to the nature of relationships between actors who are essential for the firm's success (Tullberg, 2013).

2.2.2. Sustainable development

The concept of the sustainable development was defined in 1987 within the works of *The World Commission on Environment and Development* as follows: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition includes two ideas concerning needs and limitations. First of all, there are the needs of the world's poor, to which the overriding priority should be assigned. Secondly, there are limitations imposed by the current state of technology and social organization on the environment's ability to meet present and future needs (Report of the World Commission on Environment and Development: Our Common Future, 1987). The sustainable development is, by nature, a process, not a state. Therefore, there is a need for creating the strategies for its implementation within various areas of human economic activities. These changes should be introduced jointly by the states, self-governmental organizations and industries.

2.2.2.1. Environment, economy and society

The continuing uncontrolled growth of the industrial civilization all over the world has placed an enormous burden upon the environment that may result in a global environmental catastrophe. On the other hand, the same phenomenon has contributed to establishing the concept of the sustainable development that aims at directing and organizing the economic development in the way that will trigger neither tensions among the societies nor environmental crises. The idea of the sustainable development is commonly understood as undertaking any economic activities, shaping the environment, using its potential and organizing the social life, so that they ensure the dynamic development of high-quality production processes, management systems, durable usage of environmental resources, improvement (in the initial period) and preserving the life quality for humans (individuals, families and societies) (Poskrobko, 2007). This approach stresses the necessity for preserving the balance within the macro-system consisting of three main elements: environment, economy and society.

The environment is a very specific system that is able to the self-reproduction and covers many different levels: molecular, subcellular, cellular, tissual, visceral, systemic, organismic, populational, species, biocenosis and biospheric. All these levels are subject to the influence exerted by the humans. Taking into account the current advancements in science, it is possible to influence all the aforementioned levels. Nevertheless, each change entails other changes that are not always desirable and controllable. The goal of the environment management is to counteract undesirable effects on all the levels by stimulating or preventing the anthropogenic effects on the environment. The environment is an element that evolves very slowly. However, there is a possibility to influence some changes by slowing or accelerating certain processes.

In comparison to the environment, the economy develops very fast. The concept of the sustainable development does not aim at reduction of the pace at which the economy develops, but at reducing the pressure on the environment induced by the controllable economic development. The actions in this area should address the following questions: the reduction of energy- and resources-intensive processes within the economy, increasing the economic effectiveness and continuous adjustments towards pro-environmental technologies, goods and services.

The society develops as well, but its development is heavily impacted by both the environment and the economy. Therefore, to some extent, it can be controlled. From the perspective of the environmental protection, there are certain social aspects that play an important role when it comes to the environmental protection. These include: the present norms and values, both in their cultural and ethical dimensions, the currently highly-regarded philosophy and religion, the promoted political ideas and the state of human knowledge concerning the environment, technology and humanities. All these aspects are interconnected and directly influence the environmental ethics, starting from the individuals and resulting in the general environmental awareness of the whole societies. In turn, this awareness may translate either directly into pro-environmental actions, or indirectly into support of activities aiming at environmental protection. Increasing the environmental knowledge, imagination and awareness among the members of the society is of critical importance when it comes to the effective implementation of the sustainable development.

The sustainable development of these three elements can be influenced by shaping three types of order: the environmental order, the economic order and the social order. The environmental order is shaped by humans' actions impacting the natural processes within the environment. The economic order is shaped on the given territory ranging from small districts to the entire world. The social order is seen as an organization of the social life within the given society (Borys, 2011).

The general conclusion is that the concept of the sustainable development is about ensuring the development of the economy and society while maintaining the environmental fundaments of humans' existence, so that they resemble these that have been naturally shaped within the natural evolution. The aim of this policy is to ensure the high quality of human life that is not only measured by the consumption of goods and services provided by humans, but also by the well-being of the natural environment. From that point of view, the life quality is the level of economic development, the effectiveness of it, the awareness and knowledge of the societies and the quality of environment measured by its biodiversity and productivity. Last, but not least, the striving for the sustainable development shall take place on many levels, starting from the individuals and single companies and ending with national, international and global bodies.

The idea of green chemistry focuses on preventing the pollution at the molecular level taking into account chemical substances (materials). The logical addition to this should be the concept of clean technologies that, in turn, focuses on processes. These clean technologies constitute steps that are taken in order to either reduce, or eliminate the production of any pollution. The clean technologies shall possess the following features (Kołtuniewicz, 2014): conservation of raw materials, optimization of production processes, rational use of raw materials, rational use of energy, rational use of water, disposal of recycling of unavoidable waste, accident prevention, risk management to prevent major pollution and restoring sites. The concept of green technologies is perceived as implementation of the idea of the sustainable development. Application of clean technologies creates a chance for the improvement of the natural environment by separation techniques for removing, recovering, reusing or recycling various materials.

Integration of the sustainable development policy with industrial policy in practice usually results in restructuring the industries, introducing modern technologies and economizing on raw materials. Entrepreneurs undertake action connected with modernizing productive process as well as investing in environmental protection. These ventures are aimed at increasing the production efficiency, limiting emissions of pollution and decreasing ecological charges. Industry is a sector of the economy in which it is possible to introduce rules of the sustainable development to decrease external costs. Within a free market economy, the implementation of the sustainable development policy seems to be feasible. Yet, there is a necessity to integrate the policy for the sustainable development with industry policies. Economic measures undertaken within the sustainable development policy have influence on optimization of production processes, use of raw materials, other materials and thus shape the costs incurred by the industry. Compliance with the sustainable development rules within industry aims at reducing the negative impact on the environment. The restructuration of the industry, the implementation of new technologies and effective management contribute to further reduction of the negative influence on the environment.

The analysis of the sustainable development concept results in four possible business models to be adopted by business (Stawicka, 2017):

1) Social: significant undertakings come from the companies advocating for the positive impact on society and creating the value not only through financial, but also through social and environmental goals;

2) Lean: the key issue for the future is the capability to optimize the use of various resources and capital: financial, intellectual, social and natural;

3) Integrated: the companies search for common values within different economic, social and environmental systems;

4) Circular: enduring advantages are more likely to be sustained by the companies that concentrate on products manufactured using the resources acquired in a sustainable way.

