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SUSTAINABILITY CHALLENGES AND OPPORTUNITIES IN THE SATELLITE SPACE INDUSTRY: ANALYSIS OF CORPORATE PRACTICE AND A NEW SUSTAINABLE BUSINESS MODEL

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Thesis

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Thesis abstract

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Title	Sustainability Challenges and Opportunities in the Satellite Space Industry: Analysis of Corporate Practice and A New Sustainable Business Model		
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The thesis presents a sustainable business model and analyses of the satellite industry and sustainability. The thesis consists of three goals. The first objective was to talk about the advantages and disadvantages of satellites on Earth and space, as well as space sustainability in the satellite industry. The second goal was to present a sustainable business model as a model framework to advise satellite firms on how to operate profitably, innovatively and sustainably. Anticipating future developments in technology that could boost sustainability and increase business efficiency was the final objective.

The knowledge base of this thesis mainly focuses on sustainability in environmental, social, and economic aspects, as well as space sustainability. The term sustainability was clearly defined by definitions and Sustainable Development Goals. The background of the satellite industry covered its history, basic manufacturing structure, and launching process. A qualitative research method was used in the research process, in which literature reviews, semi-structured interviews, and grounded theory were the main approaches to gathering, analysing, and formulating the theoretical framework.

After gathering and analysing the data, the ESG sustainable business model was created to show how companies can achieve sustainability in social, environmental, economic, and governance aspects. The thesis also discussed the challenges companies face when using the framework at the current stage and how these challenges could be solved. It also mentioned how technological innovations could help solve challenges, contribute to sustainability, and enhance business efficiency and productivity.

The terms “sustainability” and “space sustainability” are of rising awareness nowadays. Governments, companies and authorities have recognised the importance of sustainability. However, there is a crucial need for regulations and financial funding from governments and authorities to supervise and support the companies in investing and adopting sustainability into operations since companies are currently facing challenges in achieving sustainability.

Keywords space, space debris, sustainable development, corporate responsibility, satellite, business model, business

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1 INTRODUCTION

The commercial space industry and space economy are emerging and expected to grow rapidly in the next five years. Space economy means the activities and use of resources that generate value and benefits for humans while exploring, understanding, researching and utilising space (OECD 2012). The space economy and its commercial activities are still new and have yet to mature in the world, but it has the potential to be a new trend. According to the report released by McKinsey & Company, the space industry has grown from about 280 billion dollars in 2010 to approximately 447 billion dollars in 2022, and it is expected to reach around 1000 billion dollars by 2030 (McKinsey & Company 2023). The space industries have different fields of business, such as space tourism, satellite launch and manufacturing, space mining, satellite navigation and communication services, etc.

This research will focus only on satellite manufacturing and launching to narrow down the topic since, among the fields above, satellites have been a leading trend. They are utilised in many industries and businesses worldwide. For instance, navigation satellites are utilised for forecasting weather and storms, signalling in trains and aircraft, emergency responses in ambulances, fire-fighters and the police, and organising power grids in energy networks (ClearSpace 2023). Although satellites have helped humans in daily life, even helping track and observe global warming on Earth, they generate light pollution, space debris, and carbon emissions during the launch of rockets and the function of satellites. Soon, more companies will join the satellite and rocket launching industry, meaning more rocket launches will happen in different countries, and the impact on Earth and space will be more serious. Therefore, to ensure sustainability in this new industry, more research will be needed to discuss the effects and challenges of companies working towards sustainability and possible ways of achieving sustainability. This research may help companies find valuable methods to adopt into operations and help other people develop further detailed research in the future.

The thesis aims to analyse the current situation and practices in the satellite industry and introduce a sustainable business model for companies to work towards sustainability. Setting objectives can clearly outline what is included in the research topic. The first objective is to discuss the impacts that satellites bring to Earth and space and the current situation of space sustainability in the satellite industry. The second objective is to introduce a sustainable business model as an example framework to guide satellite companies on how to act and behave sustainably to protect the rights of future generations to use the space while making profit and continuing innovations. The third objective is to anticipate how technology innovation could enhance space sustainability while improving business efficiency in the future.

The research questions fulfil the thesis objectives and guide and present the main points. Questions include what impacts the satellite launch and operations may have on the environment and space, how the sustainable business model could solve problems and help companies work towards sustainability, and what the possible challenges are at the current stage. Moreover, the research question is how technology may enhance the efficiency of satellite business operations in the future.

This thesis has four main parts. The first part is the knowledge base about satellites. It briefly introduces and explains what a satellite is, its history, its functions, how it works, and the negative impacts of satellites. The second part also includes a knowledge base about space sustainability. It consists of an explanation of the term “space sustainability” and the current situation of space sustainability in the satellite industry. The next part concerns the methodology used in this thesis, the data collection process and analysis. The last central part introduces the sustainable business model, a framework for organisations to create and deliver values based on sustainability principles. It guides satellite companies on how to work on sustainability while aiming for profit. This model is designed after collecting and analysing the data.

This research uses a qualitative research method, which uses in-depth interviews and literature reviews as the primary approaches. Data is collected through interviews with experts and satellite companies in Finland. Theory and knowledge are collected from literature such as academic and research articles, books, and online information from authorities and companies. The interviews in this research aim to invite satellite companies and professionals to share, for example, possible challenges of implementing sustainable practices in operations, what they could do to help achieve sustainability, and prospects. Furthermore, the literature analysis could help add more explanation and detailed information about the space and satellite industry. The data collected through literature reading and interviews can help holistically construct a sustainable business model with possible solutions for sustainability, sustainability practices of companies, potential challenges of the companies and industry in the present, and the prospect of the sector.

Though the satellite industry is developing rapidly, and satellites have been used vastly in daily life, the terms of sustainability and space sustainability are still not mature in the industry. Technical skill and cost will be the main problems in technological advancement in the satellite industry in order to achieve sustainability. There needs to be more literature and research papers on this topic. These are the reasons that could limit the research process and results.

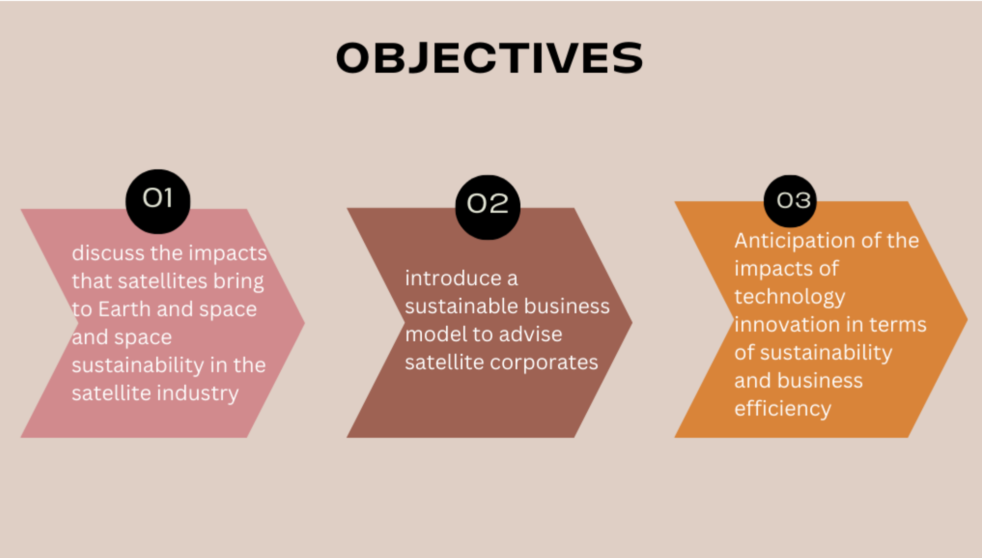

Figure 1. Three objectives of the thesis

2 SATELLITE INDUSTRY

2.1 Introduction of a satellite

A satellite is an object that shifts around a larger object. There are two types of satellites: natural and artificial. Natural satellites are, for example, Earth and the Moon because the Earth travels around the sun while the Moon goes around Earth. Artificial satellites are machines that are produced and launched into orbit by humans. These satellites are mainly used for communication, scientific research, navigation, Earth observation, weather and even military purposes.

At the early stage of the development of artificial satellites, the Soviet Union and the United States were the first two countries to propose plans for constructing and launching satellites. The first artificial satellite in the world was Sputnik 1, which the Soviet Union launched from Baikonur Cosmodrome at Tyuratam in Kazakhstan on 4 October 1957 (National Aeronautics and Space Administration 2022). The Soviet scientists had been researching and making satellite Object D since 1954. However, they worried they might be unable to launch in time, and Object D might be too heavy to launch on the available rocket (Lewis 2017). Therefore, they decided to produce and launch a lighter-weight satellite, Object PS, also known as Sputnik 1 (Lewis 2017). The purpose of Sputnik 1 was to test if placing a satellite in orbit was feasible. During its operation, it provided scientists with data about satellite pressurisation, radio wave transmission, and the density of the atmosphere, and this data gave scientists a way to learn how to track objects in orbit (Lewis 2017). After three months of operation and 1440 orbits, Sputnik 1 fell onto Earth and burned in the atmosphere. The launch of Sputnik 1 had shocked the world. The United States caught up with launching their first satellite, Explorer-1, on 31 January 1958 by Jupiter-C rocket from Cape Canaveral. It led to the space race between America and the Soviet Union to prove who was the most technologically advanced. Since then, satellites have been continuously improved to have more functions such as communications, weather forecasting and navigation.

Manufacturing a satellite involves numerous material requirements since different factors could affect its function, durability, and probability of a successful launch.

Satellites have several typical subsystems, and each has its unique operational function. Satellite subsystems comprise the mechanical structure, propulsion, thermal control, power supply, telemetry, tracking, command, attitude, orbit control, payload, and antenna subsystems.

To begin with, the mechanical structure serves as an interface between the satellite and the launch vehicle and a structure for intensifying other subsystems. For example, it supports all the electronic equipment on the satellite and protects the satellites from energetic radiation, dust, and micrometeorites in space. The common materials used to produce a satellite are aluminium alloys, magnesium, titanium, and beryllium. The feature of these materials is that they are lightweight but strong enough, as the essential requirement for a satellite is the lightness of the mechanical structure. Otherwise, it will be too heavy to launch. Moreover, the mechanical structure design should withstand various conditions, including vibration, temperature change and accelerations that could cause failure and plastic deformations, and ensure reliable operation (Reda et al. 2023).

In addition, the primary function of the propulsion subsystem is to offer the thrusts needed throughout the satellite's lifespan, including velocity adjustment, change in orbit altitude, attitude control, station keeping and deorbit at the end (National Research Council, Division on Engineering & Physical Sciences 2006). It generates thrust in the opposite direction by expelling mass at a certain velocity in one direction. There are three propulsion systems: solid fuel propulsion, liquid fuel propulsion, and electric and ion propulsion. The next subsystem is the thermal control subsystem. It aims to keep the satellite platform working within temperature limits for the type on board the satellite and ensure the desirable temperature distribution throughout the satellite structure. It is vital in providing specific equipment's dimensional stability and alignment.

