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Development of Supporting Technology for Sustainable Spaceport Development

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ABSTRACT

Spaceports have experienced rapid growth in recent years, but have also faced significant challenges related to management and sustainability, particularly in developing countries like Indonesia. This literature review examines the role of supporting technologies in promoting sustainable spaceport development. Environmental and social concerns, such as disruptions to community activities, emissions, and environmental damage, have emerged as key issues associated with spaceport activities. By promoting open innovation and actor interaction, however, spaceports can foster sustainable development, taking into account infrastructure, social, and economic considerations. This approach aligns with the increasing demand for environmentally friendly practices in the space industry, which can attract investors and support further development. Safety and sustainability considerations should be integrated into every aspect of spaceport operations, given the high risks associated with rocket launches. Overall, this study contributes to a better understanding of the complex interplay between actors and technologies in shaping sustainable spaceport development.

1. INTRODUCTION

Satellites and rockets play a crucial role in advancing a country's space capabilities. The development of the space industry began during the Cold War, particularly in the United States [1]. In 1989, the Florida Spaceport Authority began launching rockets from Mexico [2]. In recent years, interest in the space sector has grown significantly with the construction of spaceports, leading to competition among countries in America, Europe, and Asia. Spaceports are built to support satellite and rocket launches, and offer opportunities to boost a country's economy. Many countries are competing to build spaceports, with the industry in the UK growing fourfold compared to economic growth and providing job opportunities [3].

There is a significant amount of research on spaceport development in various countries. Chang and Chem evaluated Taiwan's potential for space development, including supporting infrastructure for spaceport development [4]. Diana et al's research focused on the feasibility of spaceports in Indonesia, evaluating potential infrastructure, economic factors, and market demand [5]. The study compared two potential spaceport locations and found that Biak-Papua was the more suitable option due to its industrial development goals and lower level of community vulnerability [6].

Satellite launches are increasing in several countries, leading to competition for profits. For example, Spaceport Cornwall received a £20 million ($26 million) investment to conduct the first UK satellite launch by the end of 2021, with the UK space industry accounting for 7% of the global space market [7, 8].

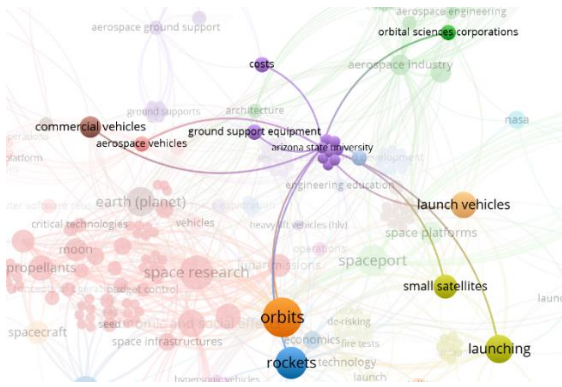

Figure 1. Aeronautics and astronautics program in ASU publication

Developing spaceports requires multidisciplinary research due to the complexity of the supporting technology. A bibliometric analysis of Scopus-indexed journals from 2019 to 2023 reveals that the most researched areas include engineering, Earth and planetary science, and physical and astronomy [1].

Figure 1 illustrates the author's use of bibliometric analysis to examine publications from Arizona State University (ASU), which has programs related to aeronautics and astronautics. Keywords related to technology that supports spaceports include stages, multi-payload adapters, United States Air Force, research and development, boosters (rockets), space launch vehicles, spaceport systems international, orbit, rockets, commercial vehicles, aerospace vehicles, and orbital science corporations.

While the space industry provides economic benefits, researchers are also discussing sustainable spaceports and how to minimize their environmental impact and risks to humans [2, 7]. Balancing economic development with environmental preservation is a challenge, particularly when considering the potential impact of rocket debris on living things [7].

Sustainable spaceport development requires careful consideration of a range of complex factors, highlighting the need for multidisciplinary research. To address this challenge, the researcher aims to analyze supporting technologies for sustainable spaceport development in developing countries, particularly Indonesia.

The structure of this journal article will include an introduction, a literature review covering spaceport and satellite development, spaceport considerations, and spaceport development. The methodology, results, and discussion sections will cover spaceport potential, sustainability issues, and approaches towards sustainable spaceport development. The article will conclude with a summary of key findings and acknowledgments.

