KP LABS
Mission Complete

IBM **Research**
Europe

COMMERCIALISATION ANALYSIS REPORT

SPACE-BASED DATA CENTERS PROJECT

AUTHORS: Patricia Sagmeister, Jonas Weiss

DATE: 2024-03-08

VERSION: 1.0

2023

TABLE OF CONTENTS

1. ACRONYMS 3

2. REFERENCE DOCUMENTS 5

3. INTRODUCTION 6

- 3.1. Background 6
- 3.2. Prerquisites 6
  - 3.2.1. Cloud Computing and it's Characteristics 6
  - 3.2.2. New Space Economy 7
  - 3.2.3. ESA Agenda 2025 8

4. MARKETS FOR SPACE-BASED DATACENTERS 9

- 4.1. Market Trends 9
- 4.2. Market Segments of the Space Economy 10
- 4.3. Workshop Results 11

5. BUSINESS MODELS 15

- 5.1. Business Model – A Definition 15
- 5.2. Classical Cloud Business Models 15
- 5.3. Emerging Cloud Business Models 17
- 5.4. Space as-a-Service 18
- 5.5. Workshop Results 18

6. COMMERCIALISATION ANALYSIS 21

- 6.1. Risk Analysis 21
- 6.2. Business Model Feasibility 22
- 6.3. Players in the Field 23
- 6.4. Conclusions & Recommendations 24

7. SUMMARY 26

8. LITERATURE REFERENCES 27

1. ACRONYMS

Acronym	Explanation
aaS	as-a- Service
AaaS	Answers-as-a-Service
AI/ML	Artificial Intelligence / Machine Learning
B2B	Business to Business
B2C	Business to Consumer
BEA	U.S. Bureau of Economic Analysis
CSP	Cloud Service Provider
DaaS	Data-as-a-Service
ESA	European Space Agency
EO	Earth Observation
GEO	Geostationary Orbit
GSaaS	Ground Segment-as-a-Service
IaaS	Infrastructure-as-a-Service
Info-aaS	Information-as-a-Service
Insights-aaS	Insights-as-a-Service
JRC	European Commission’s Joint Research Centre
LEO	Lower Earth Orbit

NIST	United States National Institute of Standards and Technology
OECD	Organization for Economic Cooperation and Development
PaaS	Platform-as-a-Service
PalaaS	Payload-as-a-Service
ResaaS	Resilience-as-a-Service
RD	Reference Document
SAR	System Analysis Report
SaaS	Software-as-a-Service
SataaS	Satellite-as-a-Service
SDaaS	Space Data-as-a-Service
SDC	Space Data Centre
SDR	SDC Design Review

2. REFERENCE DOCUMENTS

ID	Document
RD-1	Use-Cases Report v2 (UCR)
RD-2	User-Level Requirements Report v2 (ULRR)
RD-3	System Analysis Report (SAR)
RD-4	Media Package

3. INTRODUCTION

This document is part of the study on Space-based Data Centers (SDCs) and covers the main project requirement REQ-5 defined in the technical tender document 7732.

3.1. BACKGROUND

This commercialization analysis report addresses the main aspects of potential commercial schemes and approaches for Space-based Data Centers (SDCs). While the architecture, hardware, and software technologies, as well as the costs for the implementation of SDCs are covered in the System Analysis Report (SAR), this document focuses on the potential commercialization strategies and their different levels. In accordance with the ESA Agenda 2025 this report identifies adequate markets and market segments, as well as suitable and innovative business models for SDCs. It covers some players in the field, shows trends in Cloud Computing and matches those to the New Space Economy.

To complement the report with the knowledge of experts in the field, a workshop on Space-based Data Centers – Market Segments and Business Models [33] was conducted. The workshop took place on October 5th, 2023, and was attended by almost all members of the Advisory Board, experts from ESA, as well as from Thales Alenia Space. The goal of this workshop was to validate the unique selling points and differentiators of SDCs, as well as to understand how to map traditional cloud-computing business models to Space-based Data Centers. The collected feedback and results of this workshop are incorporated in the respective chapters of this document.