The next component is the power supply subsystem, which stores batteries and provides electrical power during eclipse periods, emergencies and the launch phase. Its function also includes the collection of solar energy and transformation to electrical power. Moreover, the telemetry and tracking command subsystems supervise and manage the satellite during its life cycle, for example, tracking its subsystem health and determining the positions of the spacecraft. The attitude and orbit control is also a part of the satellite. It is responsible for controlling the orbit path and attitude so that the satellite is functioning in the correct position and is at a fixed point on the surface of Earth. The remaining two subsystems are the payload subsystem and antennas. The payload subsystem is a system that holds the mandatory equipment for completing the mission. For instance, the main task of a weather forecasting satellite is to scan and measure clouds, the temperature in layers of the atmosphere, and ocean surface wind to provide accurate weather prediction. Therefore, a radiometer must be carried to perform the work, which is the payload system of the weather forecasting satellite. Antennas are for receiving and transmitting signals from and towards the ground stations (Reda et al. 2023).

To successfully launch satellites into space, satellites are put on rockets with propellant, which aids in lifting the rocket. When a rocket burns fuels, and exhaust is forced out, the rocket can eventually take off. This upward force that boosts the rocket is called thrust. As long as the thrust is greater than the force of gravity, the rocket can keep going without being pulled down. The speed plays a crucial role in launching. A rocket will not be dragged down to Earth if it accelerates to more than 17,800 miles per hour and passes over most of the atmosphere. A satellite will be released once it reaches a predetermined distance from Earth. The momentum pulls the satellite in one direction while the gravity of Earth pulls it in another direction. This keeps the satellites continuing to circle Earth (NASA Space Place 2024). When satellites orbit around Earth, they transmit voice, video, and data communications to numerous locations across large geographic sites. An uplink Earth station or equivalent ground device sends the desired signal to the satellite for satellite communication. The incoming signal is modified in frequency and amplified by the satellite. The signal is sent back to Earth by the satellite and is received by the ground machinery (Intelsat 2024).

Not all satellites are placed at the same distance from Earth. Their purposes and missions decide which orbit the satellites should be in. Orbits are classified into three types based on distance: low Earth orbits (LEOs), medium Earth orbits (MEOs), and geostationary Earth orbits (GEOs). Low Earth orbits mean satellites move around Earth about 160 to 500 km from Earth. Low-Earth orbit satellites are smaller, less expensive, and require less power to broadcast signals due to their shorter orbital periods and less propagation delay.

Nevertheless, because of their shorter orbital periods, these satellites only spend briefly an hour and a half over a specific ground station. For round-the-clock coverage, multiple satellites are required (Maini & Adrawal 2014, 3u). Satellites in low Earth orbits are usually used for communication, weather forecasting, remote sensing, scientific studies, and surveillance. Compared to low Earth orbits, satellites in medium Earth orbit maintain a longer distance from Earth, between 10000 and 20000 km. Since medium Earth orbit has a longer distance, these satellites have more extended orbital periods of 6 to 12 hours and increased propagation delays. Medium Earth orbits are suitable for communication and navigation satellites (Maini & Adrawal 2014, 3v). The distance of the geostationary Earth orbit is much greater than the previous two orbits. It requires satellites to keep approximately 36000 km from the surface of Earth. Due to the long distance, it is prograde and has the same orbital period as the rotation of Earth. When an orbit is circular and in the plane of the equator, it remains stable for a particular place on Earth. This is why it is called geostationary Earth orbits (Maini & Adrawal 2014, 3v). Geostationary Earth orbits are suitable for communication, TV broadcasts, and meteorological and military surveillance satellites.

2.2 The functions of a satellite

Satellites are built to be used for different purposes. The commonly used satellites are weather forecasting satellites, communication satellites, global positioning systems, and remote sensing satellites. Weather forecasting satellites scan and measure the weather patterns and conditions such as clouds, wind speed and temperature. It helps the Weather and Meteorological Institute to provide weekly and daily accurate forecasts, and people can easily plan for outdoor events and prevent potential disasters.

Communication satellites are responsible for global communication through Internet connectivity, telecommunication, and television broadcasting. A communication satellite refers to a microwave repeater station exchanging data with earth stations by permitting two or more users in numerous methods (Elbert 2008). The information and data are delivered by communication satellites by receiving and transmitting signals from and to the ground. The coverage of satellites is not limited by regional, national, or continental boundaries, and satellites can provide services to any size of region they can see in the world (Elbert 2008). For example, when people make phone or video calls globally, these services rely on telecommunication networks worldwide, which are supported by communication satellites. It works similarly to transmitting television signals so that households can have a variety of television channels and programmes such as sports, entertainment, news, and education. In addition, communication satellites can be used for military and government purposes. Secured and encrypted voices, videos, and documents from the military and government can be delivered safely through communication satellites for embassy, command, and information collecting.

Global Navigation Satellite System is also known as GNSS. Navigation services that offer accurate position and timing information for vehicles, mobile and other appliances rely on these global positioning system satellites. The standard features that people use in daily life are, for example, navigation applications such as Google Maps and Apple Maps, as well as navigation systems in cars to search for the destination. The application guides the different routes, directions, transportation methods, and predicted arrival times. Global Navigation Satellite System can also help search and rescue in accidents and emergencies. When a person activates an emergency distress beacon, it transmits rescue signals containing the position information to the authority. GNSS system accurately follows and monitors the location and movement of the person. Rescuers can use GNSS systems, which are usually equipped for rescue vehicles, aircraft, and boats, to find the location of the person quickly. One of the well-known GNSS systems in the world is Galileo, which is a European global navigation satellite system. Its purpose is to offer a precise, certain and worldwide positioning service under civilian control that civilian European institutions fund (Leick, Rapoport & Tatarnikov 2015).

Remote sensing satellites are known for scientific research, environmental assessment and monitoring, agriculture, urban planning, and tracking disasters and weather. A remote-sensing satellite uses high-resolution cameras, multispectral scanners and thematic mappers to scan and collect data about Earth's surface, atmosphere and oceans. The data could be from different types of radiation, including visible light, infrared, microwave, and radio waves. It is also advantageous in protecting the environment by tracking land use, climate change, and air pollution. One of the cases is water resources management. A remote-sensing satellite can help achieve water security by data collection and observation. Scientists and authorities can use the data to forecast floods and droughts and implement mitigation measures beforehand. For instance, it can measure the hydrological cycle involving rainfall, evaporation, lake and river levels, surface water, soil humidity, snow and total water storage (Sheffield et al. 2018, 2).

Additionally, remote-sensing satellites collect data about water security in regions, food production, storage and trade (Sheffield et al. 2018, 2). With the help of satellites in monitoring water supply and quality, governments and policymakers can better understand the water usage in each area, water sources and locations. They can make efficient decisions on infrastructure upgrades and maintenance, such as building pipelines, dams, and irrigation systems to increase the water supply and access.

The development of various types of satellites has helped us enhance the sustainability of Earth. On social sustainability, satellites can help protect human rights and work for better human lives. For example, satellites RF Geolocation from HawkEye 360 can collect and process signals from VFH radios to communicate between vessels and offer location and activity information to users. Actively tracking ship movements can ensure safety and security, such as helping in navigation, preventing collisions of ships, assessing the suspicious activities of vessels during the dark period and monitoring illegal activities, including human trafficking, smuggling, IUU fishing and piracy (HawkEye 360 2024).

Satellites are also helpful in solving hunger and poverty. According to the statistics, 18000 children die from poverty each day globally, and 836 million people live in extreme poverty (UN Office for Outer Space Affairs & European Global Navigation 2018). Governments and authorities can use satellites to monitor crop health, land use, and agriculture. They can also acquire accurate data about weather forecasts and disasters such as drought and floods to prevent them on time and enable early warning systems. When farmers receive detailed analysis and information about agriculture, they can quickly respond to weather changes, bad health of crops and natural disasters. This can help minimise the negative impacts and ensure agricultural productivity and food security. If the supply of crops rises, farmers can sell and make more profits while other people can have enough food to eat, which can decrease poverty and hunger.

Regarding the environmental aspect, satellites play a crucial role in monitoring the environmental conditions on Earth. Climate change is mainly caused by greenhouse gas emissions from burning fossil fuels such as coal, oil and natural gas to generate energy, production in factories, deforestation and transport. In order to understand the amount of carbon footprint generated, some companies adopt the carbon footprint calculation or their consumption calculating formula. According to the corporate value chain accounting and reporting standard from the Greenhouse Gas Protocol, it includes three scopes of emissions from companies: direct sources, indirect sources and upstream and downstream sources (Bhatia, Cunnis, Rich, Draucker, Lahd & Brown 2011). Direct sources refer to the energy consumption and materials processing during production in factories of the company, and the emissions generated through their vehicles. Indirect sources imply the emissions from the purchased electricity. Upstream and downstream sources mean business travel, processing of sold products, transportation and distribution and use of sold products (Bhatia et al. 2011). There are two quantification methods to collect emission data. First, companies can do calculations by multiplying activity data by the emission factors (Bhatia et al. 2011). Another method is direct measurement of direct emissions data, which uses direct monitoring, mass balance or stoichiometry (Bhatia et al. 2011). After calculation, they publish their environmental impacts and sustainability efforts in the annual sustainability report according to the reporting standards. However, this type of sustainability measure is optional for all companies. It is voluntary for them to implement sustainability reporting in their operations.

Moreover, the sustainability calculation may need to be more accurate. Additional methods, such as carbon dioxide and methane, can help improve the accuracy of tracking and measuring greenhouse gas concentrations in different regions and the atmosphere. For example, GHGSAT, a Canadian satellite company, manufactures satellites to help companies and government entities track greenhouse gas emissions worldwide and understand their sources (GHGSAT 2024).

Satellites also play an essential role in tracking global efforts in environmental sustainability. Global warming has significant environmental impacts. The main phenomena are rising average global temperatures, changes in precipitation patterns and more extreme weather such as intense rainfall and drought, rising sea levels due to ice melting, and ocean warming and acidification. With the application of satellites, scientists and government entities can track the current condition and environmental changes by observing sea levels, ice cover including ice caps, glaciers and ice sheets, ocean surface temperature and circulation patterns, and weather patterns. By raising the understanding of current climate change and global warming conditions, governments, companies and authorities can make more accurate predictions and develop effective strategies to mitigate climate change and minimise emissions.