As interest in the space sector grows, it is important to address the challenges facing spaceport management and sustainability. The findings of this research are expected to provide alternative strategies for supporting sustainable spaceport development in developing countries.

2. LITERATURE REVIEW

2.1 Spaceport and satellites

A spaceport is a designated area on land used for the foundation and/or launch of spacecraft, equipped with safety and security facilities and other supporting infrastructure [9]. According to Button [10], spaceports are an integral part of extra-terrestrial transportation and require consideration of various disciplines, including technical, economic, social, and political aspects. The main activities carried out at spaceports include flight testing, space industry development, maintenance, and aircraft/rocket storage [4].

In addition to these activities, spaceports have broader benefits. They can facilitate microgravity research, pilot and astronaut training, and experiments in the aerospace field [11]. Spaceports also offer opportunities for celestial body research and development [12].

The construction of spaceports provides countries with potential access to space for both research and development and commercial purposes [6]. As such, spaceport development is an important consideration in the broader context of advancing space exploration and research.

A shift is starting to occur where industry is starting to shift to the space field. Several countries began to switch to compete in the development of the space field. Handberg [1] describes the development of spaceports, analyzing the growth and development patterns of spaceports. The first development of the space field occurred when the Soviet Union collapsed in 1991. The second wave came when there was the development of the internet used as communication. The third wave of space development occurred in 1996 when Nasa developed a reusable launch vehicle. And the last wave came when there was interest in suborbital launches. These launches were aimed at opening space tourism, attracting a number of tourists to participate, and now there is a trend towards competitive private commercial launches.

In America, the development of the Space field was encouraged because of the sluggishness of the industrial field. America began to look at the space field in 1989 when national security restrictions were relaxed [1]. ULA, SpaceX, and Orbital, have committed to spaceport development. Italy is also starting to investigate spaceport transportation. Many airports have transitioned to spaceports including Ellison Onizuka Kona International airport in Keahole, Kinston Regional Jetport at Stallings Field, Wilmington Air Park, Crater Lake/Klamath Regional, and Grant Co International, Spaceport Sweden located in Kiruna, CAAS Singapore [4, 13]. Mojave Port in California, has conducted horizonal launches of spacecraft. Some areas have the potential to build spaceports, namely in Jornada del Muerto in New Mexico in the United States and the port of Mojave [4].

The types of vehicles used in satellite launches vary. Disposable expendable launch vehicles (ELV) are starting to be replaced with reusable launch vehicles (RLV) [4, 10]. ELVs are less efficient, so developments are being made to reduce dependence on orbitals. Space is developing orbital RLVs as well as the development of more economical mini-aircraft. RVL is excellent, where when the rocket is launched to the orbital plane, the accompanying vehicle will return to earth and land back on the airport runway.

Microsatellites, solid rockets, and microsatellite launchers can be a viable option for development in small countries due to their lower cost and the ability to launch them using smaller and cheaper launch vehicles [14]. The use of solid rockets to launch microsatellites can also provide flexibility and ease in launching satellites quickly and efficiently. Small countries with limited resources can utilize these technologies for their national interests, such as natural disaster monitoring, resource management, scientific research, and improving communication and transportation. The development of these technologies in small countries can also spur the growth of the space industry and open up opportunities for international partnerships in the field, ultimately reducing technology gaps and improving technological self-sufficiency and capability in small countries [15].

Lower Cost: Microsatellites are smaller and lighter than traditional satellites, which means they require less material to build and launch, resulting in lower costs. Solid rockets are also simpler and more cost-effective than liquid rockets [16].

Access to Space: Developing countries with limited access to space can benefit from microsatellites and solid rockets as they can be launched into orbit using smaller and less expensive launch vehicles [17-19].

Technology Transfer: Developing countries can acquire knowledge and technology through partnerships with established space-faring nations or through international collaborations, which can support the growth of their domestic space industries [20].

National Development: Developing countries can use microsatellites and solid rockets to support national development objectives, such as improving communication and infrastructure, monitoring natural resources and disasters, and enhancing security and defense capabilities [21].

As the space field advances, the RLV system is becoming a popular system chosen by the government or industry. By utilizing one device to launch satellites and rockets. RLVs have 2 subcategories, based on the payload in achieving trajectory, namely vertical takeoff, and horizontal takeoff [13].