3.2. PRERQUISITES

3.2.1. CLOUD COMPUTING AND IT'S CHARACTERISTICS

According to the Special Publication 800-145 of the United States National Institute of Standards and Technology (NIST), Cloud computing is defined as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." [24] .

Based on this definition, the cloud model features the following five core characteristics [24] :

1. On-demand self-service
2. Broad network access
3. Rapid elasticity
4. Measured service
5. Resource pooling

These core characteristics allow clients to provision cloud computing capabilities automatically, access these via the network from heterogeneous client platforms, and scale/release those services according to their needs. Measuring services allow monitoring and provide transparency about the usage of utilized services and resources to the clients as well as the Cloud Service Providers (CSP). To be able to dynamically respond to customer demands, but also be cost and resource effective, all cloud environments are characterized by resource pooling. This key feature of any cloud environment allows CSPs to operate under a multi-tenant model.

3.2.2. NEW SPACE ECONOMY

Already in 2012, the OECD defined space economy as "the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilizing space." [32] . While this first definition provides a wide scope for interpretation, in 2020 the U.S. Bureau of Economic Analysis (BEA), formulated the following more concrete definition: "The space economy consists of space-related goods and services, both public and private. This includes goods and services that:

- Are used in space, or directly support those used in space
- Require direct input from space to function, or directly support those that do
- Are associated with studying space" [31]

The space economy was originally driven and financed by governmental organizations with the task to push space exploration for scientific purposes or civil security. Even if both definitions cover the public and private sector, the latter played only a minor role. Nowadays the private sector gains more and more significance, coining the term "New Space Economy". The characteristic of this "space renaissance" [5] is the push of technological innovation done by established actors as well as new private companies leading to a considerable reduction of costs in all space-related areas (launching facilities, rockets, satellites, space-enabled components, etc.). Those falling market entrance costs are attracting new non-traditional players and allow also developing countries to enter this domain. The focus of the new space economy is not traditional scientific exploration, but the commercialization of space and space resources, leading to the development of new business models and new markets [5] . Additionally, the number of public-private partnerships is growing, giving organizations, such as ESA, significantly more options to tailor launch locations or rocket sizes to specific missions [6] .

While the economic barriers to enter the new space market are shrinking, the “overlapping, complex, and sometimes contradictory regulatory structures inhibit efficient access to space.” [4] . To allow “companies to operate efficiently, effectively, and safely” [4] in the space domain, a harmonization of domestic as well as international regulations must take place.

3.2.3. ESA AGENDA 2025

ESA’s Agenda 2025 defines the priorities and objectives to foster and grow the role of Europe in the space economy. To be able to assess if SDCs and their commercial approaches meet those priorities, this paragraph will recap the most important points of this Agenda.

According to [1] ESA defines the following five priorities for 2025:

1. Strengthen ESA – EU relations
2. Boost commercialisation for a green and digital Europe
3. Strengthen Space for safety and security
4. Address programme challenges
5. Complete the ESA transformation

To accomplish those priorities, it is important that all European countries agree on a common European space vision that defines its ambitions for the future [1] . In order to establish a “vibrant commercial space sector to serve its own societal and economic needs and priorities” [2] , ESA commits in this Agenda 2025 to support the creation of new markets for new applications, speed-up innovation cycles, accelerate space data transformation into actionable insights, as well as establish open standards and interfaces [1] [2] .

4. MARKETS FOR SPACE-BASED DATACENTERS

4.1. MARKET TRENDS

The increasing privatization of the space industry, as well as the growing number of public-private partnerships, and a jump in technological innovation, have significantly reduced the costs of space missions [5] . These falling mission costs make space more accessible for companies or even small or developing countries that could not afford to launch satellites in the past, leading to a democratization of space access. As the number of private companies in the space economy rises, the number and variety of launch locations and systems, rocket types and sizes increase tremendously, allowing to tailorize space missions [6] . But the dropping costs also attract non-traditional players into this field, such as car manufacturers, finance and insurance institutions, or pharmaceutical companies. With these market entrants new space-related products and services are offered, reaching out to a significantly growing customer base.