Another aspect of sustainability is economics, which refers to sustainable economic growth, sufficient investment, and decent employment and work opportunities. Although the satellite industry is new, it has contributed much to other sectors and economic development. According to the literature from the United Nations Office for Outer Space Affairs and European Global Navigation, space programmes in Europe have supported more than 50000 occupations, and the innovation programmes funded by the European Union instruments have encouraged and helped establish many SMEs in the space industry (UN Office for Outer Space Affairs & European Global Navigation 2018). Hence, the emerging space industry provides employment opportunities to society and facilitates economic growth. Apart from generating more work opportunities, satellites also offer space data to help increase the productivity of other industries. For example, in the transport and logistics industry, satellites provide navigation and positioning services such as real-time traffic information, route navigation and vehicle tracking for transport operators to monitor driver performance, arrange efficient and time-saving routes, and reduce inventory losses and delivery inaccuracy. It could help reduce fuel consumption and operation costs and improve efficiency and productivity. Households could also save money on fuel expenses, which leads to more income savings and better planning in resource allocation.

2.3 Issues and problems of satellites

Satellites have become indispensable in daily life since they contribute to various aspects of society. Without satellites, economies, industries and even humans would not be able to be as productive and efficient as now. Despite the vast contribution of satellites to society, the space industry's awareness of satellite-related issues has been rising.

The first concern is light pollution. The satellite itself will not generate light, but the light source is usually the reflection of sunlight. It mainly affects stargazing, astronomical observations and scientific research performed by ground-based telescopes and observatories. The satellites and space debris will be captured with ground-based telescopes, which may cause loss and damage to astronomical data and information. The issue can be significant and affect night sky visibility during the twilight hours or in spots with dark skies. However, the possibility of the brightness of satellites affecting astronomical activities depends on the altitude of the satellites, the position of the observer and time. The brightness of satellites that are in low Earth orbit is stronger. Still, since they enter the shadow of Earth earlier than the satellites in higher orbit or geosynchronous Earth orbit, the impact is less significant (Koller, Thompson & Riesbeck 2020). Satellites at higher orbits or geosynchronous Earth orbit have longer interference periods. Nonetheless, they are far away. Thus, they could be brighter for observers (Koller et al. 2020).

Although light from satellites is not a serious problem compared to streetlights and buildings, it is a rising concern. When satellite launches become frequent, and the amount of satellites in orbit grows in the future, the problem will worsen. Moreover, if the number of satellites and space junk significantly increases, the probability of any plan and adjustment of observation position and altitude will still be affected (Kocifaj, Kundracik, Barentine & Bara 2021). In recent years, the number of satellite launches has been growing rapidly, and it has been an alarming topic for scientists and astronomers. SpaceX launched the first 60 Starlink satellites in May 2019, and the total working satellites until the beginning of April is more than 5500, according to the astrophysicist and satellite tracker Johnathan McDowell (McDowell 2024). Globally, there are more than 9600 active satellites in April 2024, most of which are in low Earth Orbit (Orbiting Now 2024). These satellites are mainly for communication. The number of satellites is constantly increasing, and astronomers and scientists are concerned about the impact on night sky visibility caused by satellites and space debris. According to research conducted in 2021, the night sky brightness caused by space objects, including satellites and space objects reflecting and scattering sunlight, increased (Kocifaj et al. 2021). There will be more satellite launches from various countries in the future. Therefore, it is necessary to find mitigation solutions.

The next concern is greenhouse gas emissions. Satellite launching to space relies on rockets. Several stages are needed for orbital rockets to generate thrust through the atmosphere of Earth. The first stage is burned on the launchpad, which will use most of its fuel and be discarded before lighting the next stage. Booster or lower rocket stages not attached to the central launch vehicle are disposed of or reused after every phase (Ryan, Marais, Balhatchet & Eastham 2022). They either return to the surface of the Earth and fall into the sea or land if they are reusable (Sirieys, Gentgen, Jain, Milton & de Weck 2022). The speed of the upper stages is usually excessive enough to remain in orbit for a while, and then they re-enter the atmosphere and partly break down (Sirieys et al. 2022). The common fuels used in rocket launches include kerosene, hypergolic fuels, liquid hydrogen, and solid fuels (Ryan et al. 2022). The emissions generated from burning fuels are, for example, water vapour, chlorine, hydrogen gas, hydroxide, alumina, soot and nitrogen oxides (Sirieys et al. 2022). The amount of these emissions depends on the size of the launch vehicle, but they will disperse globally, disturbing the atmosphere of Earth and worsening the problem of climate change. The possible impacts on Earth are stratospheric ozone depletion, ice nucleation, high-altitude cloud formation, radiative forcing and climate change (Sirieys et al. 2022). Although the emissions from rocket launches are little compared to the common air pollution generated from burning fossil fuels, such as motor vehicles, household devices, factories and forest fires, the problem of emissions from launches will be more serious when there are more launches globally. Therefore, discussing ways to mitigate and prevent the problem from worsening is necessary.

Space debris is also one of the concerns, and it has been the most frequently discussed recently. Space debris is any artificial space objects that are no longer in active use, such as spaceships, satellites, and rockets. The types of space debris are, for instance, inactive satellites that have ended their life span, spent rocket parts that are used for satellite launches, and debris generated by explosions and collisions (Habimana & Parama 2018). Typically, commercial satellites such as communication satellites are put in the low Earth Orbits and can fall back to Earth due to atmospheric drag and their design to minimise the generation of space debris. However, if the satellites are placed in higher orbit, the orbital debris will remain in Earth orbit for longer. Debris in low orbits below 600km will return to Earth in several years. If satellites are placed higher, it will take centuries for 800 km altitude and more than a thousand years for above 1000 km altitude to fall back to Earth (Astromaterials Research and Exploration Science 2022).

The generation of space debris due to breakup events from explosions and collisions could be intentional or accidental (Habimana & Parama 2018). Intentional explosion and destruction mean that the space object is designed to have a self-destruct mechanism. There was a case of severe destruction, regarded as one of the worst events. The Chinese Fengyun-1C satellite, an obsolete weather satellite launched from Earth on 11 January 2007 and orbiting at approximately 900 km, was deliberately destroyed and generated over 3300 space debris. (Habimana & Parama 2018). Accidental collision refers to two space objects crashing into each other and being destroyed. There was a case in history where two satellites crashed together. This accident happened 800 km above Northern Siberia on 10 February 2009 where Iridium 33, which was an active US communications satellite, collided at a speed of over 40000 km per hour with Cosmos 2251, which is a defunct Russian satellite (Habimana & Parama 2018). Both satellites were completely destroyed after the collision, producing more than 2200 fragments (Habimana & Parama 2018).

Another type of accident is related to propulsion-related failures, which means that propellants explode and generate space debris when carrying spacecraft or liquid-fuel rockets into high orbits. However, the chance of explosion related to propulsion failure has been lower since ESA, Japan, and the United States now exhaust their upper stages after payload delivery (Habimana & Parama 2018).

With the increasing number of satellites and frequent satellite launches, the collision risk is increasing since the orbit has become more crowded. If space debris crashes with active satellites such as navigation and positioning satellites and communication satellites, it will disrupt network and navigation services. The crowding orbit will potentially interfere with radio frequency and narrow the margin of error for preserving separation between satellites (Secure World Foundation 2018). Moreover, the collision will generate more space debris and make orbits more crowded. According to NASA information, as of January 2022, there are over 25000 space debris bigger than 10 cm in Earth orbit, and small debris between 1 and 10 cm in diameter is estimated to be 500000 (Astromaterials Research and Exploration Science 2022). At the current stage, cleaning space junk is still a challenge, so companies need to minimise and prevent the generation of space debris, which can be done by careful design and operations.

3 SPACE SUSTAINABILITY

3.1 Definition of sustainability

The term sustainability was defined and clarified by the United Nations Brundtland Commission in 1987 as fulfilling the current needs without negotiating the capability to meet the needs of future generations (The United Nations, 2023). In other words, it means that the present development should prevent depleting resources so that they can be maintained continuously in the long term and the future generation can have the ability to meet their needs. The report introduced the three pillars of sustainability development: economic, social, and environmental.

Environmental sustainability refers to a balanced, resilient, and interconnected condition in which humans satisfy their resource needs without exceeding the capacity and health of ecosystems (Morelli 2011). The main focuses in environmental sustainability are, for example, the loss of biodiversity, exploitation of natural resources, climate change, and water and soil pollution. In order to achieve environmental sustainability, businesses could be aware of the use of energy, carefully track their greenhouse gas emission and improve their manufacturing process by researching environmentally friendly and technological methods to reduce the emissions. They could also supervise sewage treatment and avoid draining sewage into the sea. Moreover, corporates can improve their products by using eco-friendly and durable materials to extend the product life cycles and reduce waste.

Social sustainability refers to the well-being of humans and the community and focuses on human rights, equality, job opportunities, and the right to education and health. The practices that companies could do are to, for instance, eliminate the inequality in gender, ethnicity, ability and cultural backgrounds in the workplaces, provide continuous development, work-life balance, health and wellness support for employees, enhance diversity hiring, and collaborate with stakeholders.

Lastly, economic sustainability refers to maintaining financial stability and engaging in prosperity without causing negative impacts on communities and the environment. Companies' sustainable practices to ensure economic sustainability could include compliance with laws and regulations, enhanced transparency in reporting, and attention to resource efficiency.

To better assess the effort in working towards sustainability in the world, the United Nations established The Sustainable Development Goals. The Sustainable Development Goals were adopted by world leaders in 2015, and it officially began in 2016 (The United Nations 2024). They consist of seventeen goals to work on the economic, environmental and social aspects of sustainability. The goals include No Poverty, Zero Hunger, Good Health and Well-being, Quality Education, Gender Equality, Clean Water and Sanitation, Affordable and Clean Energy, Decent Work and Economic Growth, Industry, Innovation and Infrastructure, Reduce Inequalities, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life Below Water, Life on Land, Peace, Justice and Strong Institutions, and Partnerships (The United Nations 2024). Although the Sustainable Development Goals are not legally binding, countries have the responsibility to evaluate the progress. All stakeholders, including governments, companies and society, are expected to contribute to these goals. The targets were set to be achieved over 15 years, which is by 2030.

Figure 2. A picture of 17 United Nations Sustainable Development Goals (The United Nations 2024)

3.2 What is space sustainability

The definition made by NASA about space sustainability means the ability to continue space activities as long as necessary to meet the needs of the current generation in a safe, peaceful, and responsible way while protecting the outer space environment for future activities and causing less harm to terrestrial life (NASA 2024). Another definition of space sustainability from the Secure World Foundation refers to ensuring that all humankind can use outer space for peaceful purposes and socioeconomic advantage currently and in the long term (Secure World Foundation 2018). In other words, it implies the ability to use outer space in the current and future. Although the problem of untracked debris increases and orbital crowding has started to be a concern for space experts since the 1970s, it did not gain awareness globally before the international diplomatic fora in the 2000s and took years of effort to be a topic on the international space diplomacy agenda (Martinez 2023). This term has come up due to the rising numbers of companies in the commercial space sector and concerns about the impacts of space activities, including the increasing crowding in orbits and the growing density of debris in orbits. To ensure the space environment can still be used in the long term, all stakeholders in the space sector should put effort into mitigating the harmful impacts of space activities on outer space.