These aforementioned business models draw the attention to the legitimacy of performing business activities in a way that is responsible from the environmental, economic, and social point of view which mirrors the concept of the *triple bottom line* (*TBL*), coined by John Elkington in the 1990s, i.e. aiming at simultaneous creation of ecological, economic, and social value while pursuing economic activities. Sometimes the concept is referred to as *3 Ps* (standing for: planet, profit, people) or *triple value adding*. In simple terms, triple bottom line can be understood as “programs, policies, or activities designed to create or retain jobs and wealth in ways that contribute to environmental, social, and economic well-being over time” (Hammer & Pivo 2016). The difference between the concept of *triple bottom line* and *economic growth/development* is that the first one entails contribution to the overall well-being covering such ideas as: quality of life, fiscal health, resource stewardship and resilience. It suggests that the environmental, economic and human well-being must be taken into consideration while designing and evaluating economic development efforts. Thus, by taking into account environmental, economic and social factors, the concept of *triple bottom line* provides a framework. The joined efforts in this aspect are also in line with the sustainable development guidelines, in particular with the idea of creating a resilient infrastructure, promoting inclusive and sustainable industrialisation and fostering innovation (Wysokińska, 2017).

3. The model

Taking into consideration the described notions of both the sustainable development and stakeholder theory, the model for space-debris related sector has been devised.

3.1. Space stakeholders

Space industry becomes more and more important for modern societies. It is evident that due to services provided by space systems, notably the application of satellite technology in navigation, communication, remote sensing or the Earth observation, space industry is flourishing and simultaneously affecting our daily life in a considerable way. Space systems play also an increasingly important role for other industries and are the source of economic growth and innovation.

The progressive development of commercial space activity is currently a pertinent issue and, in upcoming years, will pose major implications for all space industry stakeholders. According to NASA reports, there are many emerging companies, not directly connected with space exploration, but, for instance, the ones that operate in supplier, component and service segments. Therefore, the notion of space debris is a concern that has to be considered from the viewpoint of different actors, including public authorities but also private, emerging companies that are recently ruffling the whole space sector.

Taking into account the magnitude of space industry, it is vital to investigate the space stakeholders, identify them and look closer at occurring interactions within the space ecosystem.

3.2. Space stakeholders characteristics

- *Governments*: Space economy can be described by distinctive characteristics as the use of state-of-the-art technologies and time-consuming project development and return on investment. Stated that, it is evident that governments will have the biggest dominance in space sector, which is due to financial requirements, risk bearing and access to vast user market. Governments entail the defence branch which is, in turn, inherent in space activities since the Cold War. Undoubtedly, such situation also results from prominent use of space for defence. Government’s dominance comes from being the biggest customer of space-related products and services. Space investments are substantial contribution to economic development and strategy, but also to national prestige.
- *National Agencies*: In 2017, the number of national space agencies amounted to 71 public entities, what shows growing interest in space activities. These organisations usually gather under the auspices of ESA or NASA to pursue economic, political and scientific goals, for instance, NSC in Norway, JAXA in Japan, CNES in France.
- *International Institutions*: The space sector has been developing over years around two most prominent institutions, namely NASA (since 1958) executing efforts implemented by US government, and ESA (created in 1975 in Paris) mostly concentrating on European states. These two institutions frequently collaborate on scientific space research and gather numerous national agencies for the common purpose.
- *Insurance companies*: These are a crucial stakeholder because there is a considerable risk connected to the space missions and insurance premium

amounts to the price of a launch itself. Insurance applies to the satellite coverage and ground risk coverage (for instance Allianz, XL Catlin).

- ❑ *Research laboratories*: Research is of the utmost importance for space exploration and, among many other activities, includes placing relevant payload in areas from deep space to Low Earth Orbit (LEO). Research bodies can be equally space agencies, like ESA or NASA, but also ISS - International Space Station.
- ❑ *Operators with final customers*: Entities that actually make economic use out of the launched satellites. Some players in that group of stakeholders are Fixed Satellite Service Operators like Intelsat (Luxembourg/US), Eutelsat (France), SES Global or Telenor.
- ❑ *Launch Operators*: Their activities are heavily dependent on financing from the side of governments. The most renowned launch operators comprise Arianespace (France), SpaceX (US) or Space Systems Loral
- ❑ *Equipment manufacturers*: These companies are concentrated on production of systems, subsystems or components for spacecrafts and can be numerous depending on the size of components, usually originating in the US - Clyde Space, Rocketstar Robotics Inc., but also elsewhere like SatRevolution S.A. (Poland) manufacturing propulsion and various satellite modules, Kongsberg Defence & Space (Norway) producing electronics and rotation mechanisms.
- ❑ *Satellite manufacturers*: Stakeholders that are specialising in delivering the final product. Here, again, the pioneers originate in the US (manufacturers like Boeing or Lockheed-Martin) and European market is dominated by products delivered by Airbus Defence & Space and Thales Alenia Space. Satellite manufacturers are huge companies possessing superior power and financial resources. Along with commercial development of space domain, the trend of miniaturisation, locating in space low-cost constellations, new manufacturers are of growing importance. Satellite manufacturing and the competition arrangement are changing because of new stakeholders like SpaceX, Blue Origin or Google.

3.3. Interferences among space stakeholders

As enumerated in the list above, one could observe that the largest group of stakeholders consist of governments and space agencies. Despite the unprecedented growth of commercial space industry, the application of space services in the defence, that also adheres to the government, still prevails. That also results from dual use of space technologies that can be applied for civil and military purposes, namely weather forecasting also used for prior warnings or remote sensing. Therefore, governments with defence sector create major demand for space products. As Baudet et al. (2016) indicated in their research, space agencies possess unique know-how and technical expertise that are also explicit in their long-term orientation. They can also, along with international institutions, impact governments and, because of their size and number, they can work towards common goals. On the other hand, governments have at their disposal considerable financial resources and power to enforce desired space programs. Not to omit the research entities that usually conduct joint activities with national agencies in order to propagate the knowledge, progress and innovation within the framework of a project. R&D programmes are, in turn, vastly supported by public investments. Stakeholders associated with manufacturing capabilities, satellite and equipment producers, but also launch operators are in possession of necessary knowledge and technical expertise to accelerate the development of space activities.

