Master's Thesis –
Master Innovation Sciences

"Transition towards sustainable space exploration: the case of the space debris industry"

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Summary

During the 20th-century, few crucial governments, such as Russia and the United States (US), led the space exploration; thus, all the activities, policies, and fundings were influenced by governmental interests. However, the closer to the 2000s we have become, the more actors have joined space exploration, sending more spacecraft of all types to orbit, often leaving debris behind without any international regulation on cleaning up. Before that, goals for the space field were mostly mission-oriented and, thus, based on centralized governance of individual nations (for instance, sending a man to the moon), but with the appearance of private companies and catching-up countries to participate in space exploration, the role of crucial players changed, and question on diversification has risen. Thus, the space industry has faced social and technical challenges that have to be responded to by a socio-technical transition. To understand how this transition is developing and how it could be done better, we focus on the space sector's socio-technical characteristics and evolution.

Therefore, to perform the research, this study draws on transition and mission-oriented policy literature. To track the industry's development, we apply the Socio-Technical-Network-Analyses (STNA) framework, which allows us to depict the story-line. The analyzed database consisted of 289 articles discussing space debris from 2007 to 2019 to trace essential events affecting the industry. Specific policy recommendations and insights into legitimation processes in the space sector are provided.

List of Abbreviations

ADR	Active Debris Removal
ASAT	Anti-satellite
DNA	Discourse Network Analysis
DOC	Department of Commerce
DOT	Department of Transportation
DOD	Department of Defence
ESA	European Space Agency
EUSO	European Union Science Olympiad
FAA	Federal Aviation Association
FCC	Federal Communications Commission
GPS	Global Positioning System
ISS	International Space Station
LEO	Low Earth Orbit
MLP	Multi-level perspective
MP	Mitigation Practices
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
PPP	Private Public Partnership
R&D	Research and Development
SSA	Space Situational Awareness
STM	Space Traffic Management
SWF	Secure World Foundation
TIS	Technological Innovation System
TM	Traffic Management
US	The United States

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1. Introduction

Space attracts us not only for its mystery and for opportunities it brings in terms of research and development but also for economic value. But in the race for profits, we often forget about sustainability, and space is not an exception. Space sustainability following the definition proposed by Secure World Foundation “...is the ability of all humanity to continue to use outer space for peaceful purposes and socioeconomic benefit over the long term”. Once we started exploring and using space, we began to abuse it, polluting with debris. The history of the relationship between humans and space debris started as far as 1957, with the first satellite being launched into orbit (ESA, 2020). Since then, the debris population has been continuously growing, albeit not at an alarming rate until we entered the 21st century. The closer to the 2000s we have come, the more actors joined space exploration, sending more spacecraft of all types into orbit, often leaving debris behind without any international regulations on cleaning it up. Finally, space has become a junkyard filled with millions of garbage pieces flying in Low Earth Orbit (LEO) (NASA, 2020). Most of this orbital debris comprises human-made objects such as pieces of spacecraft, tiny flecks of paint from spacecraft, parts of rockets, satellites that are no longer operating, and many others. Unfortunately, over the last two decades, the space debris population has increased exponentially and has become a real hazard for people on earth, space missions, and operating spacecraft, causing substantial financial losses for space users. Space users worldwide seek cost-effective technology in response to garbage challenges as experts say that the more we wait, the more we will pay in the future. Despite wide acceptance of the need for active debris removal nowadays, such technology is still absent as research in space is complicated, expensive and involves many actors from private projects to governmental entities. In the last two decades, debates on the space debris issue and, thus, how to respond to it have grown, raising questions of a proper policy, guidance, and technological approach. Therefore, this research aims to analyze the perceived challenges and strategies for tackling the increasing problem of space debris.

Many reasons caused significant growth in the debris population over the last 15 years, but most importantly, two tragic events happened in 2007 and 2009, which increased the amount of debris by at least 30 percent (ESA, 2014). The first event occurred on January 11, 2007, during the Chinese anti-satellite ground-based ASAT system test. As the experiment's outcome, the Chinese Fengyun-1C satellite was blown-up, having produced 150,000 pieces of debris (BBC, 2012). The second event is the accidental collision of the Russian "Cosmos 2251" and American "Iridium" satellites. This collision produced more than 2,000 new objects bigger than a softball, most of which will remain in orbit for decades (ESA, 2020). Another vital stream that influenced the space industry's discussion is an increased interest in satellite constellations over the last years. Starlink, OneWeb, and many others have already sent hundreds of satellites for global internet constellations, and soon thousands more are planned.

In the last two decades, some attempts of "greening" the space sector have been made. For instance, private companies such as SpaceX start to apply different disposal rules to ensure that their satellites will be removed from orbit once not needed anymore. But during the previous phase, when the space sector was driven solely by governments, the question of cleaning space remained complementary to primary goals; thus, being judged a preferable addition rather than a requirement. As soon as they could not meet the criteria suggested by commonly accepted guidelines, organizations ignored them. However, in recent years, the discussion on cleaning the space has grown and become explicit because private companies and less developed economies face space pollution hazards at a different scale (Weeden, 2020). With the increased competition and diversity, the demand for new technologies and improvements of old ones has also expanded to tackle the space debris problem. Technology development is not an autonomous process but rather a process that needs guidance, support, and management; therefore, the design and implementation of innovation management processes are vital in many national environmental and innovation policy programs (Hekkert et al.., 2007). Ecological problems such as climate change or sustainable space exploration and usage are proposed to be addressed only through radical, structural change, and this change is called "sustainability transition" (El Bilali, 2018). Grin et al. (2010) propose a sustainability transition as follows: "radical transformation towards a sustainable society in response to many persistent problems confronting contemporary modern societies". These transitions are one of the core challenges to the society in dealing with environmental and social impacts that are associated with systems of production and consumption (Yap & Truffer, 2019).

The goals of new entrants are often more specific and more transparent while fundings are lacking compared to incumbent players or more developed economies; therefore, some players might not be able to meet regulations followed by the US, for instance. Differences in goals, perceptions, and resources might result in different capabilities or desires to meet changing needs to operate sustainably. Thus, different technologies tend to be legitimized in different ways. The issue of a legitimation process to gain acceptance for new technology is a hot topic in innovation studies. Previous studies show that such a transition is a challenging and complicated process during which the industry has to be reconstructed and directed in a sustainable stance. Debate on how to provide guidance in such a way so all the actors of the space sector could follow the direction equally in terms of sustainable usage has raised the need for transition from the existing regime to a more sustainable one.

The influence of governmental missions and lack of awareness of debris hazard over decades led the space sector to a state where it was hard for new actors to enter, and the whole system was too slow and bureaucratic to respond to the debris challenge (ESA, 2020). The preferable approaches to fight space debris were mitigation and traffic management, which aimed to decrease the creation of new debris and avoid damage by reorganizing traffic in space, thus not directly influencing actual debris. However, increased interest of private companies, development of the industry, and exponential growth of the debris population in the last two decades resulted in an overall understanding that active debris removal is essential once we want to explore space sustainably and decrease future losses damage. Nevertheless, cost-effective technology that would solve the problem is lacking despite growing debates on how to achieve it. Experts say that to decrease debris removal costs, to increase competition, and to accelerate research, it is needed to attract more private players, start missions explicitly aimed at debris removal, and provide rules and guidelines that make innovation possible for lagging players. Tackling the challenge of a sustainable space exploration that involves the whole industry always brings up the question of proper policy.

Therefore, cleaning the space debris is not an isolated technological challenge but also heavily intertwined with an institutional challenge. In the past two decades, the space industry has transformed into an ecosystem with a mix of private, non-profit, and public actors (Mazzucato & Robinson, 2017) - known as the "New Space". Before that, the space sector was mainly driven by national missions due to geopolitical reasoning, thus, based on centralized governance of individual nations (for instance, the goal of sending a man to the moon). However, with the appearance of private companies and catching-up countries participating in space exploration, crucial players' role changed, and questions on diversification of responsibilities and guidance have risen. Since the private sector often has different goals and abilities from governmental actors, it might need alternative governance approaches. However, policies created in response to broad governmental goals continue to exercise a strong influence on commercial space (Mazzucato & Robinson, 2017).

Given the high complexities of the space sector, policymakers face significant challenges. With the shift from public to private space exploration, a new policy type is said to appear (Mazzucato & Robinson, 2018). Studies on mission-oriented innovation policies show that in contrast to vertically oriented missions such as the Apollo Program or the Manhattan Project, these policies need to be enacted in a decentralized (horizontal-based) innovation sector with specific problems to be solved by a broader set of innovative actors comparing to the conventional set of actors which was mainly governmental agencies (Mazzucato & Robinson, 2017). To explore space without polluting it is such a problem. Facing this challenge, the need to form new policies is urgent, and changes in existing ones may occur. However, how this could be done is not yet well researched, as private companies have started to enter the space industry actively only in the last two decades. Existing innovation studies have also paid extremely little attention to research this problem. Therefore, this research builds-on insights from transition and mission-oriented innovation policies literature and aims to understand the challenges and hazards of space debris and derive implications for policymakers aiming to stimulate changes in a sustainable direction. The overall research question is:

"How did the perceptions and strategies of space actors change alongside the increasingly pressing space debris problem, and do we see signs of an integrated global response to solve the problem?"

Further, this question is supplemented with sub-questions to specify the analysis and to look at the problem from different scopes:

(1)"What are the strategies and challenges of different actors in the space sector in dealing with the problem of space debris?"

(2)"How did the issue of space debris management gain legitimacy over the years?"

While the general question is devoted to depicting the general storyline of emergence of space debris removal as an environmental remediation industry, sub-questions aim to analyse how actors reacted to barriers and changes and justified their activities in order to correspond to sustainability of the space sector.

To answer these questions, socio-technical network analysis has been chosen as it promises to depict the dynamic process of change of the space sector at the global international level and with both technological and social scope. This method builds on document analysis that allows reconstructing the network of actors and debates between them. We provide a storyline of the space debris sector by collecting data from journals and newspapers from the

LexisNexis database discussing space debris issues from 2007 to 2019. The time frame has been chosen because in earlier years the media's discussion remained mostly in official cabinets, thus, it is hard to track the development of discussion earlier on. Articles for the analysis have been derived from the LexisNexis media database as it allows to include not only professional newspapers, journals, and magazines about space but all sources concerning space debris issues from all around the world. It is essential for tracking both the social and technical context of the debris challenge since such challenges involve a much broader set of actors such as the non-professional public, governments, and media rather than only those of a technical orientation. The analysis is done by coding statements proposed by actors of the space sector during the selected period. It allows for tracking the industry responses for the main challenges of the last two decades. If derived information is not enough to understand some statements, additional data was gathered from companies' annual reports, annual reports of NASA, and newspapers and journals about space, especially to better depict the storyline lying behind.

Answering researched questions provides more profound knowledge about the formation of new sectors and results in advice for policymakers on how to stimulate the space sector towards sustainable space exploration during such a critical period of debris growth. To be more precise, this study's results tend to deepen the understanding of the shift of the space sector to a more horizontally-based governance approach, becoming much more diversified in terms of participating actors and proposed debris-removal solutions. The space debris cleaning sector is in its beginning stage without any successfully performed solution yet. Thus, theoretically, this research spreads the knowledge of the development of new industries and provides recommendations for policymakers who seek to stimulate research and development in response to sustainability challenges.

In the next chapter, we review theories relevant to our research and elaborate on concepts that we apply. Further, we provide an overview of the methods and framework that were used for the data collection and analysis. In the fourth chapter, we present results of the analysis, followed by chapters of conclusion and discussion in which we provide the answer to research questions summarising our findings and raise questions of validity, policy implications and reliability of the research.

2. Theory Section

Since this research aims to analyze socio-technical changes of the space sector in response to environmental challenges, as a starting point, we provide an overview of transition theories. These theories are combined with insights from studies concerning the advantages of mission-oriented innovative policies for global environmental challenges. Then we focus on legitimation aspects of innovative processes and, lastly, we highlight the most critical findings in previous literature on mission-oriented policy approaches applied to the space sector. While socio-technical transition theory is used to track dynamics through which the space industry transitions into a more sustainable form, legitimation and innovation policy studies help to derive insights into steer industrial development by an appropriate policy approach.