2.2 Spaceport development

Spaceport development requires careful calculation by embracing various multi-sciences. Spaceport development starts from determining the location, conducting a feasibility study, creating a master plan, site acquisition, and development process. According to Burleson and Kozak [13], spaceport review consists of several stages, namely site pre-application consultation, site policy review, security review and approval, environmental program review, and compliance monitoring review.

Dachyar and Purnomo [22] conducted an Analytical Hierarchy Process AHP analysis to identify spaceport site selection. Location selection as a spaceport is supported by the availability of infrastructure [5], because the availability of infrastructure is associated with capital requirements that will minimize production costs [11]. Many spaceport selections are selected from existing airports, civilian or military airports, by adding supporting infrastructure. this opinion is supported by Rongier [23] the selection of locations is seen from the geographical location and infrastructure development. Site selection also takes into account environmental protection criteria against natural events such as earthquakes, tidal floods or other destructive phenomena. Figure 2 illustrates the spaceport area connected to the surrounding environment.

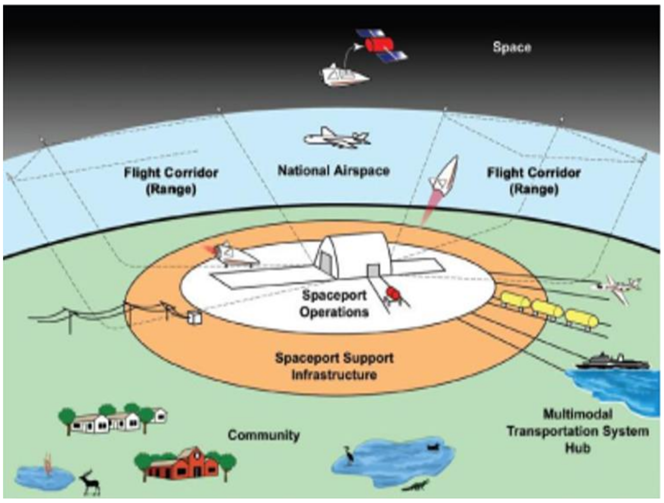

Figure 2. Spaceport area [5]

Considerations needed for spaceport development include [10]: size and type of launch vehicle (ELV or RLV), size, weight, orbit, environmental resources, crew mission and launch (vertical or horizontal) and landing. Santoro [11] discusses the selection of a suitable site. A suitable region should have low levels of commercial air traffic. For population safety and ease of launch scheduling. Also located in a low population density region with a safe distance from the take-off, landing and ascent areas. The runway length should be at least 3000 meters located between mean sea level and an altitude of 155 meters, with consideration of runway materials [11, 13]. Safety considerations and climatic conditions of the region. i.e., from humidity rainfall wind and others. Also environmental considerations in the form of noise ecosystem disturbances or hazardous materials.

Spaceport site selection needs to pay attention to previous regional development planning. Planning conflicts lead to selection mismatches. Such as research by Diana et al. [5] comparing the locations of Morotai and Biak in Indonesia. Where the location of Morotai is less suitable for spaceports because it has different planning. Morotai is designated as a special economic area for tourism, agriculture and fisheries, because it has more economic contributions to agriculture, fisheries and forestry. The largest community income comes from agriculture [6]. So that the construction of the spaceport will only increase the vulnerability of the region. in contrast to Biak, which is in fact an industrial development area, which does not conflict with the spaceport. Moreover, Biak connects the lines of Australia, Papua New Guinea, and Pacific countries.

2.3 Spaceport considerations

The interest of various countries to engage in spaceport development is the economic potential that will be possessed [1, 10, 13]. It is not surprising that the economy is a strong catalyst in every activity, to achieve increased prosperity. Spaceport development requires considerable investment and the use of skilled labor. Attracting a number of potential laborers, the development gave rise to various supporting industries. As in Italy, spaceport development catalyzes the supply chain of services supporting airport operations [11]. Several side jobs emerge to support the space activity chain. Spaceports catalyze the development of both upstream and downstream industries [5]. Encouraging the development of industrial clusters in the transportation equipment subsector, especially aerospace, electronic industry and manufacturing industry.

In addition to economic potential, the potential for scientific improvement also contributes. The construction of space facilities has developed education both at the college, school or research center level [11]. Able to increase awareness, curiosity about access to space. Opening up the potential for cooperation with other actors, regarding the science of the impact of launch vehicles on the ozone layer or the reduction of carbon footprint [23]. The development of space facilities is undeniably able to encourage other potentials. Its development requires synergy with national industrial policy. Diana et al. [5] mentioned that development must be adjusted to the regional development strategy so that there is no conflict of development goals.