The space economy doubled its size between 2009 and 2022 to US $464 billion. If it continues the same growth trajectory than it will hit US $1 Trillion by 2040 [7] . While satellite navigation or positioning services are already widely used today, the trend will continue and according to [7] space and the data generated in space will “play an increasing role in our everyday lives”. Current satellite imagery is already able to provide an almost real-time “bird’s eye view of the conflict in Ukraine” [5] and will by 2040 contain all sorts of information layers providing radar, thermal, and hyperspectral imaging that will be fully integrated in gazillions of business applications [7] . By then these additional data layers will be taken for granted and inherently used by businesses and consumers, like GNSS data is used today. Most of the participants of the Foresight Study [7] go even further and predict that within the next 10 to 20 years space data will become so widely available and used that businesses require a space strategy to keep up with their competitors.

This trend is in line with one of the findings of the workshop [33] that identified the massive amount of data generated already now as one of the major selling points for SDCs. Currently only a fraction of the data that is produced in orbit can be downloaded to earth for processing. As SDCs provide not only compute capabilities, but also offer a vast amount of storage, businesses that generate space data would be able to offload all of it to SDCs immediately and offer this data on the market. The more data these businesses can collect and offer, the more attractive they become.

4.2. MARKET SEGMENTS OF THE SPACE ECONOMY

To be able to measure space economy the OECD identifies in [9] the following three major market segments:

- Upstream
- Downstream
- Derivations from space activities

The upstream segment covers all activities that are needed to start space programs, stretching from fundamental research, over engineering, design, and manufacturing, to launching of satellites and orbital systems. The downstream segment includes the operation of space infrastructure, as well as all products and services that "directly rely on satellite data and signals to operate and function" [9] . The third major market segment deals with the transfer of space technology into other non-space related industry sectors or vice versa.

Additionally, the OECD [9] lists the following main sectors of space applications:

Market Segments	**Main Sectors**	**Selected space applications**
Downstream	Satellite communications	Telecommunication services (Voice, data, internet, Multimedia) Broadcasting (TV/Radio services, video services, Internet) Direct-to-home
	GNSS Positioning, navigation, timing	Navigation for air, maritime, land transport Location of individuals & vehicles Universal referential time & location standard for systems
	Earth observation	Measuring & monitoring of earth, climate, environment, people
Upstream	Space transportation	Launch services, Spaceports, Space adventure rides Logistic services for transportation between orbits
	Space exploration	Spacecrafts & space stations Exploration of universe beyond earth's atmosphere
	Science	Space science, atmospheric science, climate research
	Space technologies	Space systems used in space missions
Derivations	Generic technologies enabling space capabilities	AI, Data analytics SW, Not initially destined for use on a space system / application

Table 1: Main sectors of space applications defined by OECD [9]

Interestingly the OECD allocates the value of all generated space data to the downstream segment that comprises products and services relying on data that is aimed at consumer and business markets [9] . However, data that is produced in the upstream segment for example during space exploration that might not be transferred directly to earth, is not included in the current OECD space market definition.

Also, PwC identifies in its study on main trends and challenges in the space sector [10] the value of data. Specifically, as new technologies will allow to create new data, but also predictive analytics and AI/ML will assist space operations allowing to extract value from the created data right away. Besides the market segments and space-related applications identified by the OECD, PWC in [10] sees also large potential in these additional emerging space markets:

- Space-to-Space transactions
- Human space flight
- Lunar and beyond
- Terrestrial applications

4.3. WORKSHOP RESULTS

In the first part of the workshop [33] unique selling points and differentiators for SDCs, as well as potential market segments were discussed. Due to weight, power, and thermal restrictions, current satellites have limited resources specifically in compute, storage, and communication bandwidth. SDCs however, can provide massive compute, large amount of storage, and significantly higher communication bandwidth due to more flexible access to ground stations. This makes SDCs particularly interesting for markets and space-related market segments that require high compute power and/or large storage capabilities, as well as reliable and fast ground station access.