2.1 Transition theories

Issues of a systemic change and proper policy have been raised in the Technological Innovation System approach (TIS) scholars (Hekkert et al., 2007; Bergek et al., 2008; Suurs et al., 2010). However, this framework mostly provides foundations for technology-specific policies (Jacobsson & Bergek, 2011), while it is not enough for a broader transformation-oriented policy, including social context (Weber & Rohracher, 2012). Questions of how such socio-technical change unfolds and how this transition should be done have become central in the transition literature (Markard & Truffer, 2008; Markard et al., 2012; van den Bergh et al., 2011; Smith et al., 2010). Socio-technical transition approach is an umbrella term that includes the multi-level perspective (MLP) and multi-phase model, Transition Management, and strategic niche management. Among those, MLP is the most researched and developed approach that is, in comparison to TIS, puts into perspective not only dynamics of a particular innovation, thus, diffusion of a particular technology, but rather highlights a broader societal transition process (Geels, 2011; Geels, 2012; Cicchetti, 2010; Smith et al., 2010; Weber & Rohracher, 2012).

Recent studies see innovation as a joint, systemic interactive activity involving various actors with different goals, roles, and capabilities (Twomey & Gaziulusoy, 2016). These actors represent both social (its members, role structure) and technical (task structure, technology itself) parts of the whole industry (Wilpert, 2001). In these terms, the space sector consists of universities, governmental agencies of countries worldwide, private companies, research institutes, operating spacecraft, policies and licenses that regulate the market, and many other components that construct the socio-technological sector. Highly institutionalized formal and informal rules that have co-evolved with particular technologies and become a common practice or routine lead to the stability of a given sector (Weber & Rohracher, 2012). Analyzing these rules and gaining a more in-depth understanding of how they affect the industrial change, transition theories have developed a concept of "socio-technical regime" (Karltorp & Sandén, 2012; Smith et al., 2010). This term denotes the 'deep-structure' or 'grammar' of a given sector, defining appropriate, legitimate, and conceivable means-end rationalities (Geels, 2011). The transition from one socio-technical regime to a more sustainable one is hindered by the absence of shared vision among actors because sustainability is an ambiguous and contested concept (Geels, 2011); thus, debates are inevitable. Therefore, sustainability transitions should be seen not as isolated technological change but as social learning processes (Stirling, 2007). Socio-technical configurations of regimes are seen as a stable and dominant way of realizing a particular societal function (Smith et al., 2010) that spans the sector to a more sustainable stance.

2.2 Legitimation

Usually, a stable regime is legitimate by people engaged in a sector (Fuchs, 2019). Legitimation is acquiring a social acceptance of new technologies (Bergek et al., 2008). The stable regime is characterized by high legitimacy among incumbent actors (Weber & Rohracher, 2012), which is the opposite of legitimation of novel technologies or new entrants that have to pass different legitimation stages before becoming "taken-for-granted" by the whole sector. Legitimation processes fundamentally change in the subsequent diffusion phase (Johnson et al., 2006): as the innovation spreads to new contexts, it increasingly interferes with more broadly shared normative, regulative, and cognitive rules (Binz et al., 2016). There are many frameworks to access it, yet, previous studies concern four necessary steps to legitimate new ventures or technology (Binz et al., 2016). The first vital stage is the creation of the innovation itself in response to social or technical challenges. Secondly, once innovation appears, it follows the local validation process. This process aims to gain legitimacy among a limited set of actors more willing to accept innovation because of some personal interest. After a niche accepts the innovation, diffusion of this innovation is needed, which is the third step. During this process, innovation increases its legitimation among wider groups and gains more profound institutional legitimacy. Lastly, once the innovation is diffused, it passes the general validation process, which is mainly the stabilization of "taken-for-granted" into a new technological trajectory that works. According to these stages, by accessing the legitimation process, one can retrace how specific attempts to legitimize a new technology evolve (Binz et al., 2016).

2.3 Transition oriented and mission oriented policies

The design and implementation of sustainability transition are vital in many national environmental and innovation policy programs (Hekkert et al., 2007). Such transition management must always be supported by sound policy, and how these policies should be made is the researched issue of many studies in diverse industries from the solar energy sector to water management. Transition policies mainly focus on the creation of learning environments and experiments, the alignment of new actors, and the constant re-evaluation and adaptation of goals and strategies (Weber & Rohracher, 2012); therefore, the legitimacy for policy intervention in these policies is provided by consensus that is reached in direct or indirect debates by innovating actors.

A mission-oriented approach to innovation is receiving renewed attention as innovation strategies can be critical in achieving transformational change (Kattel & Mazzucato, 2018); therefore, a mission-oriented approach has recently gained renewed attention. In particular, missions can guide production, distribution, and consumption patterns in a given sector. Mission-oriented policies target the development of specific technologies in line with state-defined goals (Robinson & Mazzucato, 2018). Successful innovation in different sectors, including the commercialization of innovation, has always required both top-down (where goals are administered by centralized decision-making authority) and bottom-up policies (where goals are administered by public agents embedded in a decentralized and dynamic sector, and hence breaks down the usual dichotomy between so-called Type-1 (active and directional, vertically-oriented) and Type-2 (less active and interventional, more horizontally-oriented) policies as the way for commercialization to happen (Mazzucato & Robinson, 2017).

A decent analysis of NASA's policies is done by Mazzucato and Robinson (2017, 2018). One of the ideas that authors emphasize in their research is that NASA shows a transition from a Type-1 to a more distributed horizontal innovation policy (Type-2), where goals are set by multiple actors with different criteria of success and directions of development. It happens due to the shift from setting the industry's direction to supporting and guiding the industry's goals. In other words, the industry becomes market-led as Type-2 policies are based on bottom-up activities (common to diffusion oriented policies) (Mazzucato & Robinson, 2018). Understanding the role of new actors requires confronting missions that are technical and socioeconomic, and Type-2 policies with a more decentralized approach.

To analyse the space sector's transition towards a more sustainable stance, this research aims to reconstruct socio-technical configurations of the space sector over time. Several components of technological sectors are defined in previous literature that describes socio-technical transitions. These components are used to develop the research design, which will be elaborated in the methodology section.

3. Data and Methods

For the purpose of research we have selected the semi-quantitative approach that is based on Discourse Network Analysis as it is especially created to map and measure socio-technical alignment processes across time and space (Heiberg et al, 2020). Using this methodological framework to investigate changes of socio-technical configuration, we derive the storyline of transition of the space sector. First, we introduce the case of space debris, then we describe the STNA method, followed by a data collection process and, finally, the discussion on validity and reliability of chosen methods.

3.1 Case description

The industry is in its developmental phase; thus, there is no generally-accepted understanding of what to include in the “space debris industry” and what components of it to include in the socio-technical configuration. For example, many space sector actors refer to the term Traffic Management, which is not clearly defined, describing which space activities to include. Therefore, for this thesis, we adopt Brian Weeden’s representation of the sector (Weeden, 2020) in Figure 1:

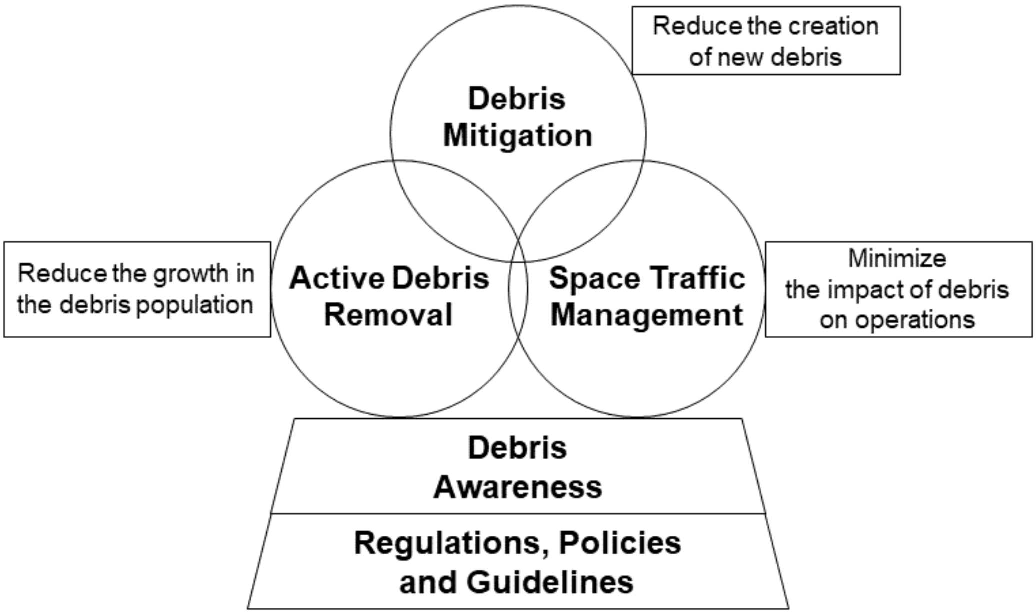


Figure 1. A framework for the space sustainability (adopted from Weeden, 2020)

The decision to choose this framework was made based on pre-analysis because Brian Weeden's testimony appeared to be the most cited document in a researched data-base, and it provided clear definitions of space activities used by other actors. This framework is a part of almost annual SWF's testimony to the US government that always describes the industry's current state and highlights possible problems and possible directions of development often referred to or cited by other actors. In this framework, all the events, activities, technologies, and external influences of the space sector are allocated to five categories, three of which are Active Debris Removal (ADR), Debris Mitigation, and Space Traffic Management (TM) as different industrial strategies (trajectories, approaches) to fight space debris hazards. While these three components represent tendencies in the sector's technological development, such as proposed technological solutions, Debris Awareness, and Regulations, Policies and Guidelines represent legitimation and governance approaches as part of the socio-technical regime of the sector. More specifically, ADR is any activity undertaken to reduce the amount of existing debris in orbit, such as removal using a robotic arm or a net. Mitigation concerns any practice of reducing the growth of the population of debris, thus taking into consideration passive practices such as debris footprint taxes or disposal rules. Traffic Management is a type of space activity aiming to reduce the impact of debris than to destroy them. An example of this is maneuvering to avoid a collision or usage of radars to predict a collision. Debris Awareness represents barriers or gaps in the space debris sector, which actors see essential to address, such as lack of awareness of problems and challenges, lack of trust among stakeholders, or the need for more intense R&D. Tracing the awareness of different challenges that space actors have faced, we analyze the story-line of legitimation development during the transition as it allows us to retrace not only which decisions actors have made but also how they justified their decisions and what these decisions were based on. Moreover, it is vital to track Regulations, Policies, and Guidelines representing external conditions under which the whole industry has to operate, such as government regulation or NASA's guidelines. The latter two categories describe ideas and events that influenced the general space sector, while the three efforts represent how the space debris industry was reacting.

Several studies have shown that entrepreneurs are more successful in achieving sustainable performance and often even become drivers of the sustainable transition (Ge et al., 2016); therefore, in addition to five groups of nodes that are in line with Figure 1, we pay explicit attention to the presence of projects or initiatives the primary goal of which is space debris removal. For such projects, we further call as debris initiative/project and code as a separate group. Overall, we assess the space sector along with six scopes: ADR, Traffic Management, Mitigation practices, legitimation, debris initiative/project, governance approach. In turn, all the organizations are classified as public, private, international governmental, national governmental, or debris initiative/project.

3.2 Data collection

The core analysis data was derived from the LexisNexis database, which provides legal, governmental, business, and high-tech information from newspapers, journals, and magazines. First, we limited the whole database by publication types to exclude transcripts of oral testimonies or public speeches and not related discussions, thus, to maximize the expertness of discussion: Newswires and Press Releases, Newspapers, Magazines and Journals (these are categories of sources distinguished by LexisNexis). Once the database was limited, we used the search line requested “space debris”, which resulted in more than two thousand sources, most of which mentioned space debris just once (for instance, as an example of environmental challenges for humanity in line with others). Therefore, to sort outsources in which the discussion was at least partly but explicitly devoted to space debris, we ran the search function:

(atleast3((space PRE/1 debris) OR (space PRE/1 junk))) AND (atleast3(clean OR clear OR remov! OR mitigate!))

The search resulted in 587 articles, which were further filtered by the English language, and the scope of the search was specified to the aerospace industry. Then, since in the years preceding 2007, data was almost absent; thus, it was not enough to derive meaningful results, so we limited the search to the period from 2007 to 2019. After selection, there were 389 articles left, some of which were considered meaningful being transcriptions of some meeting or not related to the topic. The final data set after all the filtering contain 289 articles discussed space debris challenge to some extent. Additional data was gathered from annual reports of NASA, ESA, and private organizations where needed for the explanation of events or influencing circumstances.