3.4. Legal support for space stakeholders

The interaction within that highly complex, fragmented and international industry would not be possible without proper legal framework. According to UNOOSA (United Nations Office for Outer Space Affairs) space law contains a variety of international agreements, treaties, conventions, as any other international law. In 2017, Outer Space Treaty, a document that constitutes the basis of the international space law, had 107 signatories. The issue of space debris was addressed in 2007 by the UN COPUOS (United Nations Committee on the Peaceful Uses of Outer Space) and major space agencies (NASA and ESA) have own guidelines for space-debris mitigation. Common approach can be viewed through the intergovernmental forum for dealing with orbital debris, namely Inter-Agency Space Debris Coordination Committee (IADC, founded in 1993). According to the recent report of ESA (2017), “the 13-member IADC is the most prominent body for information exchange on space debris”. International Organisation for Standardization (ISO) also strives for coordination of efforts towards space junk mitigation by providing since 2003 the Orbital Debris Co-ordination Working Group (ODCWG).

Looking at the space industry in the big perspective, we can observe that manufacturing, launch and equipment manufacturers usually are associated with relatively low margins. That goes in pair with the fact that potential customers have rather low-cost objectives. Considerable margins are indeed inherent in the potential application of space services, being the industry’s fastest-growing sector. Companies providing space-related services are normally not directly connected to the space domain, but through the use of space data, signals and satellite capacities, those firm provide customers with facilities related to location based services, communication, satellite television, geospatial field and many other value-added services.

3.5. Space stakeholders and stakeholder theory

Space debris cleanup is a very complicated activity mainly because of the financial and technical challenges which are particularly difficult to overcome in the short period. On the top of those issues there are challenges related to ownership, policy and responsibility. These aspects are inherently associated with space stakeholders.

Stakeholder theory assumes the existence of different actors that are characterized by particular interests. Even if the reference point is the company to which stakeholders relate, we can observe that the concept of the stakeholder theory could be, to some extent, applicable in the context of space debris as similar dependencies occur. As indicated above, space junk is the phenomenon that affects not only one party, but multiple parties. And following the logic of stakeholder theory, each space stakeholder might possess different approach and interests regarding orbital debris.

We may observe that entities that will probably be the most interested in the space cleanup will be governments, as they also possess financial means and power to do so. Those institutions are more inclined to have a long-lasting stake in space activity with regard to massive investments that space industry requires while not relying on profitability. Government, as a stakeholder, has a legitimacy to support efforts to remove space-debris and, because of the access to the whole market, it can promote debris-removal initiatives. Due to their political power, governments may also alleviate main obstacles, like policy and ownership issues. On the other hand, as long as space debris is only a little threatening concern, companies such as satellite and equipment manufacturers will be concentrated on their day-to-day business and selling their products, rather than sustainable protection and development of the outer space. Hence, there is an urgent need to provide incentives for manufacturers, so that they may be willing to, with their extensive technical expertise, support the development of debris-removal techniques.

The academic framework that we try to apply into the problem of orbital junk seems to address also the stakes of the general public. According to the theory, that group is very dispersed, lacking organisation and, thus, not having the attribute of power. However, having in mind the Kessler scenario, once debris collide and cause serious damage to functioning satellites, general public will be significantly affected, as it is the main recipient of broadcasting services, telecommunication or GPS. What if these services, in the worst-case scenario, were to disappear suddenly?

The question that could reveal the approach of space stakeholders is related to what is the acceptable level of risk connected to space debris for each stakeholder group? Based on available literature, one could state that it is evident that “orbital debris does not at present pose a great-enough risk to warrant the deployment of a remediation technology” (Baiocchi et al., 2010). However, current stakeholders are rather aware of the risks that space debris entails. The problem is rooted in lack of financing from the side of governments and private actors. That is due to the perceived risks which apparently did not reach the threshold that would activate the urgency for remediation measures. It is, thus, highly probable that diverse stakeholders will support the remediation measures for space-debris removal when it reaches the level of the unacceptable risk.

The outcome of the stakeholder theory in regard to space-junk threat is that there is a pertinence of ongoing institutional awareness of the problem within the whole space community, not only the affected, or so called ‘primary’ stakeholders. The theory implies the need of solutions to the space-debris issue that have a long-lasting impact and engage actors on international level. Only by cooperating towards a common goal, and merging interests of public and private stakeholders, the space industry can work out the way of preventing the aggravation of the space-debris issue.

3.6. Sustainability in the context of space debris

As space is becoming congested with space debris, our generation must take actions in order to preserve it for the generations to come. Therefore, the actions in order to handle the issue of space debris should be taken because of the reasons boiling down two three aspects:

- <u>*Environmental*</u>

Space-debris items are of anthropogenic origin. Therefore, they create pollution both in space and on the Earth (when not burnt in the atmosphere during the re-enter) that can have adverse effect on the living organisms, both flora and fauna. The imperative for the space-faring countries should be disposal or recycling the waste. Compliance with the sustainable development rules within the space industry aims at reducing the negative impact on the environment. The restructuration of the industry, the implementation of new technologies and effective management can contribute to further reduction of the negative influence on the environment.

- *Economic*

Space-debris items pose also a threat to the further economic growth of businesses and, thus, economies. The lack of space industry’s engagement in the support of space-debris removal activities, in the extreme case, may result in space being unsuitable for further exploration to the detriment of different economic activities based on the data or capacities provided by the satellites: e.g. GPS, weather forecast, surveillance, telecommunication, TV networks, etc.

- Social

Should the space activities be impaired because of the space-debris items and should a substitute technology not exist, the standard of living will decrease dramatically. Moreover, it is crucial to increase the environmental knowledge, imagination and awareness among the members of the society when it comes to the necessity for space-debris removal. This could result in planning and partnership activities that would be integrated with the social values and inclusive for all the members of the society.

The most desirable results of the implementation of these guidelines would be a business model that is social (creation of value through environmental and social goals, not only financial), lean (optimized in terms of resources), integrated (planet, financial, people’s needs are considered jointly) and circular (the resources are recycled as much as possible).

4. Results

Taking into account both the empirical and theoretical frameworks, the concept of public-private partnership has emerged as a way to support development of ADR solutions.The following chapter provides the characteristics of the public-private partnership (PPP) as a framework for cooperation between the government and private sector.

4.1. Private and public benefits and interests

Certain private undertakings are extremely difficult to accomplish without the support from the side of public actors. Simultaneously, public entities sometimes lack the creativity or technological expertise of the private firms. In the light of the above, it is essential to consider collaboration between public and private bodies in order to benefit from advantages possessed by each side and come up with common solutions.