Spaceports are an important need for humans in terms of research and development of space technology independence. Launching satellites requires a safe location that can guarantee the safety of the community and the surrounding environment. The literature on previous research emphasizes the importance of safe spaceport development, which considers economic, social and environmental considerations [24]. for this reason, this study needs to be carried out to determine the development of sustainable supporting facilities, because there is still great potential in the development of the space field. This paper can be used as a consideration in determining a more sustainable spaceport development strategy. This contribution raises alternative strategies towards a sustainable spaceport. Research that discusses spaceport sustainability is still limited, so researchers will enter the gap, seeing opportunities to discuss spaceport sustainability. This paper aims to contribute to the additional literature on spaceports. The increase in this sector signals to many parties to maintain the sustainability of the airport. There are market demands that encourage every activity to be more environmentally friendly.

3. METHODOLOGY

Researchers use the literature study method. Figure 3 illustrates the data used is secondary data from previous research. looking for several literature studies, which come from journals, books or other references related to spaceports. the analysis method used is descriptive analysis and spatial analysis. Researchers used the keyword "spaceport", "solid rocket", "micro satellite", "development country" in the literature search. From various literature reviews, researchers limited references related to social, economic, and environmental aspects.

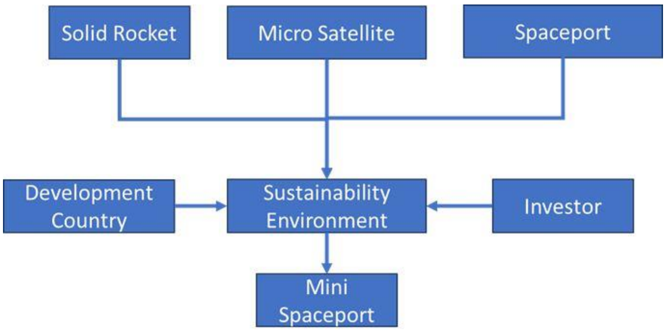

Figure 3. Keyword bibliometric analysis

4. RESULTS AND DISCUSSION

Indonesia as a developing country has achieved several achievements in space technology. Some of these achievements include: Satellite Launches: Indonesia has successfully launched several communication and earth observation satellites, such as LAPAN-A1/TUBSAT, LAPAN-A2/ORARI, LAPAN-A3/IPB [25]. The Ground statiun Satellite operation, Indonesia has five ground stations in Indonesia and ground station in Spitsbergen, Norway. The ground station in Indonesia consists of ground station in Rumpin and Rancabungur (Bogor, West Java), Bukittinggi (West Sumatra), Parepare (South Sulawesi) and Biak (Papua) [26].

However, despite achieving some progress in space technology, Indonesia still faces several challenges and obstacles in developing this technology. Some of these challenges include limited budget for research and development of space technology, lack of trained human resources, the absence of a spaceport as a means of independently orbiting satellites, and inadequate infrastructure and equipment. Therefore, Indonesia must continue to strive to improve its capabilities and achievements in space technology in order to compete with other countries in this field.

4.1 Spaceport potential in Indonesia

The need for the benefits of satellites and rockets cannot be ignored. Satellites become tools used for monitoring and protecting natural resources, communication or maintaining state security. The development of the space field in various countries encourages Indonesia to take part in the space sector. Indonesia is committed to increasing space research. Indonesia began to participate in orbital launches and spaceport construction. The real evidence of this implementation is contained in Law no 21 of 2013 concerning space. Space activities include launching satellites/rockets used for remote sensing. Indonesia's first rocket launch began in 1964, launching the Kartika 1 rocket and then continued with other rocket launches.

Spaceport development became Indonesia's 2016-2040 master plan, and became an urgent agenda to be able to compete with other countries in the space field. Regulations govern space development in Indonesia which consists of research and development of rockets, satellites and aeronautical development [9]. The demand for spaceport facilities in Indonesia supports the need for spaceport development for Indonesia [5] specifically for rockets and satellites.