If there is a high risk of disruption and collision in the space environment, the space activities that we are currently doing and using for, such as navigation and positioning, earth observation, and telecommunication purposes, will not be able to continue to be implemented in the future. Regarding telecommunications, humans will no longer have access to the internet, communication, and connection with people around the globe, as well as television, entertainment, and even data transfer. The economic and social development will be disturbed, and the disruption of the use of satellites will seriously affect our daily lives. Regarding earth observation, satellites are used to observe the environmental situation, such as sea level, ocean surface temperature and circulation patterns, and weather patterns to assess and track climate change and greenhouse gas emissions. If humans can no longer use satellites to help with environmental sustainability on Earth, it will be difficult to achieve sustainability and protect the environment. Therefore, in order to protect the capacity to use the space environment for future generations, it is essential to come up with strategies and measures to mitigate the harm to outer space.

Since the launch of the first artificial satellite, Sputnik I, the United Nations has paid attention to the peaceful use of outer space and recognised the potential of space technology for socioeconomic development. The Committee on the Peaceful Uses of Outer Space, also known as COPUOS, was established by the General Assembly in 1959. Its purpose is to manage space exploration and utilisation for the benefit of all people, including peace, security and development (United Nations Office for Outer Space Affairs 2024). The tasks of COPUOS include revising worldwide collaboration in peaceful uses of outer space, reviewing space-related actions that could be carried out by the United Nations, supporting space research programmes, and considering legal problems resulting from space exploration (United Nations Office for Outer Space Affairs 2024).

In order to promote cooperation between countries and international organisations about peacefully using outer space, the United Nations organised three conferences in Vienna. The first conference, UNISPACE I, was held in 1968 and aimed to raise awareness of the potential of space benefits for all humans (United Nations Office for Outer Space Affairs 2024). The second conference, UNISPACE II, was organised in 1982, focusing on the methods to preserve outer space for peaceful purposes, prevent military race in outer space, and foster global collaboration so that developing countries can benefit from the peaceful application of space technology (United Nations Office for Outer Space Affairs 2024). The third conference, UNISPACE III, was held in 1999, developing a proposal for the peaceful uses of outer space in the 21st century. The plan was about the protection of the worldwide environment and management of natural resources, increasing usage of space applications for the safety, development and wellbeing of humankind, space environment protection, and raising the access of developing countries to space sciences and its advantages (United Nations Office for Outer Space Affairs 2024). After this conference, the topics regarding space sustainability, such as space debris and the development of space law and regulation, started to be mentioned in the plan of COPUOS. But it was not a hot topic as it is nowadays. Gerard Brache, who was the French president of COPUOS, suggested putting the space sustainability topic into the agenda of

COPUOS. It took several years to discuss the issue of space sustainability in the United Nations, and it eventually became a global problem that required all countries to take action (Martinez, 2023).

3.3 Current action and framework of space sustainability

The process of working for space sustainability is not easy, and there are several challenges that organisations and governments face when taking action. First of all, space sustainability may be in conflict with current space missions. The primary purpose of space activities, for example, manufacturing and launching satellites, is to provide communication and network services, navigation and positioning services, Earth observation, and scientific research to improve human life. Taking consideration of space sustainability in operations includes cost and schedule constraints because space operations are complex and require decades of coordinated efforts to develop and enhance space technology (NASA 2024). Each space mission requires the expensive construction and hardware cost of developing the spacecraft and launching the vehicle or satellite. A mission failure can cause substantial financial losses, delays in future space mission schedules and even loss in partnerships and collaboration. Hence, companies may prioritise mission success and cost efficiency over space sustainability unless there are incentives provided to the companies to reduce the pressure and obstacles of pursuing space sustainability.

Moreover, uncertainty in the space environment is one of the challenges in achieving space sustainability. Uncertainties in the space environment include space debris, radiation, space weather and orbital dynamics. Learning more about the space environment and clarifying uncertainties can help us understand what action we could take to protect space while ensuring the safe operation of space activities and mission success. For instance, understanding the accurate trajectories and physical features of all orbital debris can decrease the risks of crashing with space debris by applying evasive manoeuvres and shielding spacecraft (NASA 2024). Additionally, understanding the natural variation in the radiation and background plasma environment can help improve the survivability and durability of space object operations (NASA 2024). Fewer uncertainties in space can help make better decisions and develop space technology.

Furthermore, the lack of international regulations and frameworks is a challenge to gather all participants in the space industry. There is little international law about space sustainability, especially space debris. The International Space Law has five treaties: The “Outer Space Treaty” " the “Rescue Agreement” " the “Liability Convention” " the “Registration Convention”, and the “Moon Agreement”. The treaties regulate arms control, the freedom of exploration, liability for damage caused by space objects, the safety and rescue of spacecraft and astronauts, the prevention of harmful interference with space activities and the environment, the notification and registration of space activities, scientific research and the exploration of natural resources in outer space and dispute resolution (United Nations Office for Outer Space Affairs 2024).

In the treaties, space debris needs to be defined and stated. The Outer Space Treaty and the Registration Convention do not recognise rescue rights in space, so a space object, including space debris, still belongs to the launching country (Haroun, Ajibade, Oladimeji & Igbozurike 2021). It is possible and legal to remove them and take space debris remediation only after granting the permission of the launching nation. Besides, international space laws need to be more precise to address the problem of space debris. For example, Article IX of the Outer Space Treaty states that countries are illegal to contaminate outer space. Still, it does not mention what leads to detrimental pollution, what is contemplation, to what extent of degradation, and what type of contamination is prohibited (Hofmann & Bergamasco 2019). Suppose the definition of space debris is not clearly stated, and there are no means to constrain and supervise the harmful impacts caused by space activities from the launching nation. In that case, the problem of space debris will worsen because it may not violate the law and is still legal.

Due to the rising awareness of space sustainability and the urge to take action to remediate and prevent the damaging effects on the outer space environment, the European Commission has been preparing new legislation and rules for safe, resilient and sustainable space activities. The proposal of the regulation aims to pay attention to safety by establishing rules on collision avoidance and space debris mitigation, resilience by establishing regulations specifically designed for the space sector for risk management and cybersecurity, and sustainability by regulating life cycle assessment of space activities and prevention of the light pollution of the night sky (European Commission 2023). The commission adoption is planned to be held in the first quarter of 2024. With the new regulations, it will be easier for governments to supervise the space activities of space operators, prevent and mitigate contamination and worsening situation of space debris, and facilitate the efforts of companies in achieving space sustainability.

Apart from legislation and regulation, there is yet to be a widely accepted conceptual framework and metrics for the space industry to use for measurements, modelling, and assessments. If the space sector does not have precise criteria to assess the risk and impacts caused by, for example, launching vehicles, space debris, space environment, and active spacecraft, the organisations and governments cannot determine whether the space companies are sustainable enough in their operations including risk approach, investment decisions, and future plans (NASA 2024). The effectiveness of their actions cannot be assessed. With assessment, the organisations can reflect on the current effort and improve by planning more suitable mechanisms.

The space industry acknowledged the mounting threats to the Earth's orbit and its ability to contain various new and large space objects safely. Therefore, the World Economic Forum proposed the concept of rating in the Global Future Council on Space in 2016 in order to lessen space debris and ensure safe and sustainable space exploration missions. In 2019, the European Space Agency, the Massachusetts Institute of Technology BryceTech and the Univeristy of Texas at Austin were appointed to develop the methodology of the Space Sustainability Rating (Space Sustainability Rating 2022). In 2021, eSpace, which is under EPFL Space Centre and responsible for education and research, was selected to operate and implement the Space Sustainability Rating (Space Sustainability Rating 2022). Space Sustainability Rating has gone live since June 2022, and the Space Sustainability Association was officially created and will be operating in January 2023 as a non-profit organisation (Space Sustainability Rating 2022). The Space Sustainability Rating is a tiered scoring system which includes four levels: Bronze, Silver, Gold and Platinum. The modules include mission index; detectability, identification and trackability (DIT); collision avoidance capabilities (COLA); data sharing; application of design and operations standards (ADOS); and external services. The mission index weighs the most heavily among the six modules, while DIT, COLA, and data sharing weights medium. ADOS and external services weigh the lowest.

The mission index evaluates how space missions affect the space environment in order to quantify the level of detrimental physical interference brought by the planned design and mission operation. Satellite and mission design, orbital parameters, post-mission disposal strategy and collision avoidance strategy are taken into account. The detectability, identification and trackability, also called DIT, mainly focuses on whether the company can accurately detect, identify and track the spacecraft from the ground (ESA 2023). Collision avoidance strategy aims to enhance the ability of satellite operators to identify, respond to, and mitigate collisions (Space Sustainability Rating 2022). It is measured according to four categories, including orbital state knowledge, availability to coordinate, capability to coordinate and manoeuvre capability. Data sharing refers to satellite and launching operators sharing data such as collision avoidance coordination, satellite and mission information and autonomous systems with stakeholders (Space Sustainability Rating 2022). Different scores will be given according to whom they provide information. The stakeholders included in the evaluation criteria are social security administration providers, other operators upon request for coordination, a voluntary network of operators or stakeholders, and the general public. Application of design and operation standards is seen as a bonus part of the evaluation process since it assesses the operators if they have followed the international guidelines, for example, space debris mitigation guidelines, guidelines for the long-term sustainability of outer space activities, space debris mitigation standards, and standardised operational products. These guidelines are voluntary, and treating this part as an extra part is not to disproportionately discourage the launches from developing space-launching nations that may not have strict regulations (Space Sustainability Rating 2022).

Moreover, this module includes a questionnaire to evaluate the effort in achieving space sustainability regarding releasing space debris, minimising the probability of explosion, spacecraft and launch vehicle passivating after a lifetime, and committing to the guidelines. The questionnaire uses multiple-choice questions, and each answer has different points. The last module of the evaluation process is external services, which is also a bonus part of the rating since not every operator invests in external services. The scoring categories of the external services approach are an on-orbit feature, standardised interfaces, life extension services and use of external ADR (Space Sustainability Rating 2022).

With the Space Sustainability Rating, operators can assess and acknowledge whether their current operations are sustainable or harmful to the space environment. It also encourages all the stakeholders in the space sector to cooperate and research possible and innovative technology and strategies.