3.3 STNA

The STNA method is based on the coding of actors' statements. It is believed that assessing the socio-technological transition by mapping institutional and technological elements as networks allow tracking the emergence of new socio-technical configuration and the shift in the existent one. Coded statements here are judged as a proposition of actors on how best to solve the challenge. Applying the method, all the data was coded in statements. Each of the statements was further assigned to a node including information about the stating actor and the statement's content. Once the same actor mentions two nodes, they are linked. The link's intensity represents the connectedness between concepts, meaning they were co-mentioned by the same actor. Together all the nodes construct a network representing the socio-technical configuration of the industry. Actors refer to some group of concepts for an advocacy coalition with some degree of ideological and intrinsic compatibility, while referred concepts together might depict a coherent storyline (Heiberg et al., 2020).

In the policy discourse, we expect a patchwork of alignments that are stronger between actors sharing the same set of goals and norms (Heiberg et al., 2020). It may result in difficulties interpreting the actor-network solely. This is where the major contribution of STNA is seen as through concept networks, STNA can depict not only socio-technical elements of the storyline but also the strength of their alignments (Heiberg et al., 2020). Therefore, the analysis's crucial point is to derive two networks (see Figure 2): the network of concepts (or ideas) and the network of actors proposing ideas. To do so, all the articles from the database were coded as statements using the software called DNAnalyser. Once we have derived the first iteration of codes, we revised the coding scheme during a few aggregation stages to visually simplify the network and make codes more meaningful. The coding scheme containing an explanation of codes is attached in the appendix1 with both the first iteration of codes and aggregated ones to help the reader to understand the logic of aggregation.

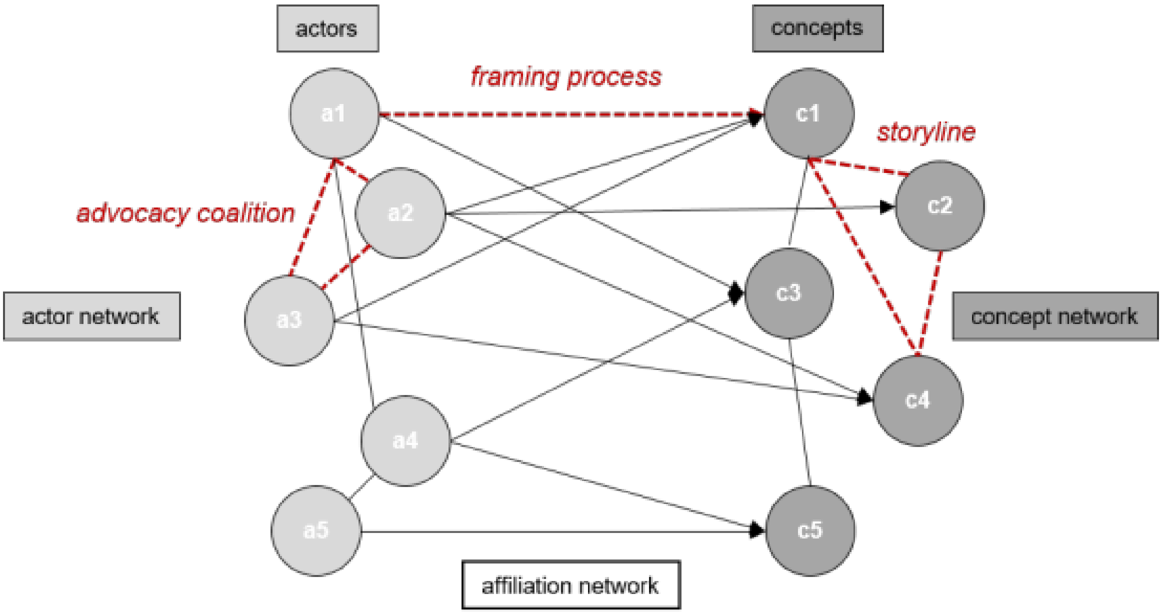


Figure 2. Affiliation network (Heiberg et. al., 2020)

The statements were then exported to software called Visone that is used to draw and analyze networks. First, each node has its size representing how often the concept was mentioned. We trace the frequency of mentioning because it shows how the importance of a concept changed among phases. However, being mentioned does not necessarily mean being meaningful or crucial. Therefore, we have counted the centrality degree for each node to represent statements in the centrality layout. A higher degree of centrality in concept networks reflects that actors have mentioned a concept conjointly with many other concepts (Heiberg et al. al., 2020). Authors of the STNA propose that competing socio-technical configurations can be depicted as networked elements in a 'radar plot' where the centrality of elements represents their institutionalization degree. The presence and width of the links between concepts reflect the strength of their alignments. Based on the degree measure, this layout allows us to analyze the importance of concepts as bigger centrality stands for higher connectedness to other concepts. Closer to the center (or even in the core) concepts represent the discourse's dominant paradigm (Heiberg et al., 2020). A person with a higher degree of centrality can be interpreted as "a major channel of relational information" (Wasserman & Faust, 1994).

3.4 Validity and reliability

The quality of this research is measured in terms of validity and reliability. Reliability means whether others can replicate the study with meaningful outcomes (Bryman & Bell, 2015). To ensure this, developing the coding scheme, we started with bottom-up coding in line with relevant theoretical concepts and definitions widely used by the space sector.

To ensure the validity of conclusions, the primary dataset is combined with additional data from trusted sources such as NASA and ESA reports. Therefore, every time the reason, meaning, or outcome of some states is not clear, it is not judged subjectively but rather supported by additional data and arguments. It decreases the randomness of results, therefore, increasing the validity of the research. What is more, to increase the validity of the research, once one researcher coded all statements, the coding scheme was discussed and revised by the second reader. In case of disagreement on the coding process, additional information sources were used to enrich the consensus.

4. Results

In this chapter, we present the results of the data analysis. Firstly, we show how and why we divide the timespan by phases providing a brief overview of crucial events that influenced the sector over observing timespan. Secondly, we describe derived networks in line with phases starting at the general level in terms of density, clustering, connectedness and other characteristics of networks. Then, in phases, we scope to the content of the discussion itself starting from the centre to the edge depending on the most frequently mentioned concepts. After an overview of the concepts network, for each phase, we also look at the organization's network. Lastly, we give a summary on technological development of active debris removal.

4.1 Developmental phases

The decision of how to approach the selected time span in terms of phases of the development of the industry was driven by three crucial circumstances. Firstly, the US being the most active space explorer and the most successful in creating debris mitigation guidelines has heavily influenced the industry over the whole space exploration. Most of the world-wide accepted guidelines (such as the rule of disposal spacecraft within 25 years after launch) are provided by NASA. What is more, a lot of organizations around the world are embedded in American space industry being partners with private or governmental entities working under US regulations (such as disposal rules or taxes operators have to pay if they want to cooperate with US actors), thus, these organizations have to meet sometimes very hard-to-follow laws or policies. Secondly, the explosion of Chinese satellite in 2007 and the collision of Russian and American satellites in 2009 together raised awareness to the problem of space debris and, therefore, made people review their position on active debris removal. Last but not least, in recent years there is tremendous growth in the population of satellite constellations (for instance, Starlink or OneWeb) which together are going to consist of tens of thousands of satellites each of which can be damaged by space debris but also become debris itself one day. Therefore, the timespan was divided by four shorter periods so it is possible to depict industry transitions in response to these crucial events.

The first period from 2007 to 2011 is dedicated to the growth in the debris population which changed the way space actors thought of urgency of active space debris. Figure 3 represents the types and population of space debris over history (ESA, 2014). The significant growth of the debris population in 2007 and 2009 is caused by two crucial events which together almost doubled the amount of space debris. The first event happened on January 11, 2007, during the test of the Chinese ASAT ground-based system. As the outcome of the experiment, the

Chinese Fengyun-1C satellite was blown-up, having produced 150,000 pieces of debris (BBC, 2012). The second event is an occasional collision of Russian "Cosmos 2251" and American "Iridium" satellites. This collision produced more than 2,000 new objects bigger than a softball, most of which will remain on-orbit for decades to come (Weeden, 2020). Before 2007, the amount of debris was continuously growing, while the rising problem was not addressed in the media or by the public. All the mitigation guidelines were still voluntary and rarely renewed but the two events mentioned above have finally attracted the attention of space users.

The second period from 2012 to 2014 is devoted to tracking the response of the industry to the US National Research Council report that was published at the end of 2011 that has increased an overall awareness. The report warned NASA and the whole world that we have reached the tipping point polluting space environment (US National Research Council, 2011) and called for international regulations to limit the junk and to stimulate more research into the possible use of Active Debris Removal (ADR) technologies.

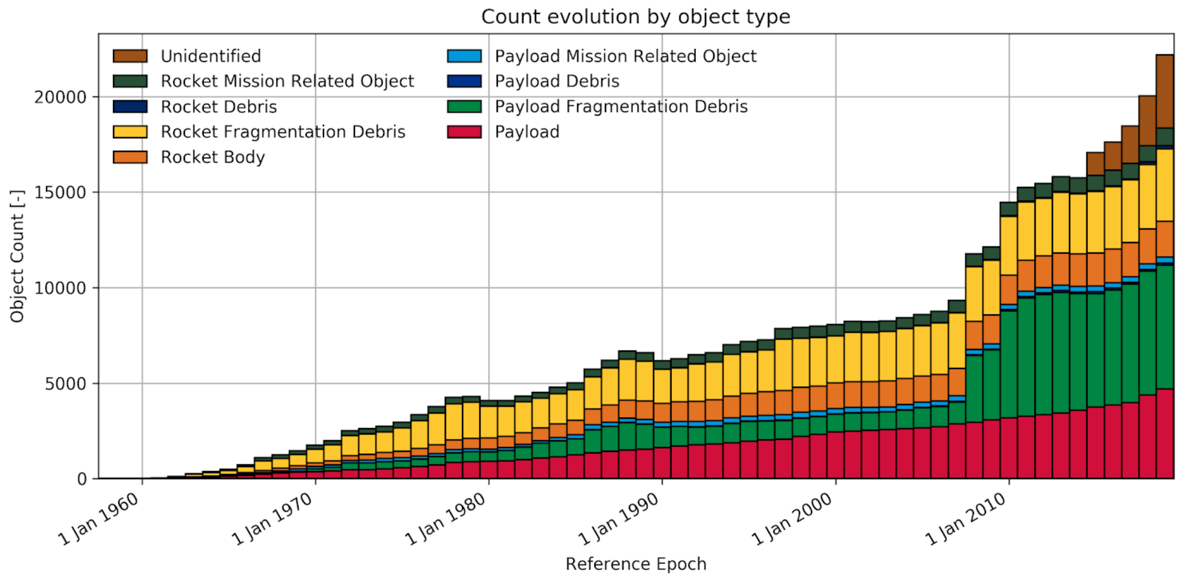


Figure 3. Evolution of debris counted by types of objects (ESA, 2014)

In the last five years completing researched timespan, it has been an additional challenge of renewed interest in large satellite constellations. Satellite constellation means a group of satellites working together as a system. Examples of such systems might be weather forecasting satellite groups or global internet systems which specifically gained high attention over the last years as in 2015 the first global network satellite constellation was publicly announced by Starlink soon followed by Boeing, OneWeb and others. These constellations are a special case for space debris issues because once one satellite in such a system stops working the whole system might fail its mission. What is more, these systems consist of thousands of satellites each, polluting space a lot as each satellite is an object of a possible collision. Graph below (see Figure 4) shows how ratios of space objects being in the constellation to the total amount of space objects changed over time:

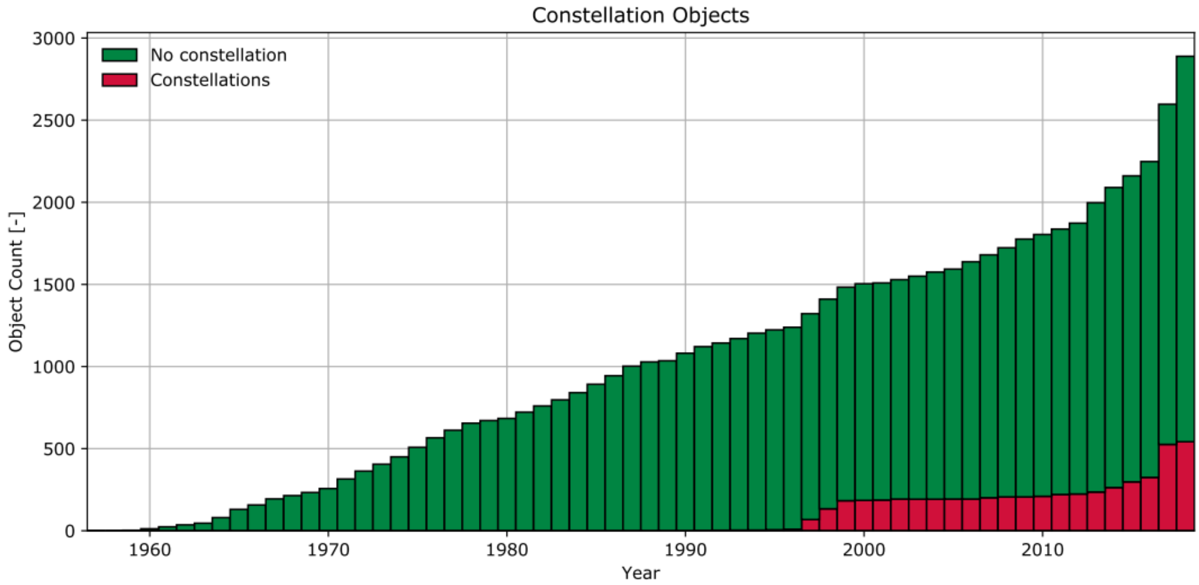


Figure 4. Evolution of number of objects in LEO (ESA, 2020)

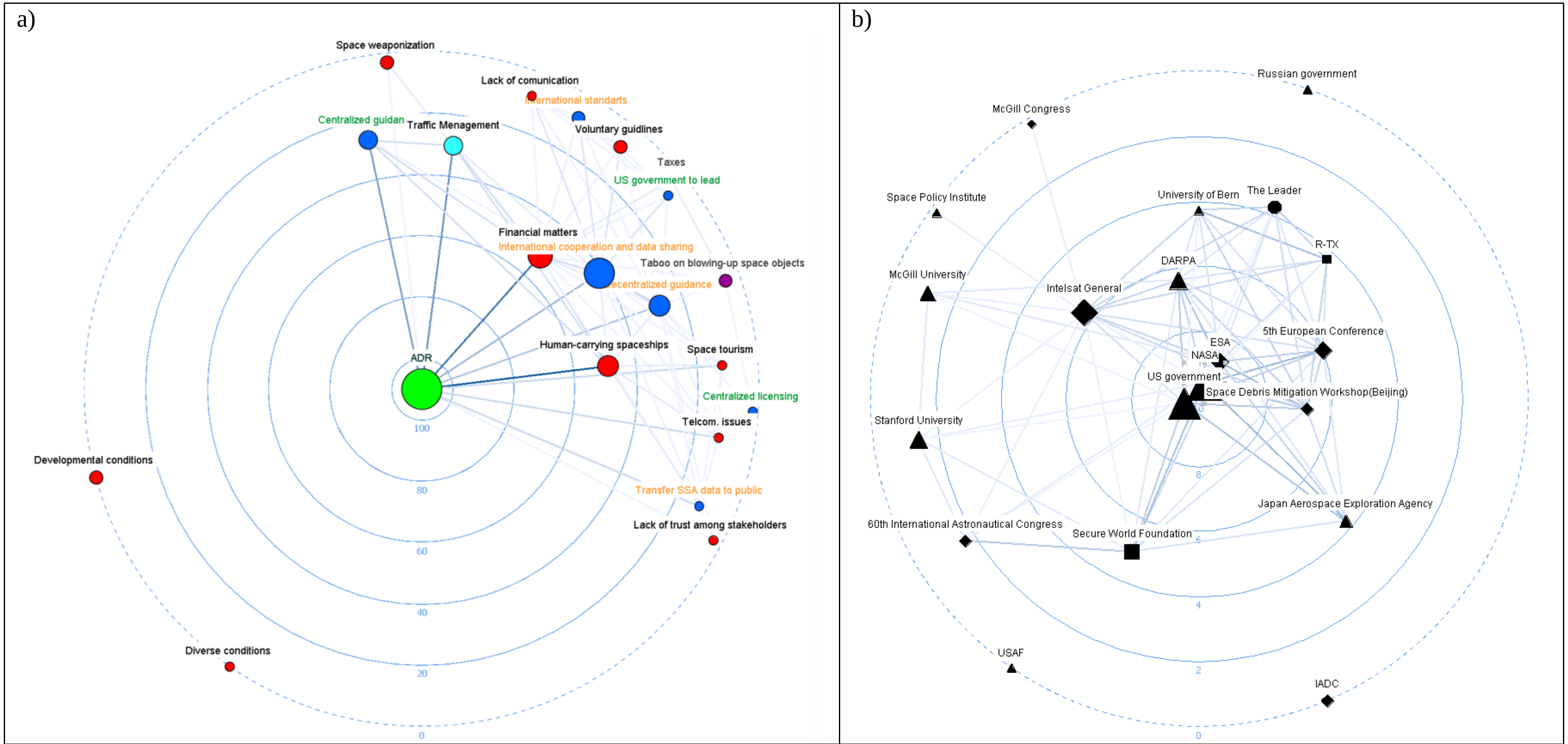
Yet, it took almost three years before the first group of satellites were sent into orbit, therefore, we distinguish two sub-periods here: from 2015 to 2017 standing for the start of interest gaining and from 2018-2019 standing for the reflection on actual launches of constellations.

4.2 Data analysis

4.2.1 Period 1: 2007-2011

General overview of the period

At the general level, the discourse during the first period disperses around the network as people mostly raise questions from the side of their interest rather than trying to bring up broader questions of sustainability or overall performance of the industry which could attract more people or gain awareness. Therefore, statements are not well connected, most of the ideas are mentioned only a few times and the density of nodes is relatively low. Cleaning the space only starts its development as a separate sector, thus, all ideas are novel, being proposed by relatively few actors. People only start to raise awareness of possible hazards from space debris. But despite the low intensity of connections, the whole discussion formed a vague cluster with only a few outstanding nodes.



Node colors:		Label colors:	Types of organizations:
ADR	Mitigation practices	Green – vertically-oriented approach (Type-1)	▲ - governmental
Legitimation	Governance approach	Orange – horizontally-oriented approach (Type-2)	■ - private
	Traffic management		◆ - international
			⬣ - public

Figure 5.
a) Concept network for Period 1: 2007-2011
b) Organizational network for Period 1: 2007-2011

Analysis of concept network

While the destruction of the satellite in 2007 brought up questions of how to interact in space and, thus, highlighted the need for cooperation, the collision in 2009 showed that so-called "Kessler syndrome" is much more relevant than it was thought. This term was named for the famous NASA's researcher Donald J. Kessler who in 1973 first proposed the idea that one day we will reach the tipping point and pieces of space garbage will start to collide, producing new debris in a cascade effect. Together, these events have led to the understanding that even halting all space launches wouldn't solve the problem. This understanding then has brought ADR up to the centre of the network at the first stage. Rationale during this period is clustered around the dominant idea that the ADR becomes essential if one wants to succeed in fighting space pollution.

Legitimation aspects that people often refer to discussing the need of ADR are possible financial profits and opportunities for entrepreneurs in the sector [financial matters] and hazard to human-carrying space missions and ISS [human-carrying spaceships]. Experts see huge possible profits for entrepreneurs recycling space garbage in future once a cost-efficient technology will be invented as spacecraft are a treasure box of expensive materials that could be reused. During this stage, people seek economically profitable technology to fight space debris as they believe ignoring the problem will cost more than a possible solution. In other words, people start pushing forward the idea that mitigation of debris is not enough and that the more we stay idle, the more debris will negatively affect us in the future. Other legitimation issues that are also in the core discourse but less linked or less mentioned are a hazard for the telecommunication sector [Telecom issues] because of the possible harm to operating satellites; the possible danger for space tourism [Space tourism] as the idea of travelling in space attracts more and more attention; lack of communication between stakeholders [lack of communication] in the sense of sharing the data that could help avoid collisions; and the voluntariness of the existent guidelines [Voluntary guidelines]. Brian Weeden from Secure World Foundation highlighted that some operators such as developing economies or small research groups, just can not afford the same mitigation measures as American companies, NASA or ESA, and, thus, simply ignore suggested guidelines.

Ideas advocating horizontal or vertical governance are not strongly competing as the question is still whether space actors need to act now and to which extent rather than how to do it. Nevertheless, discourse about both governance approaches starts to rise and is linked to all solution trajectories - ADR [ADR], Mitigation [Taxes, Taboo on blowing-up space objects] and Traffic Management [Traffic Management]. Here, the incumbent governance approach is represented by the overall idea that guidance should be centralized no matter who leads

[Centralized governance] and the idea that the US government should play the leading role in space debris mitigation [US government to lead]. On the other hand, people promoting the governance shift to more decentralized refer mostly to the idea of international cooperation to create proper policies [International cooperation and data-sharing]. Less often they support their beliefs with the need of a non-professional audience to understand the problem, thus, the need for data transfer to the public in order to gain public awareness of the problem [Transfer SSA data to public] and with the need for international standards [International standards].

Looking at the more peripheral nodes, it is noticeable that Mitigation is the most isolated solution trajectory out of the three. There is almost no discourse about mitigation as NASA has crucial influence and authority, thus, once actors decide to apply some mitigation rules they tend to follow those proposed by NASA. Other aspects that were less discussed among the community are raising awareness of space weaponization [Space weaponization] due to the 2007 Chinese satellite explosion, inequality between different actors in terms of financial abilities of developing countries [Diverse conditions; developmental conditions] and lack of trust between stakeholders when it comes to data-sharing and technological cooperation [lack of trust between stakeholders].

Analysis of organizations network

In general, the discussion is almost equally formed by national and international governmental entities. Holding the trend of the historical development of the whole space sector, the discussion is highly influenced by NASA and the US government being both the most central and biggest nodes. ESA is also well connected to other nodes but is relatively less referred to than the former two entities. This might be explained by the fact that ESA has a more complex structure because of the involvement of many countries. This organizational complexity, in comparison to NASA who makes decisions on its own, makes it more difficult for ESA to lead the partners as ESA has to gain awareness and understanding of the problem among all stakeholders. Also, NASA's awareness of the problem seems legit as the US is the main user and, therefore, the biggest polluter of space so far. What is more, the space sector of the US is the most diversified in the sense of private actors. Generally speaking, the network of actors consists mainly of national or international governmental entities with only two private organizations [R-TX, Security World Foundation] as exceptions.

The only government that is present in the core is the US government, while other governments are at the edge and have weak linkages attending the discussion mostly at international events. Representatives from developing countries are almost absent, especially when it comes to governmental entities. Presence of universities is also very pure with the University of Bern as the only clustered to the core representative, and with Stanford university being almost at the edge.