Indonesia smells great potential to develop the field of space. Indonesia's geographical conditions are very supportive for airport development. Based on latitude, Indonesia is located in the equatorial region. The equatorial region is considered easier to launch rockets to reach satellite orbits [2, 10]. The equatorial region is the Geostationary Orbit (GSO) path. The GSO region is the operating trajectory of telecommunications satellites and weather satellites. Regions located on the equator get the help of the earth's rotation, allowing larger vehicles to be lifted into orbit more easily [2]. The equator, which is the trajectory of telecommunications satellites and weather satellites, makes the satellite launch path shorter. Launching also requires a shorter duration of time than other regions. This will be an advantage for Indonesia in terms of cutting fuel expenditures, so that the costs incurred in launching are minimal. This is a comparative advantage that Indonesia has.

Indonesia is surrounded by sea, and has many small islands that can be utilized for airport development. Stakeholders in Indonesia have looked at a number of areas that have the potential to become spaceport development locations. Papua region, especially in Biak [6] and Kalimantan [27]. Areas that have low populations minimize the risks that will occur. So it can be said that Indonesia is a strategic area in launching satellites and rockets. This potential must be utilized by Indonesia by developing a sustainable spaceport.

Indonesia has the potential of natural resources and human resources that can be utilized in the development of spaceports. Development to achieve goals in economic improvement, community welfare and defense and security development. The development of space facilities in Indonesia is a form of the country's efforts to achieve independence in the field of technology and space [5] for which it needs supporting facilities. The construction of spaceports makes dependence on other countries less, in facilitating satellite launches. Spaceport ownership minimizes launch delays from spaceports in other countries [8]. Indonesia also does not need to pay launch fees to other countries.

Indonesia's rich natural resources require proper monitoring and management. The development of satellites in facilitating the government's efforts, or conservatorship for the protection of the country. Protection in the maritime area. Indonesia's vast territorial waters will be greatly helped by satellite monitoring. Satellites can also be used for monitoring other resources, such as forestry. Remote sensing activities can monitor the reduction of forest degradation and deforestation.

Much research has discussed about the unsustainability of spaceports due to the risk of environmental impacts that can damage the sustainability of life on Earth. However, spaceports are a necessity for improving a nation's technological self-reliance, which can create a significant gap in needs.

The commonly discussed issues include the impacts of failed rocket launches [27], the falling debris of rockets [28], the toxic residues caused by rockets [29], the greenhouse gas emissions from launched rockets [29, 30], the noise pollution resulting from rocket launches [31], and many others. In this paper, I want to discuss how the unsustainable space industry can be caused by the suboptimal technology innovation due to poor interaction between innovation actors. Technology innovation is crucial in the development of a sustainable space industry. It can help develop environmentally friendly, efficient, and sustainable technologies that can minimize the environmental impact of space operations.

Furthermore, technology innovation can also improve the operational efficiency of the space industry. For example, new rocket fuel development technologies can help reduce greenhouse gas emissions and reduce soil and water contamination around launch facilities. New waste management and wastewater treatment technologies can also help minimize the environmental impact of space operations.

However, it is important to remember that technology innovation must meet the space industry's technology needs to ensure the continuity of operations [11]. Technology innovation that is not in line with the space industry's technology needs can cause the space industry to become unsustainable, and even worsen the environmental impact of its operations.

Therefore, it is important for technology developers and space industry builders to collaborate effectively in building innovative and sustainable solutions that can meet the space industry's technology needs and minimize environmental impact. Collaboration and information exchange between innovation actors, such as universities, industries, and governments, can also help facilitate sustainable space technology progress [17].

To address the issue of unsustainable technology innovation, it is important for technology developers and space industry builders to collaborate effectively in building innovative and sustainable solutions that can meet the space industry's technology needs and minimize environmental impact. Collaboration and information exchange between innovation actors, such as universities, industries, and governments, can also help facilitate sustainable space technology progress. The problem often encountered in technology development is the limitation of funds. However, the concept of interaction among innovation actors can be one solution to accelerate technology innovation [32]. An open innovation system can be one acceleration of technology innovation. The concept of open innovation is opening up the innovation system by involving laboratory relationships, technology innovation enthusiast communities, industries, and technology intermediaries [33]. Automation technology now leads to machine-to-machine interaction, human-to-machine interaction. Therefore, under certain conditions, technology innovation interaction can hinder or accelerate [34]. Many new technologies have emerged from collaborations between information, open innovation, research collaborations, and intensive data utilization [35]. The form of social innovation interaction also brings up collaborative economic ideas with co-working space models. This co-working space model class is very flexible and limited to participating professionals [13].