Firstly, it is important to differentiate between the benefits and interests of the public and private actors. Public bodies, for instance, governments and multilateral organisations, are in possession of limited amount of resources. Additionally, their capabilities and level of reliability can differ. That is akin to private actors as well. Notwithstanding, public actors can be characterised by two major differences. The variation is manifested in different objectives. Namely public entities are aiming at maximizing public benefits (e.g. GDP per capita or sustainable development), while private actors concentrate on maximization of private benefits like firm's economic profit and long-term oriented, independent business conduct.

Moreover, public institutions usually take advantage of greater authority and legitimacy compared to the private firms. It is undoubtedly connected with monopolistic power of governments concerning policy creation and its enforcement. Generally speaking, public interest will usually have greater legitimacy over the private one (Rangan et al., 2006). According to the model elaborated by Rangan et al. (2006), the alliance between public and private sector is a suitable solution once the need for realising the economic opportunity requires very technical, specific competencies and simultaneously involves important positive externalities, namely specific private actions that result in considerable public benefit. Additionally, constructive partnership is appropriate when the problem is connected with high uncertainty on the side of private firms and entails high governance costs relating to governance function (contracting, coordinating and enforcement).

Opportunity that is directly connected with a public-private partnership is present in the fact that usually public bodies, especially governments, are considered in developed nations as reliable partners for the establishment of the PPP. However, it is vital to consider that governments may lack significant credibility because of insufficient achievements or bad political relationships. In this case, the role of public actor can be performed by multilateral organisations (for instance United Nations agencies) often possessing much more expertise and reliability than single national governments. Multilateral organisation can play numerous roles in terms of coordination, administration or being a moral watchdog - the intermediary between the market, government, and the corporate world.

4.2. Public-private partnerships - definition and advantages

Programmes of PPP provide a long-term, sustainable approach towards international challenges. The concept of PPP is present since many centuries but recently, paired with economic development, it has been applied even more intensively. There are numerous types of PPPs with varying domination of private or public actors. Basically, the PPPs are characterised as “agreed, co-operative ventures that involve at least one public and one private-sector institution as partners” (Akintoye et al., 2003). Public firms in PPP mostly take advantage of present and future profits from sales, patent royalties and the proper allocation of their resources. There is, however, the uncertainty about the net benefits.

Public-private partnerships occur in various forms. According to Taylor (2006), generally speaking, each entity taking part in the partnership comes in with an input and, at the end, derives some advantages from the cooperation. The key is to decide what and how much each participant is contributing in the partnership, thus each PPP is an exceptional undertaking.

4.3. PPP application in the space domain

Taylor (2006) underlines that partnerships in space domain vary in terms of forms, but always entail the possibility to share technology, reduce costs and encourage diverse entrepreneurs from different backgrounds to collaborate. What is more, global PPPs help to leverage governmental participation along with business support. One of the guidelines proposed in 2017 by the Committee on the Peaceful Uses of Outer Space refers to the promotion of public awareness referring to space applications by using extensive information-sharing and common efforts of public institution and non-governmental bodies. These efforts take into account sustainable development and the needs of present and future generations. The UN COPUOS puts the emphasis on the need of cooperation between multiple stakeholders, both from public and private sector.

Speaking about synergy of advantages between public and private institutions, it is appropriate to recall the issue of space exploration and efforts put in that regard by U.S. government with help of NASA. Undoubtedly, considerable future opportunities are inherent in the space exploration. Yet, that opportunity entails substantial level of uncertainty what, consequently, may undermine efforts of scientific research. Since the space domain is still immensely undiscovered, there are very few private entities that could provide extensive expertise in that regard, compared to public actors. Hence, there is a huge potential in the growth of private companies that could specialise in space business, but without significant help from the side of public bodies, it seems impossible to excel in space activities. The call for partnerships in space domain is inevitable if we want to pursue research and exploration of space.

PPP may be a promising opportunity in heterogeneous industries where there is a considerable cost of coordination between different stakeholders, which seems like the case of the space industry. Despite huge cost for public entities for such coordination, the public benefit resulting from that activity surpasses all incurred costs.

4.4. NASA and Swiss Space Center efforts towards public-private partnerships

Striving for public-private partnerships has already been pursued by NASA since the launch of the Commercial Orbital Transportation Services (COTS) program in 2006. Later on, in 2014, NASA announced the initiative with regard to cooperation with private entities, the so called Collaborations for Commercial Space Capabilities Agreement (CCSC). Main purpose was to improve private sector development referring to integrated space capabilities and make the emerging products and services commercially accessible for government and non-government clients within the short time frame. NASA's aim is to share with private firms its facilities, its manpower's technical expertise, its robust experience gathered during more than 50 years of spaceflight and grant the access to all the 'lessons learned'. In turn, NASA anticipates to benefit from private firms' creativity and financial resources, so that new business opportunities can be derived from space.

Resulting from the above deliberations on space debris, it is clear that something has to be done in order to hamper the possible negative implications of orbital junk for the outer space. Current situation can be mitigated through the discussed active debris removal (ADR) techniques. Since it is related to waste management on the Earth, space cleanup is an issue pertaining to public and private sectors. Given that, a creation of public-private partnership seems to be a viable solution to foster ADR implementation. Emanuelli et al. (2014) claim that PPP in that regard can be economically sustainable and enable creation of relevant standards and best practices. An example of a feasible PPP addressing active debris removal is the Clean Space One project proposed by Swiss Space Center (Fig. 8). The case study aimed at demonstrating possible technologies for debris removal missions of small satellites. Swiss Space Center (SSC) came to the conclusion that the phenomenon of orbital junk is too complex to be tackled by either public or private entities. According to SSC, PPP is the right way to proceed within active debris removal projects. It is worth mentioning that the Swiss Space Center is directly linked to the Vice-Presidency for Academic Affairs of the Ecole Polytechnique Fédérale de Lausanne and has numerous connections with industries and academic institutions. Common efforts of these entities resulted in the program for development of technologies for nano-satellites aiming at orbiting debris removal and Clean Space One is one of the projects. Additionally, Switzerland not being a space-faring nation, is renowned for responsibility, peace-promotion or rule of law. Given that, Swiss initiative for ADR could address simultaneously the notions of security and perplexing legal environment - one of the aspects that pose major obstacles for debris removal advancement.