4.2.2 Period 2: 2012-2014

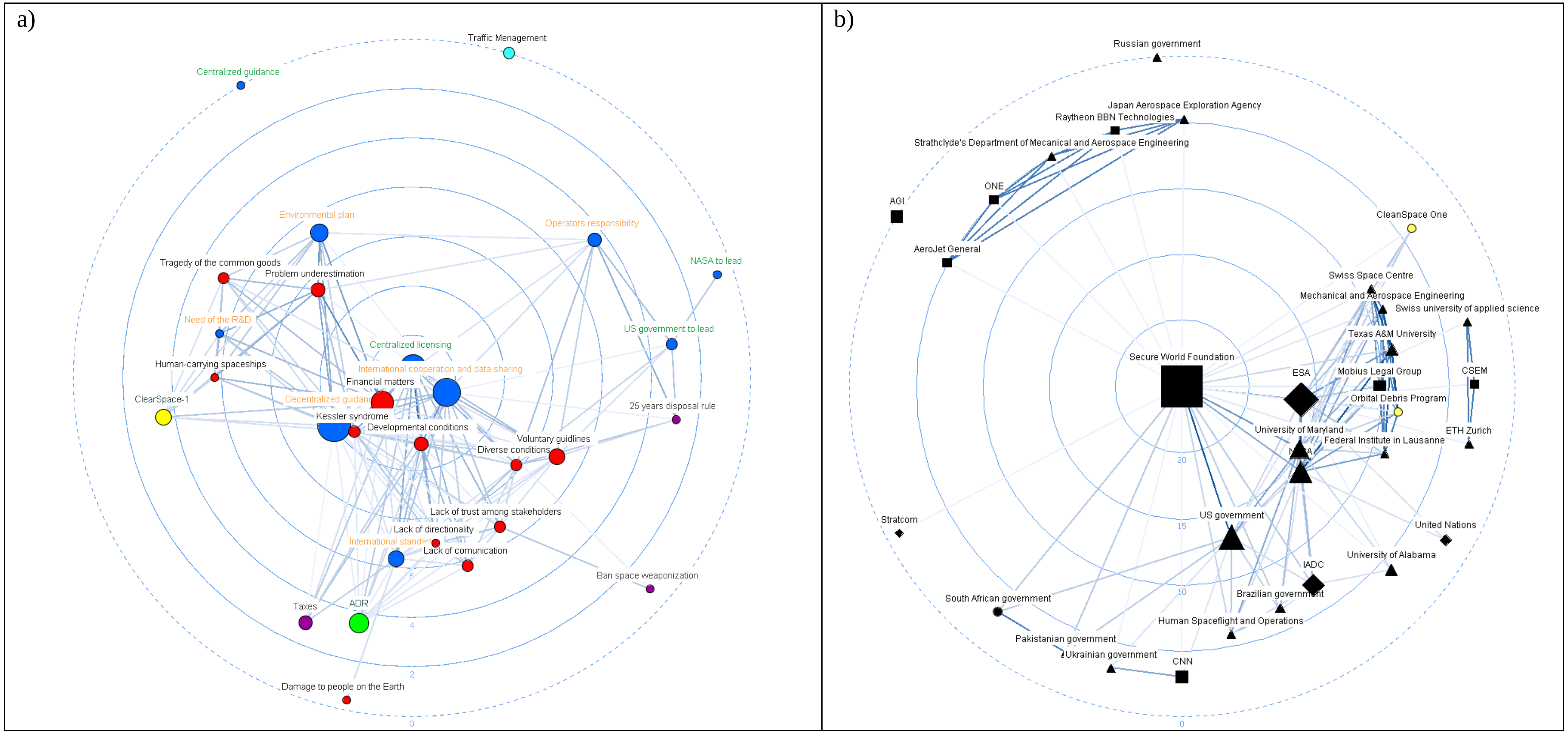
General overview of the period

At the most general level, compared to the first period, the discussion is more active and controversial now as more ideas were proposed by more actors. Yet, the industry is in its early developmental stage, therefore, the whole set of nodes only starts breaking up into more visible core and peripheral arguments. While in the first period the whole discussion was built around the idea whether ADR is essential and urgent or not, now, the dispute is rather about who should be responsible for the debris removal and/or for the guidance of the sector. The idea of active removal is pushed out of the centre as the necessity of ADR is accepted by most actors in this period, but the debates now are on whether we should keep the vertical policy guidance [Centralized guidance] or shift to the horizontal one [Decentralized guidance]. The general notion of legitimation arguments, thus, has also shifted from awareness of ADR to organizational and operational issues.

Analysis of concept network

As during this period the cost-effective technology is still missing and the annual damage by debris is growing (for instance, ISS has to maneuver more and more often), people still refer to possible financial losses and profits for the industry [Financial matters]. The other bothering industry awareness is developmental conditions of different types of actors [Developmental conditions]. It stands for difficulties that might occur for some players in order to meet regulations due to their direction of development that was chosen before such as lock-in in the direction that differ from the suggested one or high level of bureaucracy that limits and slows down any processes of change (for instance, in Russia all the private companies were bought by government and now there is only one big governmental company that is allowed to operate in space). More than that, experts say that strategies of actors differ not only by the way actors have been developing earlier but also in the way they can develop further due to inequality in capabilities and resources they have both in general and when it comes to space activities [Diverse conditions]. With the growing number of arguments for the proper guidance approach, we can see more variety in arguments legitimizing both types (centralized and decentralized). What also hinders the industry development now is lack of directionality and clear guidance in terms of goals [Lack of directionality] as experts say that setting a clear goal fighting debris might be needed in order to gain legitimation among industry and public. What is more, people still often say that communication between actors in terms of data-sharing and creation of new guidelines [Lack of communication] is lacking. The same situation is with trust between stakeholders from different countries [Lack of trust between stakeholders] as in many countries space research and development are often related to national security issues which can be deemed politically sensitive. The fact that existent guidelines are still voluntary, thus, often ignored [Voluntary guidelines] is also seen as important as more new entrants appear. Another interesting group of legitimating arguments is the group of nodes that is more linked to the firstly appeared debris-project called CleanSpace One. These are the possible hazards for operations in space with humans on board [Human-carrying spaceships], the question of who should be responsible for removing others garbage [Tragedy of common goods] and underestimation of the problem by the whole society [Problem underestimation] as some experts say that the tipping point proposed by Kessler has been reached already. By tragedy of common goods, we have aggregated arguments underlying the fact that we all use space but only a few are aware of sustainability. What is more, even having stopped operating satellites remains to belong to somebody, thus, the question of how to deal with such objects is also an issue of common goods. Lastly, we can see that people have mentioned possible physical damage to people on Earth [Damage to people on the Earth] as since 2010 every year we have at least one accident with big pieces of debris falling being not burned in the atmosphere. The connection between the project and awareness issues might be explained by actors' acceptance of this project as a sufficient response to these issues.

Coming to the governance, the most active discourse is about centralized licensing [Centralized licensing] as for now only in the US three different agencies (the National Oceanic and Atmospheric Administration, the Department of Commerce, the Federal Aviation Association) are responsible for licensing and some rules of those are different. Actors seek for a clear system of licensing and often say that to achieve it we rather need to concentrate responsibility for the licensing process at a single agency. Another governance shift that is discussed is a shift to more diversified guidance of the whole industry [Decentralized guidance] as more different actors with different goals and needs appear and existent policies and guidelines are often judged to be unequally suitable for everybody. Both approaches are well-linked to the need for more intense international cooperation in terms of research and data-sharing [International cooperation and data-sharing]. Less often mentioned, yet well-connected to the central cluster idea is the need for a boost of R&D [Need for the R&D] in order to achieve a cost-efficient technology as soon as possible.



Node colors:		**Label colors:**	**Types of organizations:**	
ADR	Mitigation practices	Green – vertically-oriented approach (Type-1)	▲ - governmental	● - public
Debris initiative / project	Governance approach	Orange – horizontally-oriented approach (Type-2)	■ - private	○ - debris initiative/ project
Legitimation	Traffic management		◆ - international	

Figure 6.
a) Concept network for Period 2: 2012-2014
b) Organizational network for Period 2: 2012-2014

To stimulate R&D experts to recommend creating a concise environmental plan [Environmental plan] that would help to set clear goals and to track the success, and creating international standards [International standards] in order to properly involve and guide new or less developed players such as catching-up countries or the private sector in sustainable space exploration. By the environmental plan, we refer to a broad term that includes propositions about guidelines and goals for the whole humanity to gain legitimacy and awareness of the space debris problem (such as Horizon 2020 goals that we have for other sustainability challenges). At the same time, some actors provoking centralized guidance have stated that the US government or NASA should lead the industry [US government to lead, NASA to lead] due to their experience and abilities, yet, these ideas are peripheral and less linked to the core discourse.

While during the first period ADR was referred more to vertical governance, at this stage the link becomes thinner as ADR is proposed by relatively small actors such as private companies or institutes rather than by crucial players as US or Russian governments. These companies rather discuss explicit technological solutions than barriers for the whole industry or awareness of society. This is the other reason ADR is not in the centre of discourse anymore as these smaller companies are essentially new entries into the ADR business so to a certain extent they are the ones who still engage with the ADR topic since they have to ‘promote’ the technology. Discussion on the technologies that are needed for ADR proposing such solutions as robotic arms, umbrellas, magnetic tethers, nets and many others yet not well-elaborated ideas that are isolated and rarely mentioned together being promoted by private companies and different research groups. Among mitigation practices, the rule that all spacecraft sent to the orbit should be disposed of by the operator within 25 years [25 years disposal rule] gain wide acceptance, while the ban on weaponization [Ban space weaponization] is at the edge of discourse as there were not any incidents after the destruction of the Chinese satellite.

Analysis of organizations

In terms of the actor networks, this stage was highly influenced by the Testimony of Brian Weeden from the Secure World Foundation (SWF) where he discussed the role of NASA in national and international space exploration and highlighted problems of the global space sector. The author has touched a broad set of problems together with propositions of possible solutions and these problems were relevant to other actors, thus, SWF became the central node. As more countries from all over the world entered the discussion, the US government together with NASA were pushed away from the centre. The discussion in comparison to the first stage is formed mostly by governmental entities (governments, universities and research institutes), yet, the involvement of the private sector is also relatively higher. An important point to highlight is the appearance of first debris-projects [Orbital Debris Program, CleanSpace One] not only in terms of proposed solutions (concepts network) but also in terms of actors involved in debates (actors network). During this stage these projects tend to be linked to the national governmental entities such as NASA or research centres.

4.2.3 Period 3: 2015-2017

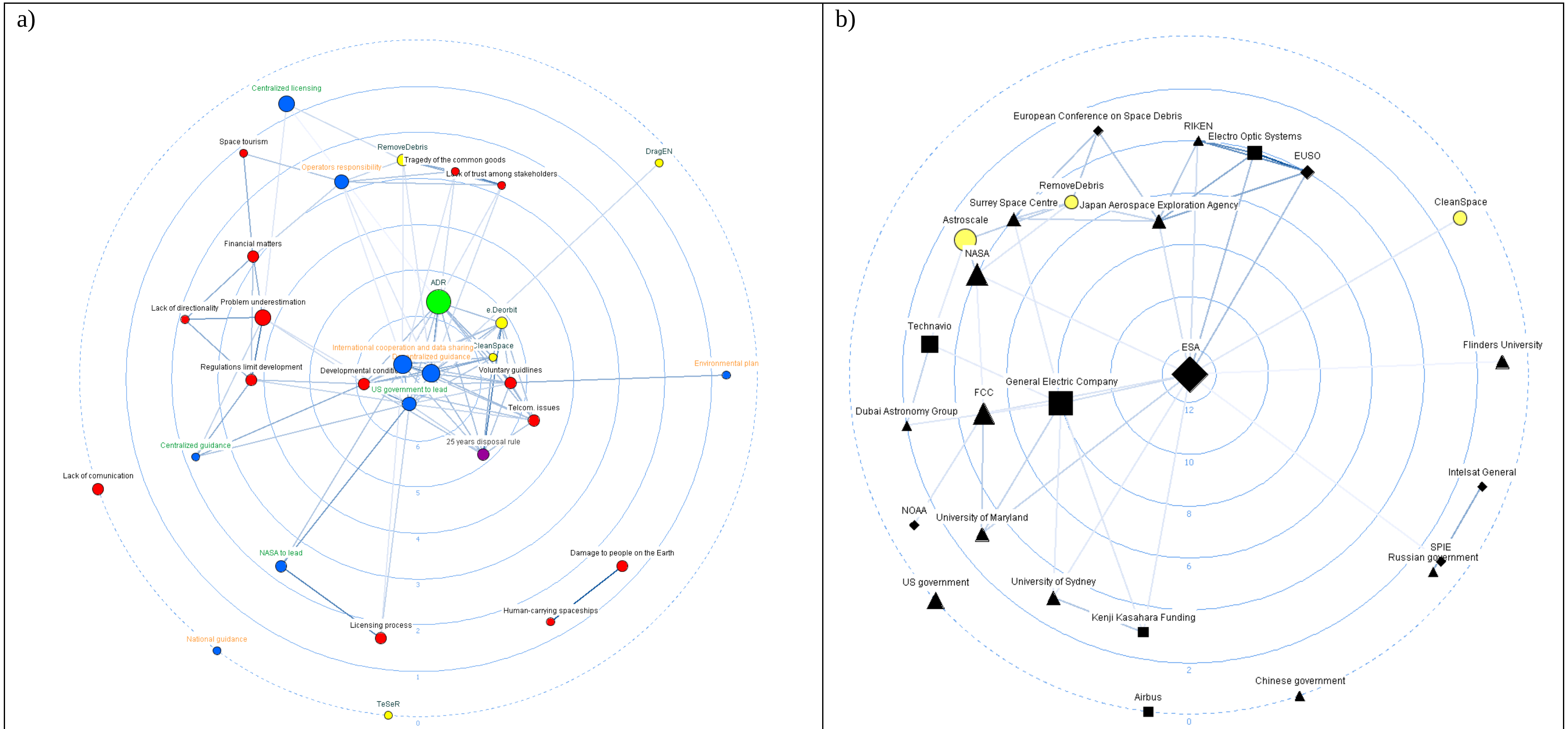
General overview of the period

In comparison to previous periods, over this stage, the discourse starts clustering around dominant ideas about ADR, the proper governance and legitimation. Therefore, searching for dominant ideas over these years, we can distinguish between the core cluster and the rest of the discussion almost equally distributed across the periphery. Interesting change in this period is the appearance of removal-aimed projects some of which are in the core cluster. Most nodes are connected with almost no isolated statements. It might mean that discussion starts to follow some direction with most of the ideas being interlinked.