4 METHODOLOGICAL IMPLEMENTATION

4.1 Approach

This research will use a grounded theory of qualitative research. Grounded theory was conceptualised and developed by sociologists Anselm Strauss and Barney Glaser. It refers to a methodology that develops a theory from data collected rather than testing hypotheses from existing frameworks (Dunne 2011). It means that a theory is developed after data collection and analysis. The essential steps of grounded theory include initial coding and categorisation of data, concurrent data generation or collection and analysis, writing memos, theoretical sampling, intermediate coding, identifying a core category, and advanced coding and theoretical integration (Briks & Mills 2015). During the development process of grounded theory, Glaser and Strauss found that they could not agree with the classical grounded theory approach due to their differences in theoretical and philosophical assumptions. As a result, they developed the theories separately in 1987 instead of in a collaborative way (Howard-Payne 2016). There are three versions of grounded theory which are classical grounded theory, interpretive grounded theory, and constructivist grounded theory. After their separation, Glaser continued developing the classical grounded theory, while Strauss started to work with Juliet Corbin to develop an interpretive grounded theory (Sebastian 2019). Kathy Charmaz, who is a student of Glaser and Strauss, began to develop a more modernised and constructivist grounded theory approach (Sebastian 2019). It is also called a constructivist grounded theory. However, this thesis will mainly use the interpretive grounded theory.

The interpretive grounded theory has several characteristics. Regarding the role and stance of the researcher, it suggests that the researcher should engage with and actively interpret the information (Sebastian 2019). It also allows the researcher to use their previous knowledge to reinforce the general research and data gathering. Moreover, it clearly states when to implement a literature review. Researchers can review the literature before or during the data collection process because it helps compare data, improve sensitivity and explain or confirm results (Sebastian 2019). Another characteristic is that the chief part of the research study is to create a fundamental or formal theory. The theory can be tested and verified by validating the equivalent data from various viewpoints (Sebastian 2019). In this thesis, a sustainable business model is the main outcome and theory created after data collection and analysis.

Data will be collected through interviews with experts and satellite companies in Finland. Theory and knowledge will be collected from literature such as academic and research articles, books, and online information from authorities and companies. Qualitative research methods are used to collect information about experiences, meaning, and perspective, and they are usually from the standpoint of the researcher (Hammarberg, Kirkman & de Lacey 2016). The data collected through qualitative research methods are unstructured, and it is difficult to do formal counting, measurement and ranking (Hammersley 2013). Qualitative research techniques include observation, audio or video recording with transcripts, interviews that invite informants to talk and interviewer follow-up and encourage more detail and explanation, and analysis of documentary data, such as media articles, official websites and reports (Hammersley 2013). Using qualitative research methods can help address the factors, reasons and possible solutions by discussing and asking what, how, and why questions. Therefore, it is more suitable to be applied in this research.

Furthermore, the literature analysis could help add more explanation and detailed information about the space and satellite industry. This research will be analysed in several sections, requiring reports and webpage information from organisations, media articles, and academic and research papers to support and prove the accuracy. The audience of this research could also gain knowledge and thoroughly understand the industry and current situation of satellite companies. The interviews in this research aim to invite satellite companies to share, for example, possible challenges of implementing sustainable practices in operations, what they could do to help achieve sustainability, and prospects. These topics relate to their experience manufacturing satellites and their knowledge about space, satellite launch, and technology. It might not be helpful to adopt quantitative research methods such as surveys because the general public may need to gain experience and knowledge about the space and satellite industry. Although satellite companies in Finland do not launch their satellites, instead sending them to launch companies in other countries, they still have experience in manufacturing, material requirements, and technology requirements for launching satellite production.

Moreover, interviews could help collect long answers and explanations compared to surveys, in which yes or no questions and scale questions are more common. Interview questions will be prepared beforehand, but it is optional to strictly follow all the questions and allow interviewees to discuss and explain more. They may provide more in-depth answers, which can help with the research.

The data collected through literature reading and interviews can help holistically construct the sustainable business model with possible solutions for sustainability, company sustainability practices, potential challenges of the companies and industry in the present, and the industry's prospects.

4.2 Target group and the choice of data providers

This thesis is about the satellite industry and space sustainability. Therefore, when considering the target group of data providers, two main factors decide whether the target interviewee is suitable for this topic. To begin with, the target interviewee should work or have relevant experience in the space industry, for example, a researcher in the space field, sustainability, and environmental protection, or a technical engineer who has professional knowledge and experience in satellite manufacturing and launching and know the structure and requirement for the satellite. Moreover, the target interviewee is from a satellite company and knows how the satellite companies work. This thesis is not only about the technical part of satellite manufacturing, such as how companies implement sustainable fuels and materials in satellite construction, but also about the practices businesses can follow and their challenges. Hence, collecting data from companies about the preferred communication and marketing strategies for sustainability is crucial; collaboration with other stakeholders such as schools, researchers, other satellite companies and the government, challenges about costs and technical skill, and possible financial incentives is crucial.

The primary method for finding potential interviewees was searching Google. Contact information about satellite manufacturing companies, professors, and specialists in Finland was searched. Emails that included the introduction of the thesis topic, interview questions, interview duration and schedule, and permission for recording and data use were sent to invite the potential interviewees. Another method was through recommendation. Another interviewee recommended one of the interviewees, and contact information was sent to me.

Four interviewees were invited to participate in the interviews. Interviewees are from the satellite industry and space research. The first interviewee is a business development specialist in a satellite company in Finland. She has over seven years of experience in ground control, space business development and satellites. The second interviewee is a doctoral researcher at a university in Finland and an aerospace project manager with seven years of experience in the space sector, ground control and satellite operations. The third interviewee is an associate professor at a university in Finland in the Department of Electronics and Nanoengineering, as well as a senior advisor at a satellite company in Finland. He has experience in satellite manufacturing projects in Finland, satellite-related workshops, and research on space sustainability. The last interviewee is a doctoral researcher at a university in Finland and a project manager for a collaboration project in the space industry in Finland that aims to support and develop space innovation in companies by guiding start-up companies in space innovation, business development and offering funds.

Through interviews with professionals from different sectors in the space industry, their professional knowledge and experiences can help contribute to the thesis about the current situation and challenges the companies have, what are the possible methods that can help with space sustainability such as sustainable fuels, materials, and innovation of cleaning space debris, the financial incentives, communication about sustainability effort to the public and collaboration with stakeholders.

4.3 Description of the data collection process

The data type will be literature, including research and academic papers, books, reports, articles posted on the organisations' official web pages, statistics, and audio recordings. The literature sources will be from LUC-Finna, Google Scholar, Statista statistic portal, and Theseus. The audio recordings are from interviews with satellite companies and professionals.

To collect literature online, the keywords for the search terms are space sustainability, satellite, corporate practices, environment, and sustainability. By entering these keywords in databases such as LUC-Finna, Google Scholar, and Theseus, there will be journal articles, research papers, and books in the results. Reading the title and abstract will help understand whether those materials are relevant to this research content. After citing the relevant information, explaining and proving the sources to show how they relate to the research idea is necessary. To demonstrate the accuracy of the materials, it is vital to find information from peer-reviewed journals and reputable databases.

The audio recordings are from interviews. The first step is to set interview questions. The interview will be conducted as a semi-structured interview. Semi-structured interviews have open-ended questions and an interview guide to help lead the directions of interviews and define sub-questions and topics (Busetto, Wick & Gumbinger 2020). The interview guide can be prepared by reading literature and previous research to decide the area discussed in the interview. After setting questions and topics, the next step is to email the satellite companies and experts and invite them for interviews. If they agree to participate in interviews, time and interview methods, such as online or in person, should be decided. It is also essential to grant permission to record and use their opinions in the research paper.

The interview will be audio-taped, and critical notes will be written during the process. Interviewees can talk and explain the topic using their experience and professional knowledge. Some questions may not be mandatory to ask when interviewees have already described in detail in previous answers, and the interviewees may mention unexpected topics.

4.4 Analysis of the data

The data collected from interviews are saved as audio. After interviews, audio is transcribed as words in dialogue formats. Transcription can contain annotations for behaviours, dialects and filler words, depending on what is anticipated and related to the analysis (Busetto et al. 2020). During the transcription process, audio is played to hear what was discussed in the interviews and write down the speech. The audio is played until no mistake is found to ensure the transcription is correct. The step after transcription is coding, which aims to extract the essential and relevant content and keywords from a sentence. Interpretive grounded theory has three stages of coding which are open coding, axial coding and selective coding. Open coding means coding data by sorting data elements into themes and categories and seeking patterns between categories (Gasson 2004). The next stage is axial coding, which finds relationships of coded elements of data between categories or subcategories and between categories and related properties (Gasson 2004). The relationships can be found by asking W questions, including who, when, where, why, how and what, or examining six Cs such as causes, contexts, contingencies, consequences, covariances and conditions (Gasson 2004). The other stage is selective coding, which combines and refines categories (Gasson 2004).

Those codes will be grouped and summarised according to the related aspects. For example, the sustainable business model aims to be divided into social, environmental, and economic aspects, as well as potential challenges of the model and anticipation of the future. The ideas relevant to these aspects from interviewees are recorded and grouped according to the core categories. Inside a category, it will also be broken down and form several sub-sections to organise descriptive ideas and help develop the theory significantly. For instance, what actions can the company take to contribute to social sustainability, what evidence can be used to prove whether the action is possible to implement, and what facts and figures are available about the situation. Their opinions could contribute new solutions and discoveries for the research questions.

The same coding and data analysis method applies to literature review. When reading and analysing a research paper, keywords and points are captured line by line. After extracting the ideas and keywords relevant to the research questions and topics, they will be recorded and grouped according to the categories.

5 RESULT

5.1 Introduction of a sustainable business model

The sustainable business model is an example framework to guide companies in the satellite industry in how to act and behave sustainably. This model aims to suggest sustainable methods that satellite companies can follow and adopt into operations to protect the rights of future generations to use the space while making profits and delivering value. The sustainable business model is produced after analysing literature reviews and interview results from researchers, experts and a company. The sustainable business model is divided into three pillars: social, environmental, economic and governance. Efforts working towards space and environmental sustainability should not be the sole responsibility of satellite companies but also of the stakeholders in the industry. Therefore, these three aspects include the participation of other stakeholders in the satellite industry, such as the public, different companies and competitors, governments, schools, and the research community. The social aspect of the model is about how companies can communicate and collaborate with society. The environmental aspect focuses on the environment on Earth and space as well. Pollution and space debris are the main topics in this aspect. The economic and governance aspect suggests how satellite companies should implement sustainable practices in treating employees, workplaces, legal and voluntary responsibilities and competitors.