5. Conclusion

For many years, the space community has been putting off the actions towards finding a solution to the issue of space debris. Never before has been more evident that the space cannot be exploited without limits. The orbital debris floating around in space poses a threat not only to operating satellites and further exploration of space, but also endanger human lives and the natural environment on the Earth. The existing vicious circle suggested by Kessler urges the international community to take action and advocate for the responsible use of space and universal observance of sustainability principles by all space stakeholders. It is even more important in the light of the advancements in technology enabling the growing number of microsatellites to be launched in the space.

The issue of space-debris removal is heavily dependent on technical, economic, political and legal barriers preventing the development, the deployment and the removal of space debris. As ADR solutions usually rely on the state-of-the art technology that is often, at least to some extent, unproven, such projects require a lot of financial and human capital. Thus, the significant costs of developing ADR solutions are unlikely to be incurred by a single actor. In addition, the very objective of space-debris removal shares the characteristics of a public good and a service provided by a private sector. Therefore, a public-private partnership seems to be a viable solution to the problem of space debris. Such an international partnership based on cooperation could also drive the creation of the appropriate regulations, standards and best practices in the sector. As the governmental bodies possess both legitimacy and power in terms of political and economic capacity, they should serve as a trigger for such public-private partnerships bringing together proven solutions and innovations. Such partnerships should have a clearly defined vision, realistic assumptions and capacity not only to operate in changing conditions, but also to quickly respond to emerging opportunities. Thanks to the extensive collaboration, PPPs should be able to pool ideas and resources that, when combined, enable bigger impacts, cost effectiveness and, at the end, bring the desired results, namely: development of sustainable ADR solutions coupled with best practices aimed at reduction of any potential sources of space-debris already in the very design stage of any space infrastructure or mission.

However, in order to provide a consistent and reliable framework fostering public-private partnerships, there are some steps that should be taken. First of all, there is a need to formally agree on a legal status of space debris. Moreover, the public-related stakeholders should provide considerable incentives for the private companies that either proactively use technologies causing less waste, or work on ADR solutions. Furthermore, cooperation involves also sharing knowledge and expertise that can be used both for more accurate tracking of space debris and performing ADR. Last, but not least, it is important to educate and to raise awareness of the space debris among all the stakeholders, all being a part of the triangle encompassing environmental, economic and social spheres. Should the industry disregard the importance of the threats posed by space debris, the consequences would be to the detriment not only of the space-related industries, but to the world’s economies that, not always knowingly, take advantage of the space-derived resources on a daily basis.

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Appendix

Size	Potential risks	Detection	Number	Mass fraction (%)
>10	Complete destruction	Tracked	21 000	>95%
1-10	Partial/total destruction	Partially tracked	500 000	<5%
<1	Damage, can be shielded	Not tracked, statically assessed	>1000 million	-

Fig. 1: Space debris classification (Emanueli, 2014)

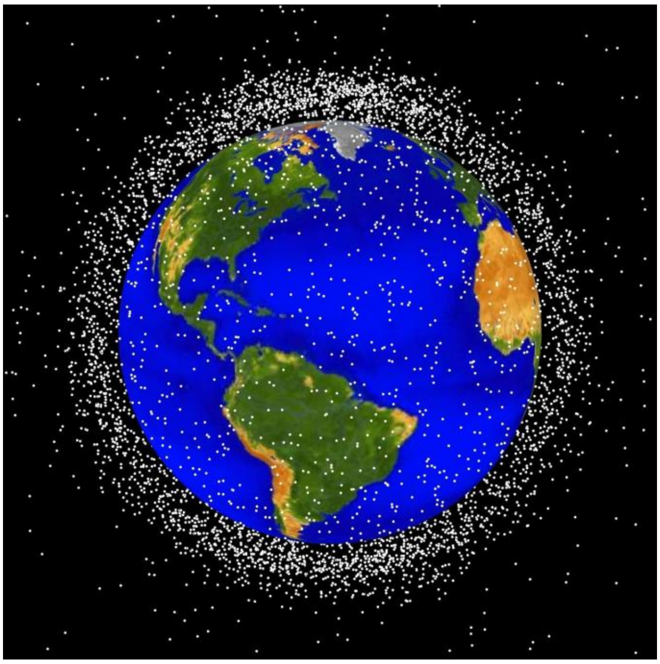


Fig. 2: The graphic is generated by computer and depicts objects in Earth orbit that are currently being tracked. Around 95% of these objects are space debris. The space debris dots are scaled according to the image size of the graphic to optimize their visibility and are not scaled to Earth (Source: https://orbitaldebris.jsc.nasa.gov/photo-gallery.html).

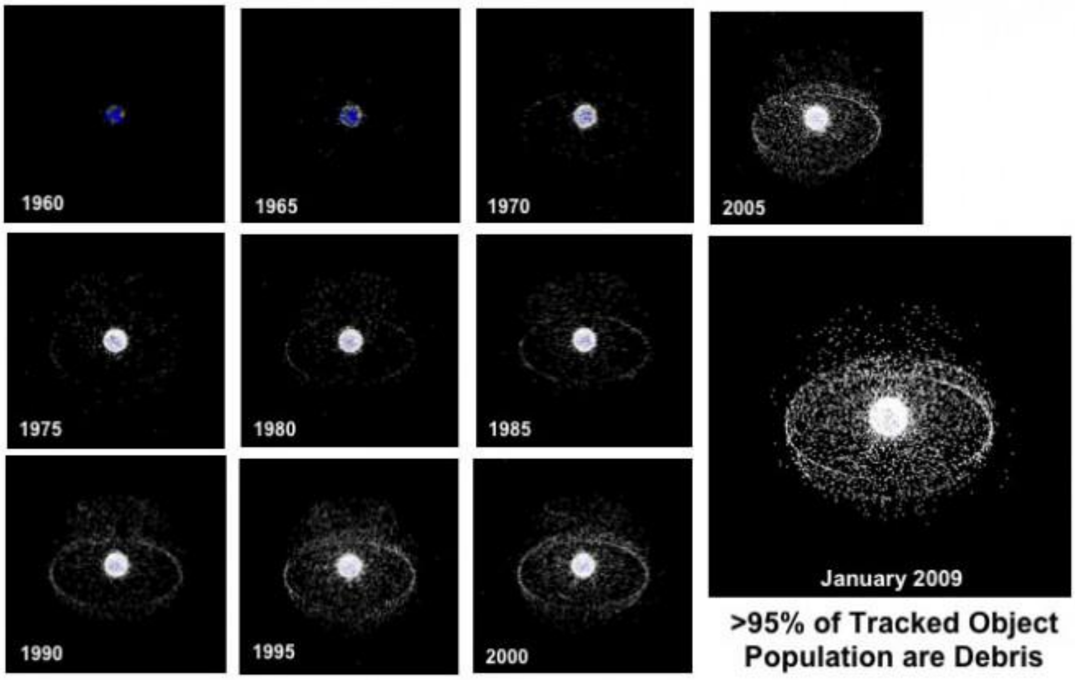


Fig. 3: The growing population of satellites
(Source: https://www.wired.com/images_blogs/wiredscience/2009/04/nasa-space-debris.jpg).