Analysis of concept networks

Tracking legitimation arguments that people refer to, it is important to highlight the three in the core: as in previous period people say that it is important to take into account how different actors have been developed earlier [Developmental conditions] developing guidelines that everybody could follow; the fact that guidelines are not followed by all actors at the same level [Voluntary guidelines] still bother the industry; possible hazards for the telecommunication sector [Telecom issues] such as possible collisions with tel.com satellites do not lose central positions because operators say they have to manoeuvre their satellites avoiding collisions more often with every year. The leadership of the US [US to lead] or NASA [NASA to lead] is in the centre of discourse because US actors often refer to these ideas discussing the need for a clear licensing process [Centralized licensing].

Closer to the edge, there is a group of interlinked issues that actors are aware of. Losses that could be caused by debris [Financial matters] are still a relevant topic because simulations of six different agencies showed that Iridium-Cosmos events can repeat once per 5-9 years. In line with the previous period, people still highlight profits from a clearer goal for the whole debris sector [Lack of directionality] such as the attraction of more engineers or achievement of legitimation.



Node colors:		**Label colors:**	**Types of organizations:**	
ADR	Mitigation practices	Green – vertically-oriented approach (Type-1)	▲ - governmental	⬢ - public
Debris initiative / project	Governance approach	Orange – horizontally-oriented approach (Type-2)	■ - private	● - debris initiative/ project
Legitimation	Traffic management		◆ - international	

Figure 7.
a) Concept network for Period 3: 2015-2017
b) Organizational network for Period 3: 2015-2017

A novel statement that is relatively actively discussed is that pollution of space can not be judged at the same level as pollution in water or air [Problem underestimation] due to a much more expensive and complex R&D and the price we pay for the damage caused by space debris (both in financial and environmental terms). These issues are strongly interlinked with the need for a clearer goal at the international level. It means players seek for a common trajectory that everybody could lean on setting its own goals and measures of success. The rest of awareness is represented by the tragedy of common goods [Tragedy of common goods] linked to the lack of trust among stakeholders [Lack of trust among stakeholders], by linked hazards for human-carrying space missions [Human-carrying spaceships] and hazards for people on the ground [Damage to people on the Earth]. Strong linkage of common goods and lack of trust might be explained by the legal question that has risen: is it legal to remove space junk as even a dead satellite is still someone's, therefore, would not the owner demand to pay back one day? Finally, the statement that communication is lacking [Lack of communication] becomes isolated, probably signing that discussion seems enriched by actors of all types and from all around the world, thus, people mostly find some response to their issues and don't have to call for more discourse.

During this stage, decentralized guidance [Decentralized guidance] in combination with international cooperation [International cooperation and data-sharing] becomes the most suggested approach. Nevertheless, even actors proposing policy decentralization, state that the US might be the right actor to guide due to its previous experience and success. Some actors go deeper with their argumentation saying that if the US is going to lead, then NASA should be the responsible representative, thus, the idea of the US holding the leadership highly corresponds to the idea of NASA being the leader. It is believed that NASA can gain legitimacy faster by both the public and the other actors as it is less politically influenced than the government itself. What is more, due to the high level of bureaucracy in governmental structures, NASA seems to be faster and more flexible in terms of decision-making. Other vertical-aimed policy statements are the need for centralised guidance [Centralised guidance] held by any individual and the need for centralized licensing [Centralized licensing]. Centralised guidance here is a point of discourse as arguments linked to it are biased. For instance, these discourses might be a reaction to Brian Weeden's testimony (2014) in which he, as well as other experts, say we need to decrease the influence of big players such as the US government or NASA because existent regulations limit the private sector, while others say we need some experienced and capable actor to rule because we underestimate the problem. Provoking decentralized governance, actors have brought up the idea that debris mitigation should be the responsibility of operators exploiting the space as they are solely responsible for the damage dealt with other operators. The need for the environmental plan is pushed outside the centre as well as the idea that guidance for each actor should be provided on its national level.

Mitigation practices are almost absent in the discourse as actors only highlight the effectiveness of the 25 years disposal rule [25 years disposal rule] which is said to be accepted by around 90 per cent of operators by 2016. ADR becomes closer to the centre again due to the first technological solutions being proposed and gaining acceptance. But people start to understand that the needed solution might be not a single technology such as a tether or a net but rather a complex technology combining few suggested so far solutions. For instance, the CleanSpace project is a satellite to test technologies for all stages of debris disposal: to track debris with high-sensitive radars, to capture the debris and to rendezvous it to the atmosphere so garbage will burn down. That is why ADR is frequently co-mentioned in combination with appearing debris-projects and with arguments provoking diversified guidance as new players invent new forms of spacecraft and appeal that these need to be licensed differently. Moreover, this rule becomes widely-accepted by many operators and governments, thus, it is in the core cluster and well linked to other core nodes. The approach of Traffic Management is not discussed because the debate on this aspect was mainly driven by governments warned by manoeuvring of ISS in order to avoid collisions, while now the discussion is driven more by universities and the private sector.

Analysis of organizations

During this stage, ESA becomes the most influential actor taking the lead in the discussion, moving NASA to the side. It happens due to the increased involvement of ESA into the research of space debris. ESA initiated programs aimed to remove debris and participated in programs of others, holding conferences such as the 7th European Conference on Space Debris in 2017 held by ESA. Nevertheless, ESA is less well connected to appearing debris-projects than NASA which might be explained by an overall higher diversity of the US private space sector, thus, private companies are more likely to have common goals or/and views with players from the US. Over this period, debris-projects are connected almost equally to all types of actors, meaning they are interrelated with issues and beliefs that are important for others. It might indicate that these projects are initiated in response to what the industry needs. Another tendency worth mentioning is the growing presence of Japan in the network, being strongly connected to EUSO and RIKEN as they often refer to the same problem.

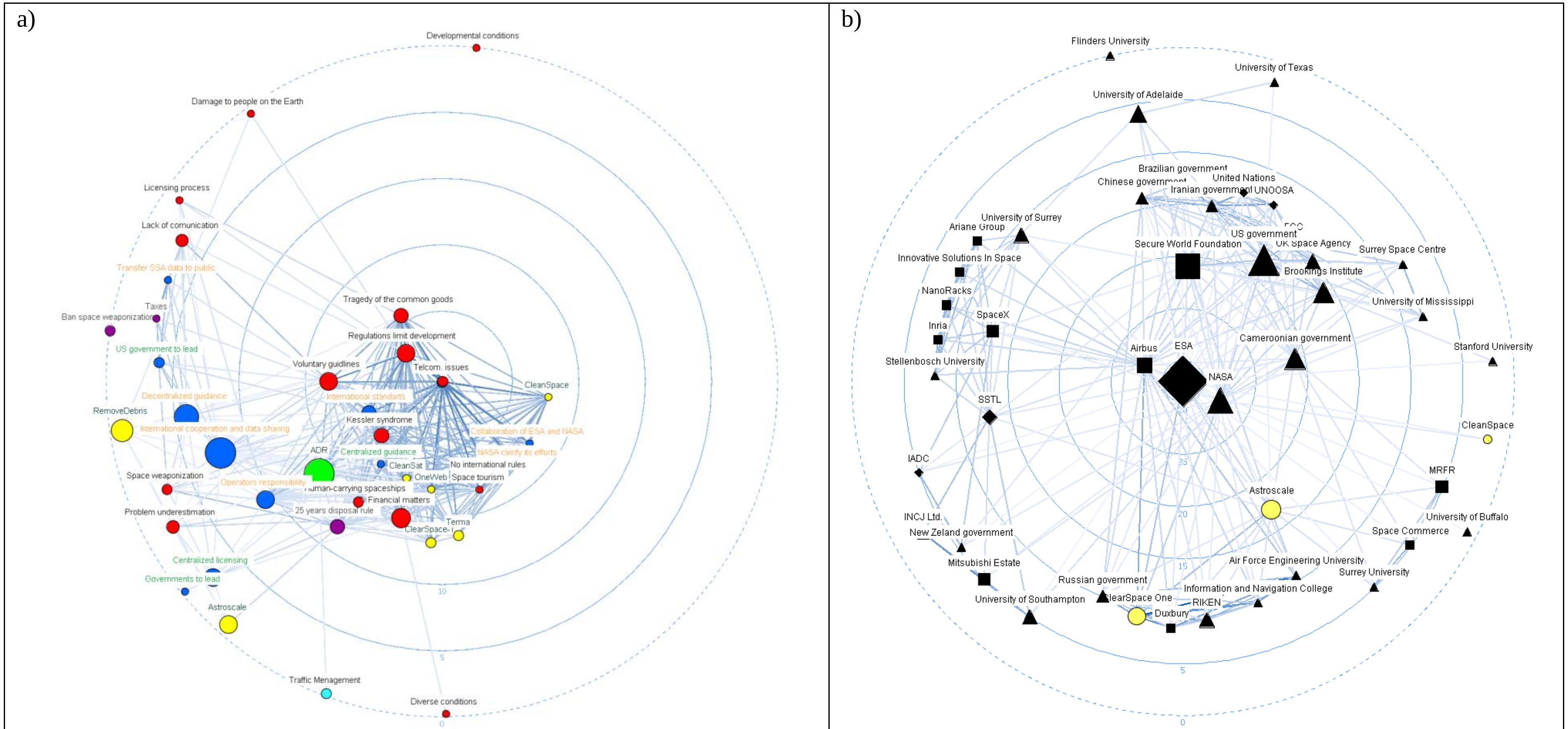
4.2.4 Period 4: 2018-2019

General overview of the period

Describing the industry during this phase in general characterization, it can be concluded that the central core is clearly visible being distant from the rest of the concepts. Core discussion now is on ADR and arguments for decentralized guidance. In the core, linkages are really strong in between most nodes. It indicates the appearance of a common paradigm on which most of the industry agrees on. Yet, some of the most frequently mentioned arguments for the decentralized guidance are in between core clusters and periphery, meaning that the approach is still gaining legitimacy among players and needs to be referred more to other concepts important for the sector.

Analysis of concept network

At the more peripheral side, there are more diversified arguments on the policy debates with fewer linkages which are also weaker. Despite being distant from the core, these arguments are frequently mentioned which means they are still bothering people but there is a lack of tangible strategy or practical way to implement them. Arguments for centralization of guidance [Centralized guidance] proposed here discuss whether governments should lead the guidance [Governments to lead] and the need of centralized licensing [Centralized licensing] but during this stage people concerning licensing issues often rely on the examples of emerging niches such as Cubesats. Cubesats are usually referred to as a satellite less than 10cm and becoming popular among small research groups or even experimenting individuals and often proposed by experts as a special case that has to be licensed differently. Here, statements about decentralization [Decentralized guidance] are also much more frequently mentioned and are represented by ideas that in order to gain legitimacy of the sector worldwide, to attract public attention we need to explain SSA data to non-expert people [Transfer SSA data to public] and to stimulate international cooperation [International cooperation and data-sharing], for instance, creating international research groups and organizing more data-sharing events. SSA data transfer is also highly linked to taxes [Taxes] as such measures as GPS-chip tax would affect prices of smartphones, thus, might not be easily accepted by the public. Therefore, it is important to inform the public in a proper way so everyone understands why it is needed to pay such taxes. Traffic management [Traffic management] is almost isolated, yet present, as it hasn’t been mentioned solely but as a part of a complex ADR solution proposed by debris-projects. In comparison to the earlier period, technologies discussed here should be rather called projects combining few approaches and technologies together, for instance, a spaceship equipped with a giant net supported by a special ground-based radar system.



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Legitimation	Traffic management		◆ - international	

Figure 8.
a) Concept network for Period 4: 2018-2019
b) Organizational network for Period 4: 2018-2019

The important event of this period is the announcement of ClearSpace-1 operating under ESA ADRIOS programme - the mission that is going to be the first to remove a space object from Earth orbit. Yet, the mission is planned for the year 2025 while the hazard is growing with every new satellite, people start to push questions of who is guilty and/or responsible for the cleaning often saying that it should be the responsibility of operators to get rid of consequences of their activity in space [Operators responsibility], pushing them to construct satellites in such a way so it does not create debris either during operation or after being used. The reasoning for these peripheral statements is represented by awareness of facts that some technologies used for ADR can also become a space weapon [Space weaponization] as some countries as China and Russia announcing anti-satellite weapons and technologies from time to time, that problem is still underestimated and the critical point has been passed already [Problem underestimation] and now the cascade collisions can start at any time. Communication is still proposed to be lacking between stakeholders and there is a need for an international data centre [International cooperation and data sharing] once we want to stimulate and coordinate cooperation properly. Finally, licensing processes still need to be clarified for each type of spacecraft, as well as for each type of actor [Licensing process].