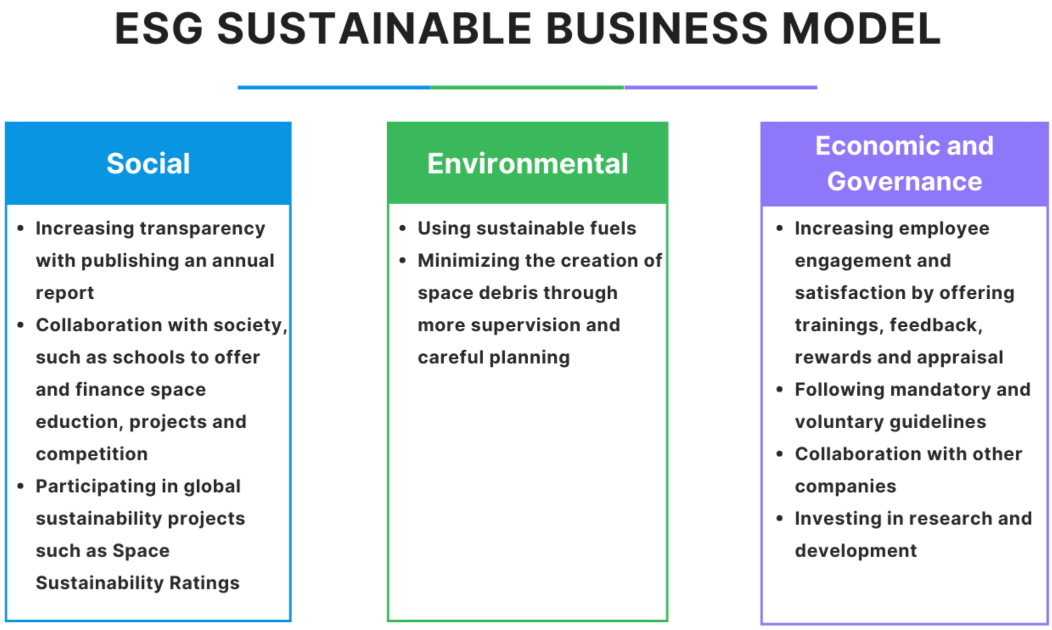

Figure 3. Summary of ESG Sustainable Business Model

In the social aspect, there are a few key points about the social sustainability of a company. First of all, increasing transparency of company information, such as its practices, performances and impacts on the operation, plays a vital role in building trust and stakeholder engagement and, for example, publishing an annual report about their sustainability efforts in environmental, social and governance to communicate their efforts and validate them (Interviewee D 2024). It is vital that the space community knows what their competitors and partners are doing and how they are operating their satellite constellation (Interviewee B 2024). Although it is impossible for a company to be transparent on everything since there is sensitive information that should be kept secret, it will be helpful if the company is honest to show their sustainable practices and impacts, including the estimated environmental emissions they have made, resources used, how they treat their employees and workplaces. Transparency should be the goal of a company instead of a mandatory mission and responsibility (Interviewee A 2024). However, being transparent could enhance their competitiveness among the competitors in the satellite industry, especially the awareness of the public towards sustainability is rising. It will be advantageous for them. Sustainability reporting can be done according to sustainability reporting frameworks such as the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board standards. Even though there are no specific reporting standards for the

space industry, companies can still utilise the existing standards to report their sustainability effort in environmental, social and governance aspects and their space operation performances.
In addition, participating in global sustainability projects such as the Space Sustainability Rating is one of the methods to increase transparency. Space Sustainability Rating is a rating system that assesses the sustainability effort of the company and provides practical suggestions to help improve its sustainability performance (Space Sustainability Rating 2022). The company will receive a badge according to their performance and level. Not only can the company receive guidance in sustainable practices, but also their stakeholders who support sustainability can decide whether to purchase and collaborate with them (Interviewee B 2024). As a result, the company will have financial gain in the long term since transparency can increase its competitiveness and strength and gain loyal customers.

Furthermore, collaboration with society benefits both companies and society, including schools, students, and the public. The collaboration, for example, finances student projects, student competitions, and courses about space can motivate students to learn about space technology and space sustainability, as well as attract future talents whose values align with the value of the company (Interviewee B 2024). Also, space-related activities are emerging rapidly, but the public is not familiar with the space industry as compared to other industries such as the fashion, beauty, and food industries. Therefore, investing in space education programmes that could be implemented in primary schools, high schools, and universities can raise public awareness of the space industry. Companies can finance schools to have space-related projects such as building satellites. Students can gain hands-on experience by making satellites with teammates and being guided by teachers and experts from companies. Students can also gain interest in the space industry and decide whether to develop their careers in the space industry in the future. Companies can benefit from spreading their positive image to society to attract future talent. Offering internship and training programmes to students is also an effective way to attract future talents and help them develop practical skills in the space industry (Interviewee D 2024). Financing and organising student competitions such as building sustainability innovations and ideas, Hackathons and Megathons can encourage students to develop their skills and knowledge in programming, sustainability, space technology and innovation (Interviewee B). Companies can gather innovative ideas from students about how to solve current space and environmental problems, such as cleaning space debris, using sustainable fuels, and even a new space technology which helps develop a new sector in the space industry.

The environmental aspect is not restricted to the environment on Earth but also includes the space environment. The main problem of satellite and rocket launches for the climate is combustion emissions. Rocket launches emit carbon dioxide, carbon monoxide, water and nitrogen oxides, but the amount of the emissions of different types depends on the engine type and altitude. Some pollutants, for example, black carbon, are generated from carbon-based solid and hypergolic fuels (Ryan et al. 2022). These pollutants could negatively impact the protective stratospheric ozone layer and climate. However, it is not impossible to use other types of fuels to reduce the impacts on the environment. During the interview, interviewee B mentioned that companies should consider how the rockets re-enter Earth and whether they will burn up in space or burn up when re-entering the atmosphere. He also suggested that companies should pick a propulsion system that is more sustainable and environmental-friendly. Interviewee C also discussed the emissions of rocket launches. Carbon emissions are almost avoidable since companies can launch rockets using liquid, liquid oxygen and liquid hydrogen, which means that these rockets only produce water, not carbon dioxide. However, it depends on how companies choose the fuel used. He mentioned that there are many rockets that use methane, natural gas, kerosene, or other carbon-based fuels, and these rockets create carbon dioxide emissions. Interviewee C also stated that the biggest problem is not carbon dioxide but the small particles in the high layers of the atmosphere. It is caused by the rockets rising and emitting soot, small particles, and aerosols. Currently, the space industry does not know how these tiny particles affect the lower atmosphere or if they are starting to accumulate due to the vast amount of space launches and the overall pollution effect. Researchers have already recognised this problem and tried to determine how much pollution there is. Although these small particles pose an unknown danger, companies can start making efforts to limit the emissions that we know by, for instance, using more sustainable fuels rather than carbon-based fuels. Even though there is no international policy that specifically regulates the fuel used in rocket launches by companies, companies should take action by themselves in order to be environmentally responsible and sustainable.

The chief problem for the space environment is space debris. Since space activities are emerging and increasing fast, stakeholders in the space industry have started focusing on how to minimise space debris. Space debris is a technical problem for other satellites and people because when the orbit is crowded with functioning satellites and space debris, companies cannot put new satellites in space. Interviewee C also mentioned this problem and said that satellites have a short lifetime, so the more satellite companies put in, the more space debris comes. For example, remote sensing satellites are between 508 kilometres above Earth because this is a reasonable altitude for making remote sensing pictures and below the radiation belts. These satellites are not long-living, and they usually come down to Earth in less than 100 years and sometimes less than 50 or 20 years. Since they will return to Earth, they will not be left in orbit as space debris. The Low Earth Orbit (LEO) is an accessible area to operate, but it is also the crowdedest area in space. Interviewee C mentioned that if satellites achieve mass density and start to collide, a chain reaction will happen, which means it will break most of the satellites. In decades or hundreds of years, there will be a tremendous amount of debris at a certain altitude, hitting all the satellites on the way. To minimise the creation of space debris, companies should be more supervised towards the equipment they are launching into space. Interviewee A suggested that companies could develop satellites that can re-enter space in a safe manner; for example, LEO satellites can go into the decommissioning orbit safely and burn up. Interviewee C also has a similar suggestion. He suggested that companies could launch satellites to a lower orbit, such as 450 kilometres or 400 kilometres orbit, where the satellites are deployed, and the satellites then use their propulsion to go to the target orbit, which is around 550 kilometres. If there are problems, for instance, the propulsion is not working, the altitude is not working, or issues related to satellites that cause satellites to not go to the higher orbit, they will eventually fall after a few months. The purpose of this method is to minimise the chance of satellites being left in space as space debris. Therefore, companies should take responsibility for disposing of the satellites at the end of the mission and lifetime rather than leaving them in orbit. It could prevent the accumulation of debris in space and reduce the risk of collision.

The final view of the sustainable business model is the economic and governance aspects. It is a viewpoint related to employees, future talents, other companies, and the government. A company that pays attention to sustainability should take care of the well-being and development of employees. They are responsible for maintaining a healthy and corporative organisational culture and ensuring the ability of workers. According to the literature, employee engagement impacts business performance, such as profitability, productivity, customer ratings and quality defect rates (Casey & Sieber 2016). To increase the motivation and engagement of employees, companies could provide resources and feedback to support the ability growth of employees, for example, skill training and sustainability training programmes, so that employees can raise their abilities and be familiar with the objectives and values of the company as well (Casey & Sieber 2016). Moreover, rewards and appraisal are other ways that could motivate and encourage employees. It could also show that the company treats each employee fairly and rewards them according to their behaviour, such as individual contribution to the company, independent decision-making, professional development activities and professional behaviour (Casey & Sieber 2016). Therefore, a well-structured reward system is a critical factor in raising the satisfaction and engagement of employees. When satisfaction and engagement are raised, employees are more willing to contribute and work in the company. Their sense of belonging towards the company will also increase, which leads to higher productivity.

In addition to employee management, a company should follow the mandatory and voluntary guidelines of both sustainability and space sustainability. The mandatory responsibility of a company is to obey the laws, such as environmental protection, labour law, consumer protection, data privacy, and anti-corruption laws. If a company fails to fulfil its legal obligation, it will result in reputation loss, legal liabilities, and risks that negatively impact profitability and financial stability.

To achieve economic sustainability, a company needs to maintain financial stability so that it can ensure business continuity, trustworthiness and confidence in employees and stakeholders. Besides mandatory regulation, a company which supports sustainability should also be responsible for ethical and voluntary guidelines, for example, long-term sustainability guidelines and space debris mitigation guidelines from the United Nations Committee on the Peaceful Uses of Outer Space, Space Sustainability Rating and ISO standards in space debris mitigation requirements (ISO 24113) and orbit data messages (ISO 26900) (International Organization for Standardization 2021). Corporate Social Responsibility implies that a company should do more than the obligate regulations regarding product safety, environmental protection, labour law, human rights, corruption and civic development (Choi & Yu 2014). Hence, following legal regulations is only a minimum requirement for a company, but working on voluntary and ethical guidelines is vital for a company to achieve sustainability. Companies can benefit from gaining reputation and satisfaction from stakeholders, including shareholders, community, employees, partners, and customers, as well as long-term profitability and financial stability.