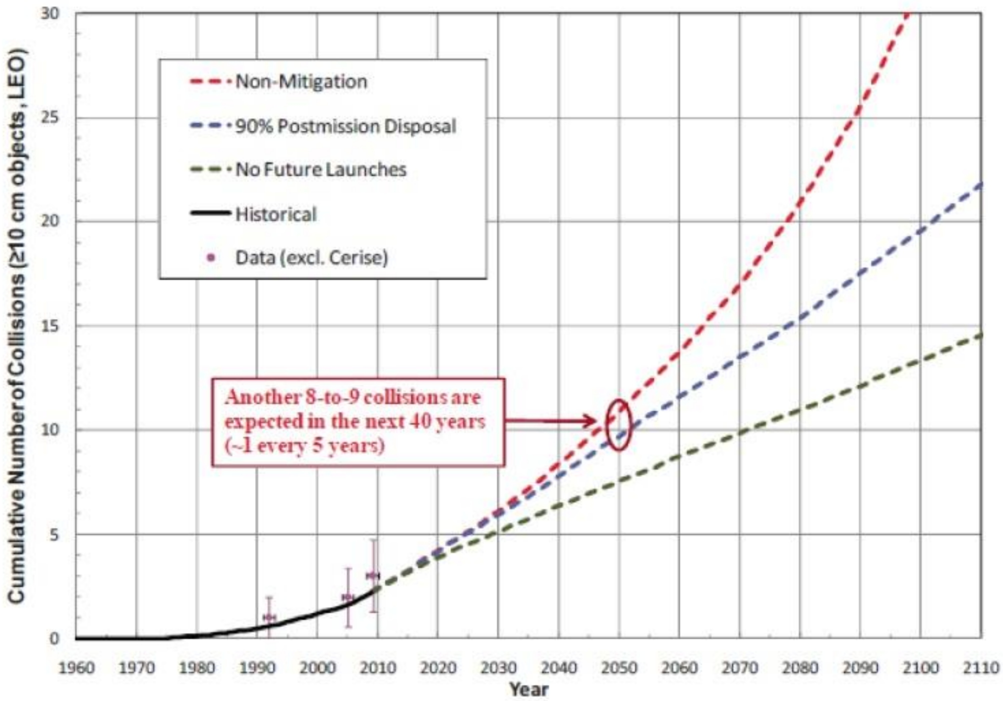


Fig. 4: The graph depicts cumulative number of accidental collisions with objects > 10 cm in LEO to be expected over the next decades under different circumstances: mitigation measures not applied (red), mitigation measures applied (blue) and no future satellite launches (green) (The Parliamentary Office of Science and Technology, 2010).

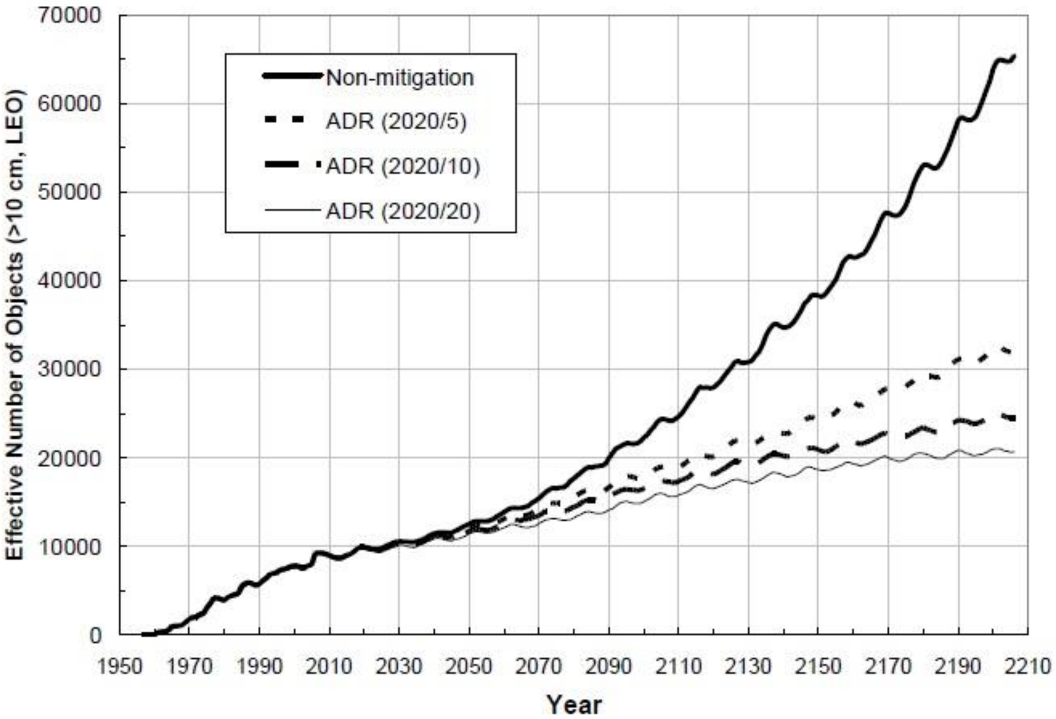
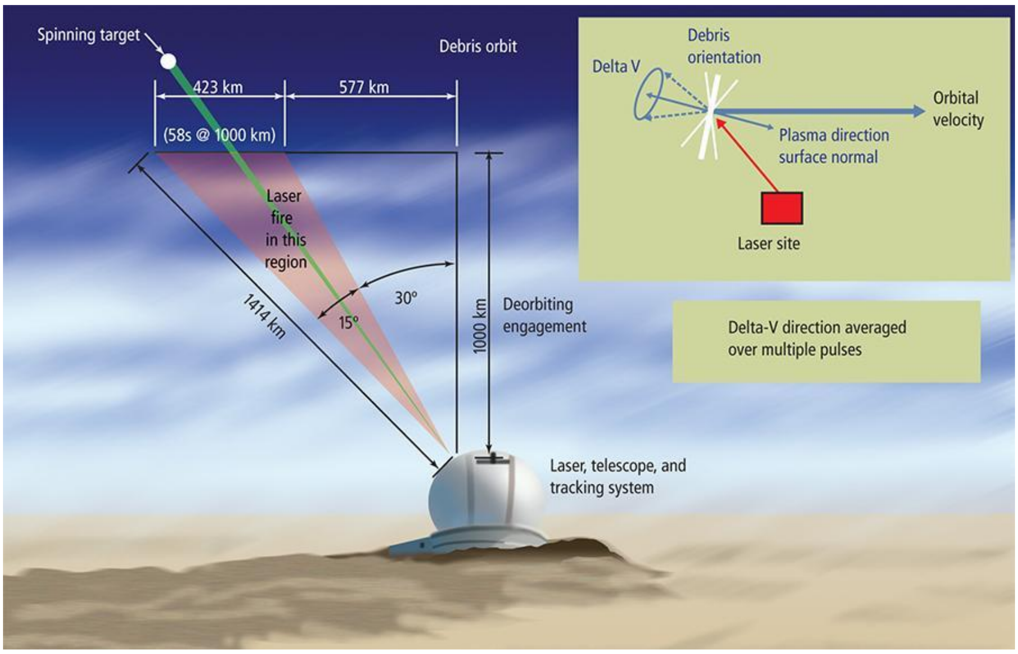