This period is remarkable not only because of the growth in the number of debris-projects but also because most of the projects appear to be well linked to other crucial concepts, thus, having gained higher acceptance. With the growth of new entities such as governments of developing countries and debris-projects, some crucial changes occurred in terms of discussion on policy guidance. Most players support the general shift to more decentralized guidance. Yet, some players mention that centralized leadership might be needed at the beginning in order to gain legitimacy of guidelines and to extend those to the whole industry in the right way using the authority of a leader. That is why, even though centralized guidance is in the core cluster, this node is weakly connected and less frequently mentioned in comparison to prevailing arguments supporting horizontal policies [Decentralized guidance]. Centralized guidance [Centralized guidance] is often related to the proposition that the goal and approach of NASA are not clear [NASA to clarify its efforts], thus, it needs to clarify its own effort in space cleaning to become a leader. What is more, people start not only provoking collaboration between countries [International cooperation and data-sharing] but also emphasise the need of collaboration between NASA and ESA [Collaboration between NASA and ESA], and say that some sort of an international working group might be the right leader. Telecommunication technologies [Telecom issues] become central and essential in the discussion with the growth of in-orbit objects because of new satellite constellations. Few thousands of satellites for these constellations have already been sent and much more are planned. The set of awarenesses that people still often refer to consists of voluntariness of existent guidelines [Voluntary guidelines], limitations of existing regulations for development of the private sector [Regulations limit development], Kessler syndrome [Kessler syndrome] and possible financial losses in future [Financial matters]. Less mentioned in the core legitimation aspects are hazards for human-carrying missions [Human-carrying spaceships], absence of clear international rules [International standards] with special focus on lacking in unified protocols for communication of operators and the increasing attention to future space tourism [Space tourism].

Analysis of organizations

On a general level, the discussion got a significant boost in terms of both size and diversity of the network. The number of players has grown, all types of players are much better interlinked and those links are stronger which depicts legitimization progress of the debris sector. There are almost no actors proposing only one statement, meaning most of the actors are involved and relatively active. We see more triangles with strong links representing growing understanding and willing to cooperate between stakeholders. One visible difference in sense of actors at this stage is relatively bigger ratios of the private sector being involved in the discussion. In addition to that much more debris-projects appear starting to lobby their interests and to propose new solutions. During this timespan, more of these projects are highly integrated into the network showing the increasing influence and, thus, value. Increased numbers of these types of organizations resulted in a new shift in argumentation for governance approaches. ESA is still in the centre but contrary to the third period, NASA is also close to the core because of debates on its leading role, yet being less frequently mentioned. We can see more developing countries (being represented by governments, universities or private companies) coming into the game and that they are becoming more involved in the debates.

4.3 Summary

To conclude the results we would like to connect our observations of the space sector divided by periods in a concise storyline linking our findings to theoretical concepts. First, we start with the analysis of organizational change that occurred and technological success during researched time span highlighting influence and performance of debris-aimed small projects because in literature these types of entities are expected to perform better achieving green and sustainable results such as wasteless space exploration. Secondly, we discuss governmental approaches that might be the best for the industry in order to achieve an overall greener performance of the space industry. Lastly, we scope to the legitimation aspect of space sector development to provide the reader with obtained results on how and which type of legitimacy was gained over stages of development.

4.3.1 Summary of technological development

Over the first five decades of interaction with space, humanity has paid little attention to the pollution created with every satellite, rocket or any other object sent to orbit. Over this stage the problem of space garbage was generally addressed as complementary to main goals, thus, responded mostly by guidelines suggested by space explorers to stick to more sustainable activities where possible. Indeed, tragic events of the first decade of the 2000s that significantly increased the amount of space debris reminded that low-earth-orbit is not our junkyard and has to be cleaned if people want to continue to use space sustainably and safely. Since 2007 the dispute on how to respond to the challenge of space debris increased and some technological solutions for active debris removal such as robotic arms, magnets or tethers were proposed, yet, these solutions were proposed as more as diverse ideas that had no practical base behind, thus, these solutions were not highly-accepted by the industry.

At the beginning of the researched period, ADR was in the centre of dispute but all the links with other ideas were weak because of the need to transfer understanding of the urgency to all actors, thus, it was mentioned often by sole actors but the whole discussion was not well connected. With the development of discussion increased the number of private companies and projects who made their main goal removal of objects from low orbit (see Figure 9).

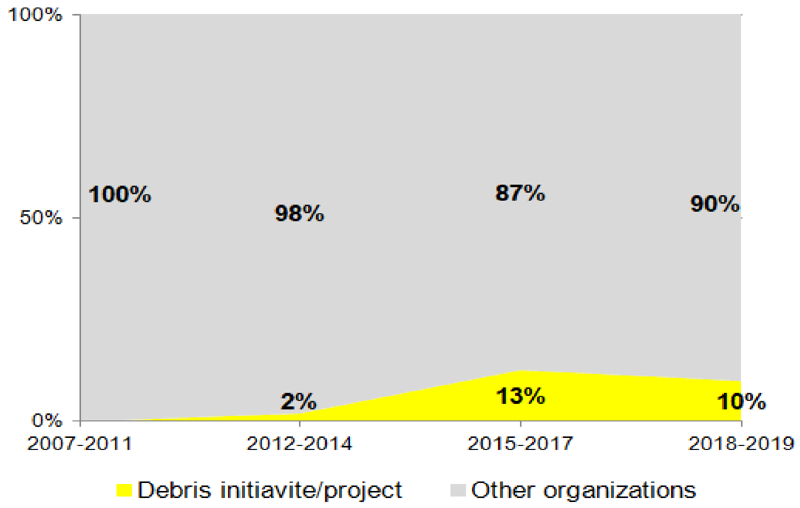

Figure 9. Ratio of Debris initiative / project

Since then active removal was mainly pushed by these actors and proposed as needed, possible and profitable solution, yet, with a lot of barriers on the way achieving it. Suggested technological solutions became more complex usually being a combination of technologies such as radars, capturing mechanisms and disposing of tethers. The more complex solutions became the more they were believed to be an answer to the growing hazard.

Our results show that, since humanity understood the necessity of active removal, the space industry became more diverse in terms of types and number of actors with more private and catching-up players such as developing countries. Ties between organizations in the industry have also amplified as the discussion becomes more directed, all ideas are more interconnected and companies tend to cooperate starting new projects together, organizing international events and exhibitions. Despite growing attention to the problem and increased involvement of players from all over the world, up till nowadays neither governmental actors nor private organizations have been successful inventing solutions for active object removal, Nevertheless, in 2019, ESA has finally announced the first mission to remove space debris - ClearSpace-1. This is only the first step in fighting against space garbage which is planned to happen in 2025 and for sure would not solve the problem alone, therefore, people still seek a proper approach.

5. Conclusion

In conclusion to our research, we would like to present the results of analyses as answers to the studied general question and subquestions. In this research, we elaborated insights from transition literature and studies on mission-oriented innovation policies applying the STNA framework for the case of the space sector in order to answer the following general question:

"How did the perceptions and strategies of space actors change alongside the increasingly pressing space debris problem, and do we see signs of an integrated global response to solve the problem?"

In general, our analyses showed that the active debris removal space sector's whole discussion became more active and densely connected. The network of actors became more diversified and broader, involving players of different types and sizes. What is more, a lot of possible technological solutions were proposed. All these changes resulted in the transition of the space sector to such a stance that led to the first debris-removal mission (ClearSpace-1) operating under the ESA foundation. Nevertheless, so far, ClearSpace-1 is the first mission proposed by the industry, and it is still in the planning phase aiming to happen in 2025. What is more, this mission is not able to deal with debris solely but should instead be valued as the first result in the right direction since the goal of CleaSpace-1 is to remove one object of debris, while experts argue that we have to remove a few most massive objects from LEO annually. Therefore, the transition to a sustainable stance is not finished, and there is still ample space for improvement in terms of the "green" performance of the space sector. To deepen the understanding of dynamics occurring during this transition, we further provide answers to researched subquestions.

Answering the first subquestion, *"What are the strategies and challenges of different actors in the space sector in dealing with the problem of space debris?"* we offer:

Historically, until the last two decades, the whole space exploration and usage process was dictated by a few crucial players mostly influenced by governments such as the US, Russia, NASA and later ESA. Because of this most space activities were guided, regulated and managed with a vertically-based approach with these crucial players being responsible for setting direction, goals, rules and norms for the whole industry. It resulted in an unbalanced and vaguely regulated system where guidance, licensing and operation, in general, are not clear and not equally affordable for all players. With the understanding of these problems grew the discussion on the proper approach which resulted in a visible shift to more horizontally-based governance where more responsibilities were placed on shoulders of non-governmental and private organizations (see Figure 10).

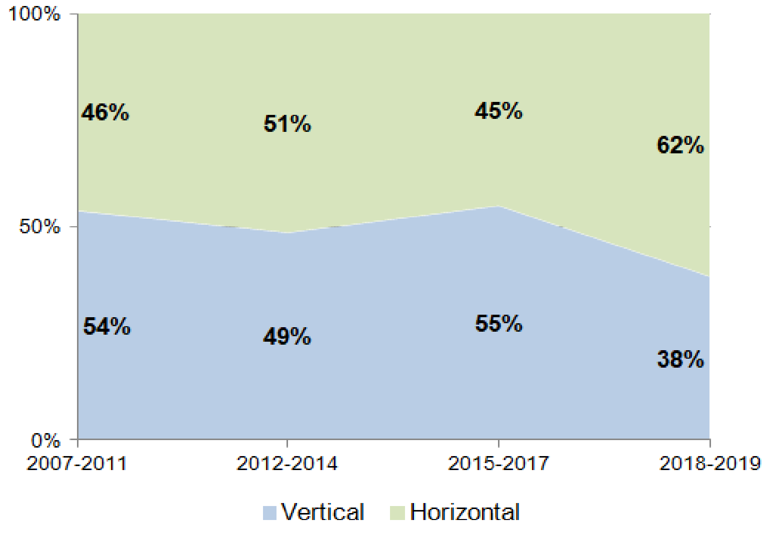

Figure 10. Governance approach discussion

On the most general level, it can be concluded that the approach suggested by most players is to concentrate responsibility for guidance and for licensing in one hand and to move the responsibility for sustainable space usage to operators making the one responsible for its garbage. Actors believe that such an intermediary would allow to gain legitimacy of solutions and chosen direction of development among all actors and public faster, while diversified responsibility for debris themselves would stimulate actors to solve the problem of pollution. Yet, questions of who should be the guiding actor and how to make it operating acceptable for all types of players is still a point of discourse due to the lack of authority and trust among stakeholders.

As the answer for the second subquestion, *"How did the issue of space debris management gain legitimacy over the years?"* we propose*:*

During the first stage of the development of ADR as innovation, the discourse was mainly formed by arguments on local validation aimed at gaining legitimacy among experts and incumbent players. Mostly, the whole dispute consisted of questions about how urgent are the needed actions and whom to involve in the process of debris removal. Thus, the dominant discourse was about possible financial profits and losses for possible strategies. Once crucial, incumbent actors have accepted the need for ADR and that it is economically beneficial for the whole industry, actors started to justify the need for ADR among all the actors of the space sector and the public.

Intense diffusion of active removal legitimation started in the second period and got the most significant attention by the middle of the second decade of the 2000s. At the same time, NASA and the whole industry have set their goals at attracting more players such as developing countries or catching-up actors to the problem; thus, the discussion here was formed to gain awareness and understanding among stakeholders. Beliefs of actors might explain relatively rare attempts to discuss general validation over this stage that all the needed actions are rather technical and touch mostly those actors who actively pollute the space.