Furthermore, collaboration with other companies can facilitate the whole growth of the space industry. Interviewee A mentioned that the collaboration of companies is a trend in the space industry nowadays, where many collaborations, acquisitions, and vertical and horizontal expansions within the industry. Previously, companies focused on one aspect of business offerings and cases. However, companies are now joining forces to provide a complete solution. For example, one company focuses on the ground, one on space, and the other on launch. Collaboration with industry peers is also helpful for countries, especially those at the early stage of space development, since they do not have enough technologies and skills to develop from the beginning. She suggested that international cooperation between companies could help these countries by providing ground segments and launching and taking care of IT. From the perspective of a company, collaborating with other companies can share human resources and skills, which helps in the research and development of new technology and sustainability solutions. Interviewee D also noted that nowadays, it is not a challenge for space companies to look for collaboration, especially in Finland and other Nordic countries, because they all know each other and attend the same workshops, conferences and events. It is easy for private companies and startups to communicate with other industry peers.

Other than industry peers, satellite and space companies could cooperate with the research community and companies to develop new space technologies and even sustainable solutions to solve existing problems such as emissions and space debris. Interviewee B stated that research communities and companies have more time to look into different scenarios than commercial companies. They can aid space companies to make more sustainable decisions or decisions that are in accordance with the policies that were implemented. With the help of the research community and companies, space companies will be able to develop space technology innovation. Research and development is critical for companies to achieve economic sustainability because investment in research and development could result in revenue growth and raising competitiveness. Interviewee A also noted that production costs will reduce when technology advances. In other words, it may also lead to business efficiency due to the advancement of abilities and technologies.

Achieving sustainability can be an opportunity for satellite companies and startups to be competitive and gain a market-competitive edge over one another. It will be a healthy market competition as companies compete to be more sustainable and create higher beneficial values for society, the environment, the economy, and space. Moreover, a rising public awareness of corporate social responsibility, also known as CSR. Corporate social responsibility means that companies should integrate social, environmental and economic concerns and fulfil the expectations of stakeholders and shareholders (United Nations Industrial Development Organization 2024). The public will pay more attention to the sustainability of the companies in the satellite industry and the whole space industry. This sustainable business model can give an idea of how space companies can maintain their business and create their values while protecting the resources of future generations.

5.2 Possible challenges of the model

Despite the sustainable business model, which includes the three main aspects and gives detailed suggestions on how companies can positively contribute to society, the environment, governance, the economy, and space, several challenges still need to be addressed.

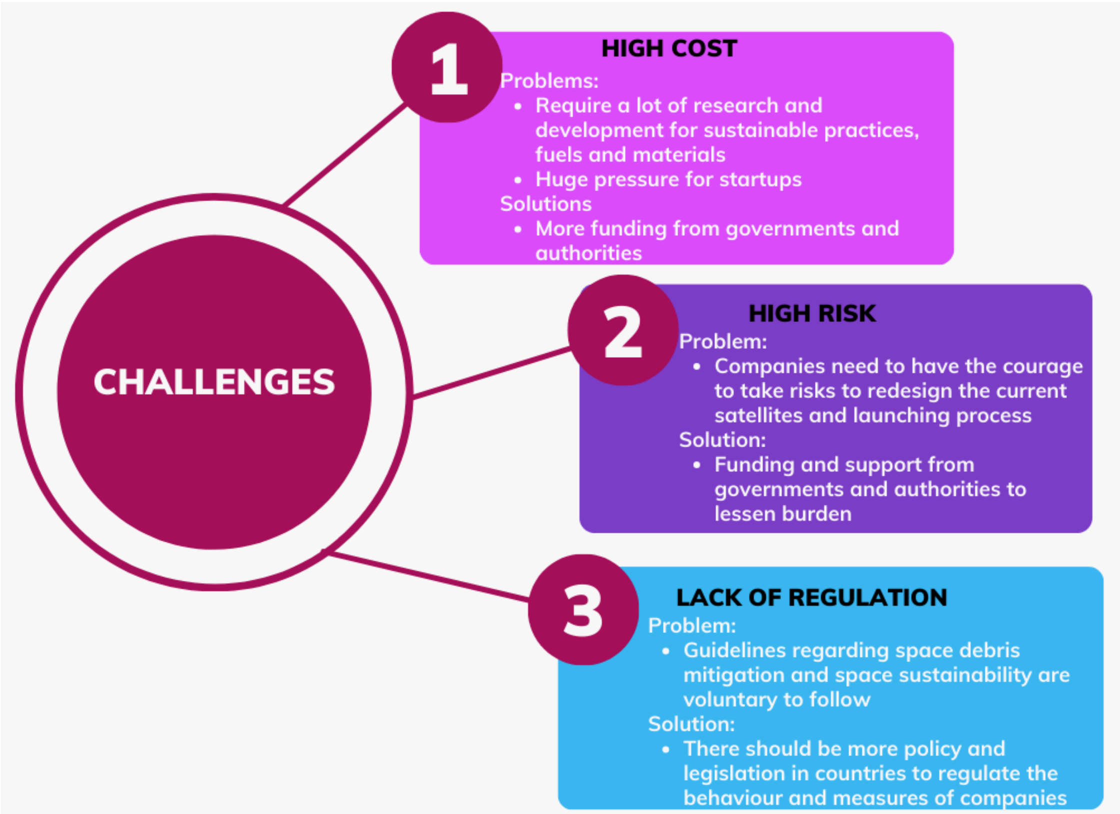

Figure 4. Summary of challenges of the model

To begin with, high cost is one of the challenges for companies in adopting sustainable strategies in their operations. Developing satellites in a company is a high-cost business in the space industry. The main goal of business entities is to make a profit. Therefore, every decision made along the way is how to reduce costs and increase their profitability. Interviewee A mentioned that there needs to be a lot of investment in research and development for materials, fuels, and manufacturing methods. For example, companies can figure out scientifically how to repurpose the gases such as methane available in the atmosphere. Moreover, interviewee A noted that when adopting sustainable practices, for example, using sustainable fuels and materials, companies will need to reconsider and redesign the whole system because they already have a method and a particular set of equipment. Hence, they need to put effort into research and development to redesign the rockets or satellites to fulfil sustainability. It will take a lot of time to shift to a sustainable operation.

Interviewee B also mentioned the problem related to startups because startups do not have a lot of capital and financial resources, and they want to own a product and start making money rapidly. If not, startups may have to close their businesses. Hence, it is tough for them to think about sustainability at the beginning of the company and still consider how to survive in the market. However, he suggested that one of the ways to reduce cost is to increase the working duration of the satellites by, for example, using as much fuel as possible so that they can live longer in space without launching other satellites to replace them. In addition, he said that the government and the European Space Agency could finance companies so that they can maintain their profitability while shifting to sustainable operations. The European Space Agency has developed various sustainability projects and is always financing projects. Thus, he believed that funding from authorities and governments could help companies a lot. Regarding the problem of startups, interviewee D also stated that the European Space Agency is going through a trial period in which the incubation process emphasises and increases the sustainability requirements, so startups are expected to discuss what their contributions or how they are negatively impacting sustainability goals and how to quantify that.

As a result, high cost is a challenge for many space companies, especially sustainable operations, which are more expensive than usual. However, if companies look into sustainable operations in the long term, it would be a strong selling point that would benefit the public and themselves. As interviewee D said, a company will have a solid financial output if it invests in research and development initially because it will pay off in the long term.

High risk is also one of the challenges for companies that need to include sustainability in their operations. Similar to the above, the space industry is a high-risk industry where companies spend an enormous amount of money on new technology. Still, it does not guarantee it will succeed. Interviewee A mentioned that companies need the courage to take risks because they do not want to spend

50000, 100 million or 300 million to launch, and nothing happens. For example, the Kairos rocket is the first privately developed orbital launch vehicle from Japan, which was built by the Japanese company Space One. It exploded around five seconds after launching on 12 March (Foust 2024). Therefore, having a particular set of equipment and manufacturing processes is difficult for a space company because these are developed after many tries. Funding is the way to encourage companies to take risks and invest in sustainable fuels, materials, or new technologies, and it is a way to relieve their financial burden.

Furthermore, regulation is another challenge for achieving sustainability in the space industry. Currently, there are guidelines regarding space debris mitigation and sustainability, such as the Space Debris Mitigation Guidelines, but they are voluntary rather than mandatory. The guidelines only recommend and encourage, so companies have no legal consequences if they do not follow them. Interviewees B and C mentioned that regulation can increase the incentives for companies to shift to be more sustainable. Although the United Nations has a space department responsible for drafting guidelines related to space, it is difficult for them to enforce them because they can only recommend them. Policies belong to countries. There are not enough laws regulating what fuels and materials launching companies should use. He suggested that it would be better if there were specific measures that satellite companies would need to adhere to. Interviewee D also recommended that to raise the incentive and responsibility of satellite companies, there should be a policy or registration that lists the responsibility of companies towards space debris. For example, when a company launches a satellite, it is responsible for any space junk, similar to vessel registrations.

5.3 Prospect of the technology

Advancements in space technology will be critical factors in solving existing challenges, such as space debris and high costs and enhancing the business efficiency of satellite companies in the future.