Fig. 5: A simulated LEO debris populations of objects >10 cm in 1957-2007 (history) and in 2007-2026 in four scenarios: non-mitigation (business as usual) and annual debris removal rates of 5, 10, and 20 space-debris items (Liou and Johnson, 2009).

Fig. 6: Some examples of the solutions used for the ADR include (Aerospace 2015 / Popular Mechanics 2012):

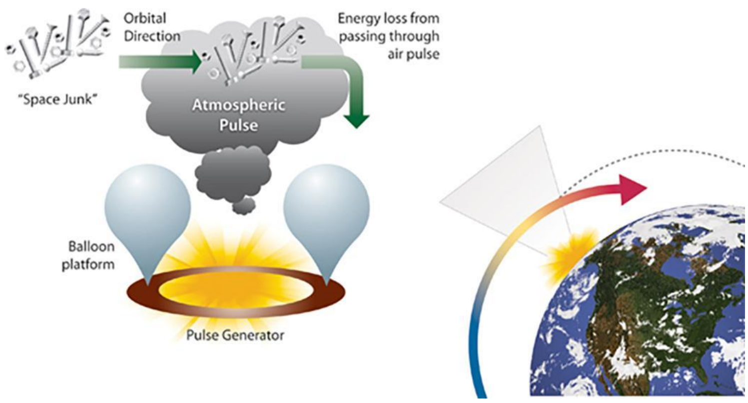
- Lasers



Source:http://aerospace.wpengine.netdna-cdn.com/wp-content/uploads/2015/11/FIg-3_Dispos-ActivDebrisRem_r2.jpg

The solution consists in vaporizing a piece of a space debris item with a laser in order to create a puff of vapour that, in turn, will generate the drag that will slow down. As a result, the item will enter the atmosphere and burn down. Lasers' advantages include lack of launch costs and propellant constraints. A medium laser would be able to get rid of small items for a few thousand dollars per item and large items for $1 million per item. However, due to the location and nature of the items it is very difficult to aim a ground-based laser and hit an object at the exact spot. Should the laser hit another working object, it can not only seriously damage it, but also create an international conflict if the hit object was launched by a different state.

- Air puffs



Source: http://www.nasa.gov/sites/default/files/thumbnails/image/niac_2011_gregory_0.jpg

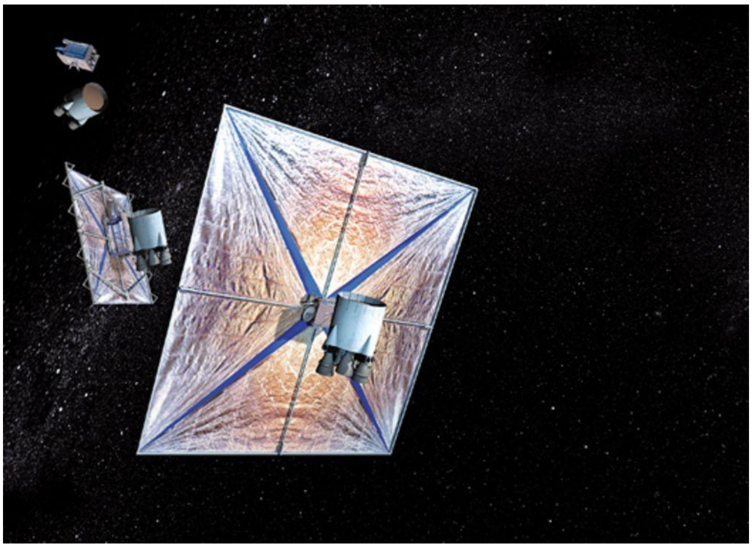
The Space Debris Elimination (SpaDE) is an idea provided by Raytheon BBN Technologies. The concept is about using blasts of air from within the Earth's atmosphere in order increase the drag and, in turn, de-orbit debris. The number of eliminated space-debris items will depend on the density thereof. The device should fall back into the atmosphere, so there should be no new space debris left behind. However, the technology may not be good enough for the large space-debris items.

- Tethers

Source: https://i2.wp.com/www.spacesafetymagazine.com/wp-content/uploads/2012/03/EDDE.jpg

The ElectroDynamic Debris Eliminator (EDDE) developed by Star Technology and Research. The device aims at capturing the space-debris items in a big net. The particular advantage of the project is that the life span of the device is not limited by the fuel. It is possible because the EDDE does not use liquid fuel, but a conducting wire that generates electrical energy as it moves in the Earth's magnetic fields. Therefore, the life of the device could be indefinite as it captures space-debris items in a net, delivers them into the Earth's atmosphere and, then, comes back for the new space-debris items. In order to remove one object, the device needs around 10 days, so one device could remove yearly around 36 objects. One such vehicle costs $5- $10 million. On the other hand, it is not economically sustainable to capture smaller space-debris items and the operation activity relies heavily on the electrodynamic wire that could be damaged and, thus, render the device useless.