In fact, suggested solutions often turned out to be a complex approach combining mitigation practices such as taxes with technological intervention such as disposal of non-operating satellites. Such solutions would affect all the people as taxes usually increase the prices of a final product such as smartphones or the internet. Thus, the space industry has shifted more to the stage of general validation and has started to discuss topics gaining legitimacy among all the non-expert public. However, data about the space itself and technologies used there usually demand a high level of awareness due to the complexity of the topic. Therefore, experts highlight the importance of proper transfer of space situational awareness data that is easy to understand for everybody. Thus, actors of the space sector provoke access to open and straightforward data-sources and discuss hazards that are clear to the public, such as possible damage to spacecraft, damage to people on the Earth, and hazards to space tourism.

6. Discussion

In this chapter, the implications of the research are discussed starting with theoretical implications to the previous literature. Further, we provide policy recommendations based on our results. Lastly, to conclude the chapter, these recommendations are followed by reflections on limitations and quality of the research.

6.1 Theoretical implications

This thesis's crucial implication in the context of mission-oriented policies and transition studies is testing of a novel discourse-based methodology - STNA. Before this research, STNA was only applied to the water management sector, therefore, our results tend to justify the analytical power of the framework. To be more precise, our findings on governance approaches dominant in the space sector correspond with results of the research done by Mazzucato and Robinson (2018) on NASA's and ESA's development, showing that the space sector, in general, has transitioned from Type-1 based governance to a more decentralized approach with more Type-2 activities.

In this line, STNA is complementary as it has provided the opportunity to broaden the understanding of why such a transition happened and what rationale behind the change. While previous research focused on actions that actors of the space sector undertake, our study adds a legitimation aspect to the analyses that made it possible to trace reasoning that different actors referred to operating. In this research, we reconstructed the socio-technical dynamics in the organizational field of the space sector and STNA allowed us to do it worldwide and over a long period of time shifting from the explicit focus on NASA or ESA.

6.2 Policy implications

One of the crucial barriers that policymakers should address is the diversity of actors regarding their goals, perceptions, and capabilities. First, this diversity often makes it impossible or economically unprofitable for lagging players to meet requirements set by suggested guidelines. What is more, actors differ by the type of spacecraft they use, thus, often using spaceships or satellites that are not appropriately licensed or licensed in the same way as other spacecraft types that are different by size or function. That is why actors of the space sector seek a proper licensing that will be, on the one hand, diversified enough to license all the types of spacecraft, but, on the other hand, clear enough to follow.

In response to these challenges, our research proposes the need for an international intermediary for the global space sector. Such an intermediary could become a proper response to many challenges that the space sector actors face nowadays. For instance, an international intermediary agency comprised of worldwide representatives could be more successful in gaining the legitimacy of regulations and guidelines faster among all actors than NASA, ESA, or governments solely. In addition to that, the actors believe such an intermediary will more likely be the leader with clear goals and efforts that are easy to understand and follow. What is more, an intermediary agency representing the whole society's interests rather than one country's goals (such as NASA) would help overcome a lack of trust among stakeholders and gain awareness of space debris among the public.

6.3 Limitations and research quality

Some limitations and possible improvements in the research should be discussed. First, the analyzed data consists of sources only in English while it may result in the absence of part of the discourse; therefore, the national context of the space sector's development might be lacking for non-English speaking countries. Thus, the researched discussion is dominated by reports and testimonies to English, American or Australian governments, while data for a proper analysis of other countries' national space activities should be gathered in their native languages. What is more, the resulting database of articles was unequally distributed among phases in terms of the amount of articles per phase. This could result in the false explanation of the development of the sector (for instance, tending to explain the strength of some links changing from phase to phase). To avoid this, in further research, phases of development should be harmonized in terms of types and amount of articles comprising each period.

Secondly, terms such as traffic management or remediation activities are not strictly defined due to the novelty and diversity of approaches among actors describing the space sector. Therefore, some activities, such as tracking the garbage pieces, might be assigned to different groups of codes. Nevertheless, to neglect this limitation, the research draws on the conceptual framework of the space sector provided by Brian Weeden (2020), making the study possible to be replicated.

Lastly, despite the fact that STNA is aimed explicitly to reconstruct the development of socio-technical configurations of the given sector, which corresponds to the goal of this study, another methodological approach could have been chosen. It would be of added explanatory value to conduct interviews with experts in addition to the core data to supplement results with experts' opinions and explanations of crucial events.

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8. References

BBC News. (2012). ISS crew take to escape capsules in space junk alert. Data assessed: 10/09/2020. https://www.bbc.com/news/science-environment-17497766

Bergek, A., Jacobsson, S., & Sandén, B. A. (2008). 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems. Technology Analysis & Strategic Management, 20(5), 575-592.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research policy, 37(3), 407-429.

Binz, C., Harris-Lovett, S., Kiparsky, M., Sedlak, D. L., & Truffer, B. (2016). The thorny road to technology legitimation—Institutional work for potable water reuse in California. Technological Forecasting and Social Change, 103, 249-263.

Cicchetti, D. (2010). Resilience under conditions of extreme stress: a multilevel perspective. World Psychiatry, 9(3), 145.

El Bilali, H. (2018). Transition heuristic frameworks in research on agro-food sustainability transitions. Environment, development and sustainability, 1-36.

European Space Agency (2014). About space debris. Data assessed: 10/09/2020. https://www.esa.int/Safety_Security/Space_Debris/About_space_debris

European Space Agency (2019). ESA commissions world's first space debris removal. Data assessed: 26/02/2020.
https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

European Space Agency (2020). ESA's Annual Space Environment Report. Data assessed: 05/10/2020.
https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

Fuchs, G. (2019). Legitimacy and field development: Electricity transition (s) in Germany. Global Transitions, 1, 141-147.

Ge, B., Jiang, D., Gao, Y., & Tsai, S. B. (2016). The influence of legitimacy on a proactive green orientation and green performance: A study based on transitional economy scenarios in china. Sustainability, 8(12), 1344.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research policy, 31(8-9), 1257-1274.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental innovation and societal transitions, 1(1), 24-40.

Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. Journal of transport geography, 24, 471-482.

Geels, F. W. (2018). Socio-technical transitions to sustainability. In Oxford Research Encyclopedia of Environmental Science.

Grin, J., Rotmans, J., & Schot, J. (2010). Transitions to sustainable development: new directions in the study of long term transformative change. Routledge.

Heiberg, J., Binz, C., & Truffer, B. (2020). Assessing transitions through socio-technical network analysis â€“a methodological framework and a case study from the water sector (No. 2035). Utrecht University, Department of Human Geography and Spatial Planning, Group Economic Geography.

Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting and social change, 74(4), 413-432.

Jacobsson, S., & Bergek, A. (2011). Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environmental Innovation and Societal Transitions, 1(1), 41-57.

Johnson, C., Dowd, T. J., & Ridgeway, C. L. (2006). Legitimacy as a social process. Annu. Rev. Sociol., 32, 53-78.

Karltorp, K., & Sandén, B. A. (2012). Explaining regime destabilisation in the pulp and paper industry. Environmental Innovation and Societal Transitions, 2, 66-81.

Kattel, R., & Mazzucato, M. (2018). Mission-oriented innovation policy and dynamic capabilities in the public sector.

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. Research policy, 37(4), 596-615.

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. Research policy, 41(6), 955-967.

Mazzucato, M., & Robinson, D. (2017). Market creation and the European space agency. European Space Agency (ESA) Report.

Mazzucato, M., & Robinson, D. (2018). Co-creating and directing Innovation Ecosystems? NASA's changing approach to public-private partnerships in low-earth orbit. Technological Forecasting and Social Change, 136, 166-177.

NASA Headquarters Library (2020). Space Debris. Data assessed: 25/09/2020.
https://www.nasa.gov/centers/hq/library/find/bibliographies/space_debris

Smith, A., Voß, J. P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. Research policy, 39(4), 435-448.

Stirling, A. (2007). Deliberate futures: precaution and progress in social choice of sustainable technology. Sustainable Development, 15(5), 286-295.

Suurs, R. A., Hekkert, M. P., Kieboom, S., & Smits, R. E. (2010). Understanding the formative stage of technological innovation system development: The case of natural gas as an automotive fuel. Energy Policy, 38(1), 419-431.

Twomey, P., & Gaziulusoy, A. I. (2014). Review of System Innovation and Transitions Theories-Concepts and frameworks for understanding and enabling transitions to a low carbon built environment. VP2040 Foreground paper.

US National Research Council. (2011). Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs. Washington, DC: The National Academies Press. https://doi.org/10.17226/13244

Van den Bergh, J. C., Truffer, B., & Kallis, G. (2011). Environmental innovation and societal transitions: Introduction and overview. Environmental innovation and societal transitions, 1(1), 1-23.

Wasserman, S., & Faust, K. (1994). Social network analysis: Methods and applications (Vol. 8). Cambridge university press.

Weber, K. M., & Rohracher, H. (2012). Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. Research Policy, 41(6), 1037-1047.

Weeden, B. (2020). Space Situational Awareness: Examining Key Issues and the Changing Landscape. Data assessed: 25/09/2020
https://science.house.gov/imo/media/doc/Weeden%20Testimony.pdf

Wilpert, B. (2001). The relevance of safety culture for nuclear power operations. In Safety culture in nuclear power operations (pp. 23-37). CRC Press.

Yap, X. S., & Truffer, B. (2019). Shaping selection environments for industrial catch-up and sustainability transitions: A systemic perspective on endogenizing windows of opportunity. Research Policy, 48(4), 1030-1047.

9. Appendices

Appendix 1: Coding scheme

Type	General code	Subcode (explanation)
Governance	Licensing process	Licensing process is not clear
		Licensing for remote sensing satellites is lacking
	Centralized licensing	NASA to lead licensing
		NOAA to lead licensing
		Clear policy for licensing process is needed
		FAA, FCC, NOAA to lead licensing
	US government to lead	DoD responsible for debris removal
		Department of Space to lead debris removal
		US government to take initiative
		FAA to lead
	Operators responsibility	Operators responsible for bringing out their debris of the orbit
		Operators responsible for caused problems
		Operators should prove the necessity of usage of space
		Owners responsible for removing spacecraft after the use
	Transfer SSA data to public	Public database is needed
		Transfer SSA data to public
		Lack of public awareness
	International cooperation	International cooperation and data sharing are needed
	International standards	International standards are needed
	NASA clarify its efforts	Nasa to set up its own clearance efforts
	Need of the R&D	Need for the R&D
	International cooperation	Protocols for informing other operators are needed
	Environmental plan	Space environmental management plan is needed
	Centralized guidance	Centralized guidance
	ESA to lead	ESA to lead
	Governments to lead	Governments to lead
	International cooperation	International working group
	NASA to lead	NASA to lead
	US government to lead	US government to lead
	Collaboration of ESA and NASA	Collaboration of ESA and NASA should be more intense
	Decentralized guidance	Decentralized guidance
	National guidance	National space agency is a proper intermediate
		National working group in needed
ADR	ADR	Laser beam
		Ground-based laser
		Space-based laser
		Robotic arm
		Tether

ADR	ADR	Magnetic capture mechanism
		Net
		Harpoon
Mitigation	25 years disposal rule	25 years disposal rule
	Taxes	Debris footprint tax
		GPS taxes
		Taxes
	Ban space weaponization	Ban on weaponization of space
	Taboo on blowing up space objects	Taboo on blowing up space objects
Traffic management	Traffic management	Avoidance of collisions
		Radar
		Telescope
		Tow truck
		Traffic control system
		Laser ejection
Legitimation	Voluntary guidelines	Existent guidelines are voluntary
		Existent rules are not formalized
		No international rules
	Problem underestimation	Maintenance in space is more difficult
		Lack of tracking technologies
	Developmental conditions	Complex nature of governments hinders flexibility
		Cultural and historical differences between stakeholders
	Damage to people on the Earth	Damage to people on the Earth
	Space weaponization	Debris removal technologies can be used as weapon
	Existent regulations limit industry development	Existent regulations limit industry development
		Existent regulations limit private sector
	Hazard for human-carrying spaceships	Hazard for human-carrying spaceships
	Space tourism	Hazard for space tourism
	Telecom issues	Hazard for tele communicational technologies
	Diverse conditions	Lack of common terms and language
	Lack of communication	Lack of communication to avoid collisions
	Lack of trust among stakeholders	Lack of trust among stakeholders
	Financial matters	The more we wait now the more we will pay in future
		Spacecraft is expensive
		No cost-effective technology
	Tragedy of common goods	Tragedy of common goods
	No required infrastructure in developing countries	No required infrastructure in developing countries
	Kessler syndrome	Passive growth of debris in a cascade effect
	Lack of directionality	Space debris is not a goal-oriented mission
		Clear goal would attract more engineers and finance