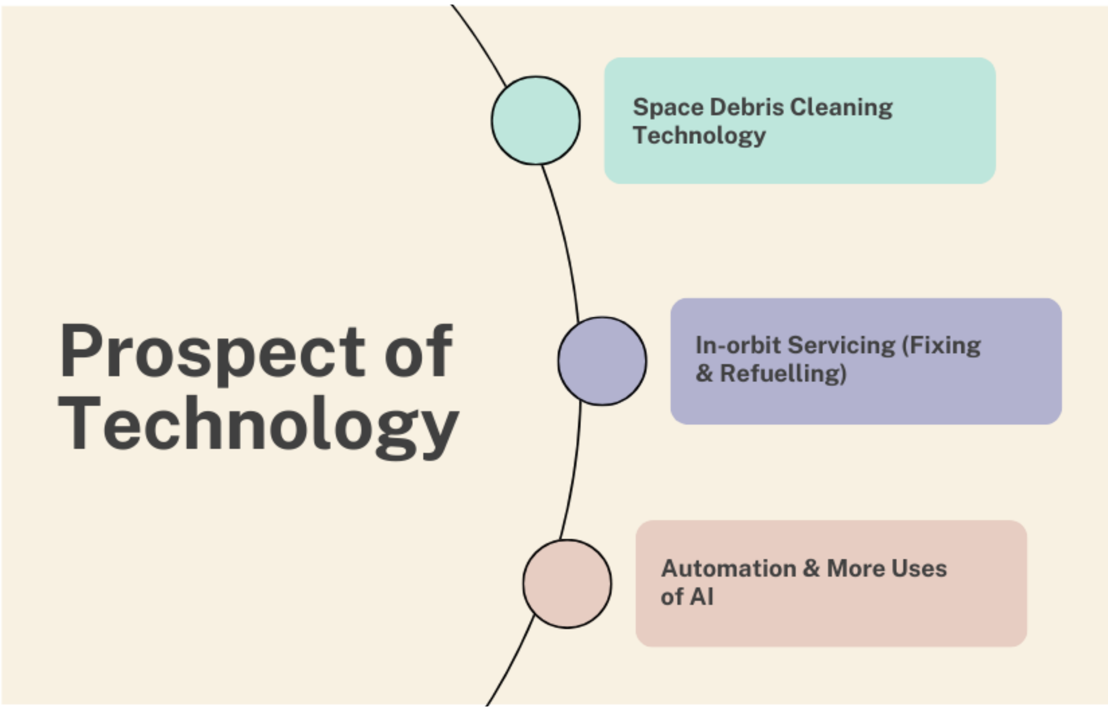

Figure 5. Summary of the prospect of technology

First of all, it is expected that there will be a new space technology to clean the existing space debris in the space environment. There is already discussion about this technology, and ClearSpace-1, the first space mission to remove debris from orbit, will be launched in 2025 (European Space Agency 2019). It will be lifted up to the target orbit to capture debris using a quartet of robotic arms after being launched into a lower 500-kilometre orbit for testing (European Space Agency 2019). In the future, a new market will be developed that offers commercial services for other space companies to clear up space debris and satellites that are no longer functioning. This technology will help reduce collision risks and free up space for new satellites for future generations. When the risk of collision decreases, the amount of space debris generated will also decrease.

Moreover, there are also discussions about extending the lifetime of satellites. Other than clearing up space, some companies are working on satellites with refuelling ports because the satellites nowadays are mostly single-use. Interviewee A mentioned that space is a high-risk and high-cost environment, and if the industry has the technology to refuel the satellites, they do not have to go, renter and run the risk. Interviewee B also stated that it is not possible to fix the satellite if it is out of fuel or broken at this moment. When the satellite is unexpectedly damaged or running out of fuel, it will become debris floating in space.

These two interviewees anticipate that there will be in-orbit servicing, such as fixing and refuelling satellites, in the future. Orbit Fab has planned and created the commercial space refuelling service Rapid Attachable Fuel Transfer Interface (RAFTI), designed to be installed on satellites so that satellites can refuel in orbit or on the ground (Orbit Fab 2023). It supports various spacecraft sizes and propulsion systems and types of storable fuel, including hydrazine, high-test peroxide, xenon, propene or ethane and nitrous oxide, krypton and water (Orbit Fab 2023). With the refuelling technologies, satellites can extend their mission lifetimes by receiving additional fuel. Companies do not have to worry about satellites using up fuel and replacing it with a new satellite. From the point of view of sustainability, this technology can minimise the creation of space debris and protect the safety of the space environment by reducing the chance of collision and conjunction. It will reduce the gas emissions generated by launching. Space companies such as satellite companies can benefit from lowering the launching and production costs because they do not have to manufacture and launch another satellite to replace the malfunctioning one. Also, when refuelling is enabled, companies can reduce the size and mass since they do not have to carry a significant amount of fuel to space. It can reduce the launching expenses. In addition, companies can benefit from increasing flexibility as satellites can easily adjust orbits and change mission objectives and requirements without worrying about the lack of fuel.

With the advancement of technology in the future, the cost of producing and launching satellites will decrease. This means that companies will have more resources and time to invest in sustainability and innovation, for example, deeper and more ambitious space missions. Interviewee A also mentioned that people are shifting towards satellites that use AI for data processing and analysis, such as sensor data, Earth observation, and imagery. The use of AI could reduce the amount of manual labour, meet the demand of the constellation that is now being launched, and even reduce operational costs. It could significantly improve the business efficiency and performance.

6 CONCLUSION AND DISCUSSION

6.1 Discussion of the results

This thesis aims to analyse the current situation and practices in the satellite industry and introduce an ESG sustainable business. The thesis includes three objectives. First, one of the objectives is to discuss the impacts of satellites on Earth and space and the current situation of space sustainability in the satellite industry. Moreover, another objective is to introduce a sustainable business model as an example framework to guide satellite companies on how to act and behave sustainably to protect the rights of future generations to use the space while making profit and continuing innovations. The last objective is to anticipate how technology innovation could enhance space sustainability while improving business efficiency in the future. The research questions were answered in each central part throughout the research process after gathering and analysing data from literature and interviews.

At the current stage of the space industry, there is a rising awareness towards space sustainability, including authorities, companies and the public. They are looking into the impact of space debris and fuels and how they can mitigate and minimise the creation of space debris. More legislation, recommended guidelines and frameworks, new space technologies, and new space markets related to sustainability are coming. Although it may be challenging for space companies such as satellite companies to work towards sustainability due to high costs and high risks, collaboration with stakeholders, legislation and receiving support and funding could help achieve sustainability.

After analysing literature and interview results, this thesis produces the ESG sustainable business model as its output and main finding. The sustainable business model recommends what companies can do to achieve sustainability in social, environmental, economic and governance aspects. Besides the efforts of space companies, other stakeholders, including the public, governments, authorities, competitors, and research companies, should also be responsible for their contribution. Interviewees have the same idea that the space industry should have a general mentality and mindset shift of being more socially conscious. They should consider the impacts of space activities. If they are not operating satellites and rockets sustainably, there will be more space junk. Their satellites could one day crash with space debris and create more space junk, affecting current and future satellites. This phenomenon is called Kessler Syndrome.

Nevertheless, there are several challenges related to high costs, high risks, and a lack of regulations that affect the effectiveness of the ESG sustainable business model. Interviewees also pointed out that it could be expensive for companies to adopt sustainability into operations. The main reason is that there is a need for more investment in research and development. Sustainable fuels and technology, such as clearing space debris and in-orbit servicing, will be available in the coming few years. Moreover, the cost of manufacturing and launching satellites is already high, so there is not enough motivation to change the current design and equipment. When it is not mandatory to follow the sustainability guidelines, some companies may not find the need to behave and invest in sustainability. It is also a challenge for startups because their aims at the beginning stage may be to survive in the market and spread their brand names. However, interviewees believe that financial support and funding would be critical solutions for space companies to overcome these challenges. In the future, when more legislation and space technologies innovation come, the problems will hopefully be solved. The advancement of space technologies could also bring advantages to companies as the production and launching costs will decrease and boost productivity.

6.2 Examination of reliability and research ethics

During the research process, the research approach follows the ethical principles guidelines from the Finnish National Board on Research Integrity TENK to protect the rights of research participants and personal data. According to the general ethical principles, this thesis does not lead to significant risks, damage and harm to participants and communities (Finnish National Board on Research Integrity TENK 2019). It respects the autonomy and dignity of human research participants such as freedom of expression, the right to privacy, life, personal liberty and integrity (Finnish National Board on Research Integrity TENK 2019). In this section, it describes how the research was conducted by following the ethical principles, including the treatment and rights of research participants, processing of personal data, and privacy protection.

The two main ways to collect information are literature reviews and semi-structured interview results. The topic related to the space industry and sustainability is chosen based on motivation and interest. The author has interest and learning experiences in sustainability at Lapland University of Applied Sciences and has taken several courses, including Social Impact Management, Introduction to Sustainable Business, Sustainable Accounting and Sustainable Logistics.

The qualitative research method was chosen, and semi-structured interviews, literature reviews and a grounded theory approach were used in the research process. The reason for selecting qualitative research rather than quantitative research is that it allows for gathering deep understanding and knowledge from interviewees. For example, interviewees are provided with questions but can talk and explain their experiences freely. The opinions and experiences of these interviewees cannot be collected through surveys by asking yes or no or by scaling. Moreover, the research topic includes a discussion of phenomena and anticipation of the future, and it requires in-depth explanations and suggestions from interviewees because the answers cannot be quantified. The interview questions were created based on what was missing in the literature review and what was planned in the research questions, for example, the anticipation of how technology advancement leads to business efficiency and sustainability and challenges for companies working towards sustainability.

The interviewees were found online on websites of organisations such as the business incubation centre in Finland of the European Space Agency, universities and companies in Finland, and through recommendations. Interviewees are experts in the space industry, such as engineers, professors, researchers, and business specialists of satellite companies. They were contacted through email. The research content, interview questions and information about processing personal data were included in the contacting emails, so that the inviting participants understood what the interview and research were about before deciding to participate. Recording and interview permissions were granted by asking them in emails and at the beginning of the interviews. The personal data collected from participants is, for example, names, roles and positions, and their opinions. The data is related to the research purposes and does not include any sensitive information.

After the audio recording, the interviews, discussion, and conversation were transferred to a text transcript by repeated listening to prevent mistakes. The text was typed in several Word documents, and who was speaking was marked. After transcription, the results were coded and categorised based on the content. The results were then grouped in the same document, and the creation of the sustainable business model started. When generating the sustainable business model, the examples given by experts, especially the company name, products and professional terms, were also double-checked online so that it could avoid misunderstandings and mistakes. When the thesis and research process are completed, all collected data, including personal data, will be deleted. The names of the participants were not mentioned so as to protect the privacy of the interviewees.

Furthermore, the literature was found in databases including LUC Finna and Google Scholar, as well as news and websites of reputational organisations such as NASA, ESA, OECD, and Secure World Foundation. When finding the literature, it was ensured that the sources related to space technology, space sustainability, and space were from nearly five years ago because the space industry is developing rapidly. If the literature had been published a long time ago, it would have been outdated unless it was related to theory and professional knowledge, such as qualitative research theory, the structure, history, and background of satellites. All the resources used were mentioned and recorded in the references.

6.3 Suggestions for further research

In the research process, semi-structured interviews and the grounded theory method were used to gather and analyse data. Although the invited interviewees are from different positions in the industry, including engineers, professors, business specialists, and researchers, it would be better to invite more interviewees in the future research because various points of view could generate more comprehensive and detailed results and framework. In this thesis research, four interviewees were invited. Hence, the results gathered from interviewees may not be thorough and deep enough. When doing further study in the future, if there is enough research time, interviews with more companies and experts are recommended.

Moreover, during the research process, it was realised that the satellite industry could be a broad topic. Therefore, the topic was narrowed down to satellite manufacturing and launching. In future research, researchers could discuss rocket launching and manufacturing because it is an essential launching vehicle for satellites. In addition, due to the limited research time, it could not provide a more detailed framework with practical methods and solutions. Future researchers can contribute their professional knowledge on these aspects.

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