A project is said to be successful when implementation can be carried out for a long period of time. Spaceport development does not stop when the airport is finished, but how to manage so that the spaceport carries out long-term goals. The success of the spaceport is seen from the selection of locations and how the development of space launch technology [2]. It is undeniable that the space sector has become one of the industries that compete with each other to remain operational.

The threat faced is the unstable condition of the space market. No one can predict how the space industry market will be in the next few years, how customers and investors will be interested in the city [2]. What types of vehicles will be popular, the size of satellites and so on.

Due to the high risk to the surrounding area, the construction of the spaceport has led to the rejection of a number of communities, whereas when there is no support from the community, the development of the airport does not proceed [13]. The rejection from the community is associated with concerns about environmental damage due to the spaceport. residents' concerns are also related to the loss of housing and livelihoods. Perwitasari [6] explained the problem of airport development related to land acquisition. rejection of land acquisition by the community occurred. The threat of deforestation is also the reason for the rejection of a number of parties to the development of spaceports that are considered unsustainable. Differences in perceptions between the community and airport developers must be resolved. These differences will become conflicts. Conflict occurs when community expectations are not considered, by considering community expectations this problem can be resolved.

Spaceport development needs to understand the aspirations of the community. How their concerns about the risks of spaceports. The spaceport industry needs to innovate on technology and risk management to minimize community concerns.

4.2 Towards a sustainable spaceport

The development planning of a spaceport is highly dependent on the role of the central government, as it is not possible to be self-reliant from the regulations and funding of the central government [36]. The development of a spaceport requires strong protection from the government. One of the protections is the establishment of laws that can support the sustainability of the spaceport. To protect the sustainability of the spaceport, each stage of the spaceport's development requires a license from authorized institutions in the country where the spaceport is built [37]. The license application includes licensing requirements, environmental considerations, responsibility and insurance, security, and accident investigation processes. The development of a spaceport can be built with a partnership model. This is important for information collaboration on multi-level environmental governance challenges and service management from global to local [38].

Economic growth is an attraction, but the development of space facilities must still pay attention to security [23]. Security is a major consideration that must be implemented. The main rejection of the community is due to concerns about the security aspects of the airport. Launching a space facility has a high risk [22], risking failure, so it requires careful consideration.

Considerations are needed from various sciences to succeed in the long-term goal of sustainability. Risk management needs to be carefully calculated for both ground and flight safety. For airport area managers, managers must have risk management management. The manager has the ability to evacuate the population in case of failure [13] so that the risk of loss of life can be minimized.

Safety is the most important thing in the implementation of space activities. Although the risks faced are very high. Spaceport managers need to ensure security both within the airport and in the surrounding community. To minimize the risk of airport location selection, it is built far from the population center [5, 7]. The selection of the location is associated with ensuring the safety of the location and the surrounding environment. The location of the settlement aims to minimize the risk of operation failure. The selected location is usually large enough. So that if there is interference and damage, it does not disturb or endanger the local community. Some studies mention that areas near the coast are very suitable for the construction of airport facilities [11] but this does not guarantee safety. It is more seen from the low population located in the peripheral or coastal areas.

There is no mention of the minimum spaceport distance from residential areas. Each region has its own distance, and it is not the same between ports in America, Asia or Europe. This is influenced by the design that will be developed. It is determined by operational efficiency including reliability performance effectiveness and launch mission. The shortest distance of airport safety from residential areas is 1.5 km at Uchinaura Spaceport, Naro Space Center in Korea is 4 km, in France-Guiana Space Center is 12 km, Alcantara space center in Brazil is 7 km [6]. Figure 2 shows the condition of the rocket launch site in Pameungpeuk Indonesia within 500 m with settlements. when rocket launch activities are carried out, residents in a radius of 1.5 km are vacated to leave their settlements.