- Solar sails



Source:https://www.popsci.com/sites/popsci.com/files/styles/1000_1x_/public/import/2013/images/2010/07/solarsails.jpg?itok=clFUxrUg

The idea consists in using solar sails as parachutes that could pull the space-debris items from the orbit. A vehicle could attach solar sails to the space-debris items. The sail will create additional drag by unfurling and, thus, slow down the space-debris items causing them to fall into the Earth's atmosphere. However, should it not burn during the re-entry, it might be difficult to control the place where it falls on the Earth.

The ideal ADR system should possess some necessary characteristics from technical, economic, political, and legal point of view. When it comes to technical aspects, the system should be easy to operate and reliable in terms of operational activity and proven technologies used to create it. Moreover, it should introduce no new space-debris into the orbit. The economic concerns boil down to the cost-to-benefit ratio, so the system provides a considerable improvement for a reasonable cost. On the political level, such system should be transparent, so it could be trusted by the space-faring countries. Last, but not least, the system should comply with the any existing and future international regulations concerning the space activities.

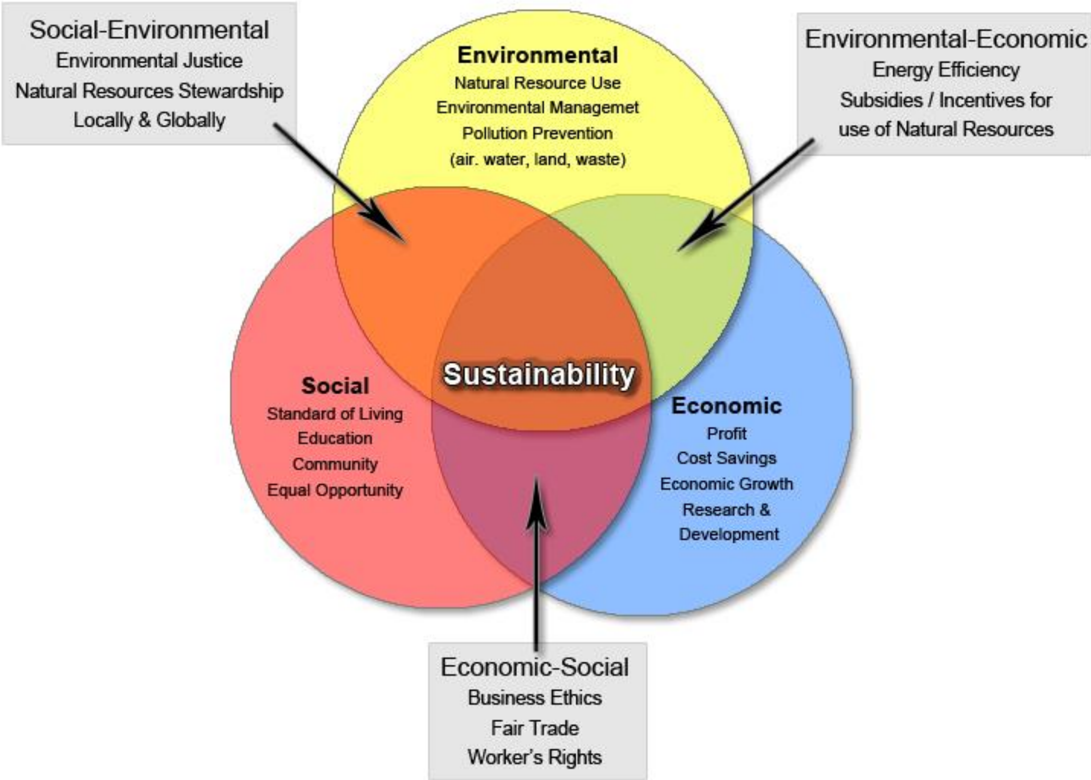
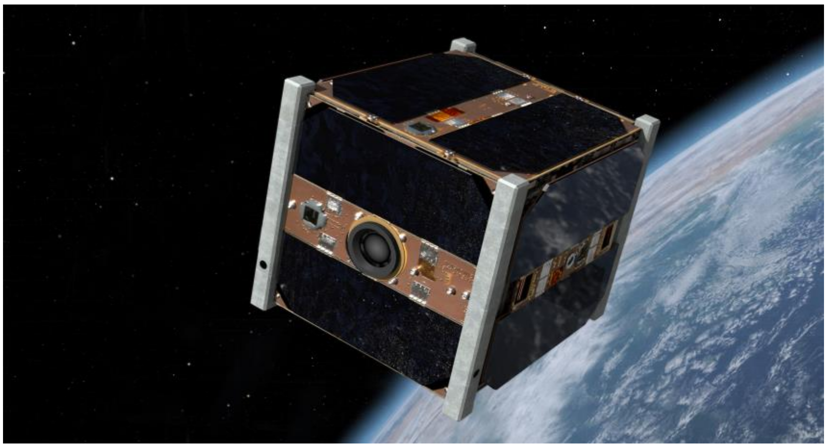


Fig. 7: The interrelationships between three dimensions of sustainability
(Source: https://www.vanderbilt.edu/sustainvu/wpcontent/uploads/sites/69/sustainability_spheres.png)

Fig. 8: The Swiss cleanup satellite
(Source: http://www.leonarddavid.com/wp-content/uploads/2015/07/swisscube.jpg)



The Swiss project resulted in creating a small cleanup satellite, called also “Pac-Man”, that is designed to capture space-debris items. Once the SwissCube is in orbit, a tiny ion engine will power this small satellite. As it approaches its target, its tendrils will unfurl from inside the device and, with some help of pressure sensors and artificial muscle-like mechanism, will grab a space-debris item. Subsequently, the satellite will destroy it in the Earth’s atmosphere. As the cleanup satellites burn as well, the advantage of the project is that the equipment does not become a space-debris item itself. However, there are also some disadvantages such as: small size of the potentially captured space-debris item, high mission costs, and inability to retrieve the cleanup satellite and use it multiple times. The Swiss scientists are currently working on these challenging issues.