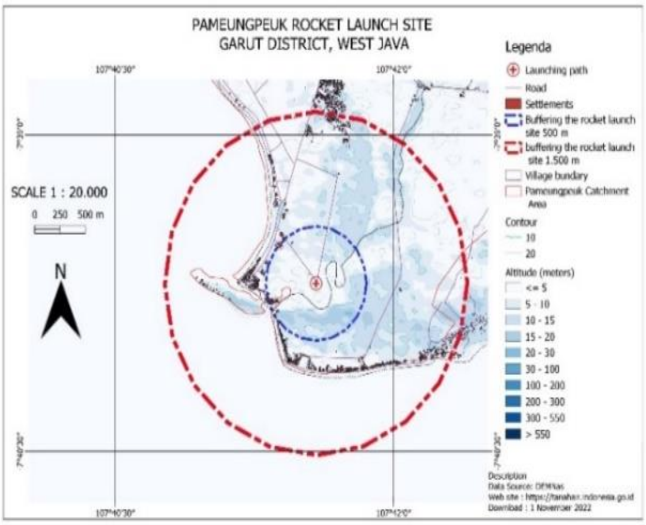

Figure 4. Pameungpeuk rocket launch site

Figure 4 shows that the sustainability of the spaceport faces several challenges from the community, including how strategies can be used to persuade the community to agree with the development of the spaceport in their area. Community disapproval is due to the high risks that will be faced in the surrounding environment. Managers who are able to manage and minimize risks so that they can be accepted by the community will greatly help ensure the sustainability of the spaceport. Moreover, the rapid development of the space industry requires efforts to maintain sustainability.

The main issue is safety and environmental sustainability, with concerns over environmental damage being the biggest reason for spaceport development. This problem can be minimized by the commitment formed by the spaceport. Managers are able to minimize the residue released in satellite launch activities. Replacing more environmentally friendly materials is a suitable strategy. environmentally friendly spaceport development will be a new trend. This trend is a form of market demand for the space sector, in accordance with the commitment of various countries to the protection of the world. For example, Cornwall has a number of strategies to move towards a sustainable airport. strategies to minimize risks from carbon emissions, biodiversity threats and airport facilities. Biofuel substitution is a popular effort, and carbon emission purchasing. Solar power utilization is also one of the strategies to reduce the use of non-renewable energy [39]. Issues related to land clearing for launch facilities are also a concern, providing solutions by offering environmental restoration efforts [39].

Market considerations are made so that the space industry can survive in the midst of global competition. The success of the spaceport is determined by meeting customer needs, successful creation of security, cost-effective and environmentally friendly [10]. The success of spaceports is determined by private actors and market considerations [4]. The biggest difficulty for countries is adjusting to the new highly competitive market. Concerns about empty cores, where the operating costs of facilities are higher [10]. As various countries have been racing to improve their spaceport aspects. The construction and operation of spaceports are highly vulnerable to external shocks, beyond the country's control.

Environmentally friendly management efforts need to be one of the trends to make the space sector sustainable. Because it is undeniable that this sector has provided economic benefits, attracting a number of investors willing to invest. Providing welfare and opening a number of jobs as well as the potential for future research. Environmental considerations have begun to be implemented in several countries including the US, Canada, New Zealand, Italy, Portugal, Spain, Sweden and Norway [7]. Environmental risks that have been considered can attract investors. Investors can provide benefits for the development of the physical infrastructure required for launch. Spaceports also have a position in the space sector trade market. Sustainable airport management practices can attract investors. A £300,000 grant for innovative projects using space data to help Scotland transition to sustainable airports [40]. Spaceports are required to be more imaginative and innovative [2]. Global competition requires spaceports to have an entrepreneurial policy.

There is some work for sector stakeholders, the private sector to ensure strategies towards sustainable spaceports. How to manage safety, human health, biodiversity, and emission management. Policymakers will need a comprehensive assessment of the global consequences of spaceflight to make effective and informed decisions to guide the development of spaceflight in the coming decades. Stakeholders across the space industry must recognize the urgency of the need for spaceport and environmental sustainability.

5. CONCLUSIONS

Spaceport development is a potential for Indonesia to increase independence in the space sector. Indonesia can also improve the economy through this sector. Indonesia's strategic location makes it easy to launch satellites and rockets. Real evidence of Indonesia's seriousness is contained in Law no. 21 of 2013 concerning the field of space.

Unsustainable spaceports not only have the potential for launch failure and environmental threats but also hinder the innovation process of technology. The interaction process between innovation actors, including laboratories, industries, technology enthusiasts, and technology intermediaries, plays a role in the sustainability of spaceports. Technological innovation sustainability has a role in mitigating technology failures and environmental damage. This effort can attract several investors to invest in spaceports, so that managers can develop spaceports. Ecological, economic, and social aspects can be achieved according to the objectives of spaceport development.

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NOMENCLATURE

t CO_2 e	tonnes of CO_2 equivalent
£	euro
$	United States Dollars