While the workshop participants could see the benefit of SDCs in traditional markets such as satellite communications, earth observation, GNSS, science, or civil security, they also identified emerging and future markets [12] like direct-to-home, space tourism, space resource extractions, and on-orbit markets, like on-orbit servicing and on-orbit manufacturing, as potential market segments for SDCs.

However, the main value propositions of SDCs independent of those traditional or emerging markets identified during the workshop that primarily are seen as enablers for completely new markets in space are:

- Data generation
- Data storage
- Data processing, combination & consolidation
- Near real-time delivery of processed results
- Space-to-space communication
- Cybersecurity of data
- Sustainability on earth

An example area where massive amounts of data are already generated is earth observation (EO). However, EO services are already too far down in the downstream line. So, the workshop participants suggest differentiating between data generators, data storers, data processors, and data users. Those companies that are already generating data in space are limited by the bandwidth bottleneck to ground stations. These data generators can produce massively more data and different data already today, but those amounts of data cannot be sent to earth. SDCs with large storage capabilities would allow data generating providers to offload all their raw data on SDCs and store them in space in so called data lakes. These space-based data lakes, which can be seen as huge databases, might be able in the future to house petabytes of raw data in structured or unstructured form establishing a completely new market segment around space data growing. The value of those data lakes increases with the amount of data, its quality, as well as the variety of the data-layers they can offer. Here, also must be said that data generators and data lake providers or data storers can be two different business entities that are in a B2B or even B2C relationship. So, storing data in space and selling this raw data to data processing businesses can be identified as new data growing market with a sales channel that is completely new to space economy right now.

Even if data lakes might be a market of the future, having a lot of storage on SDCs is particularly interesting for data that is harvested now, i.e. in science and exploration, but does currently not look worth to be processed in orbit or sent to ground. This data should not be thrown away as it could be re-used later to train for example new models for smarter AI systems or neural networks that are made available on SDCs.

Moreover, storing data on SDCs would tremendously simplify mission planning and makes data handling much more flexible. Currently mission providers must plan any mission around a specific “data dumping point”. For this it is necessary to find ground stations with free bandwidth and suitable capabilities separately for each mission and every mission profile and plan the exact point in time to send data to the ground. SDCs could take over here the function of a data relay networks where satellites dump their raw or even pre-processed data on the SDC and the SDC takes care of sending the data or the extracted insights to the ground.

As already mentioned, SDCs not only can provide large amounts of storage, but also offer excellent computing capabilities that do not require sending all data to the ground but allow to process large data sets directly in space. So, extracting and generating “intelligent data” instantaneously in orbit by leveraging AI/ML functionality and sending only the result respectively the generated insights to earth can be seen as viable market segment for SDCs that could be appealing to a broad variety of commercial, financial, and governmental industries and consumers.

Notably, the ability to process data in-space is also important for edge-processing use-cases respectively the on-orbit market that require the combination of data from multiple sensors or satellites. While low-earth orbit communication is not difficult and it is easy to connect to one satellite, it becomes complicated with multiple satellites as there is only one point of contact for all of them. SDCs could be used to consolidate the data of multiple satellites and send only the final product to the ground. This would improve the timeliness of the final product, and it would significantly reduce the bandwidth to ground stations, that are the major cost drivers for these kinds of missions. These SDCs could even serve as service providers for ground stations, generating an interesting, merged ground/space market segment.

Another very important market segment that was identified to be enabled by SDCs is real-time delivery of processed data. It is expected that only SDCs can provide as much compute as needed to produce alert messages or trigger events, i.e. wildfire use-case, and deliver the results in real-time to earth.

The workshop participants concluded that different data has different speeds. So, it is necessary to separate long-term data that is worth to be stored from short-term data that could be obsolete right after it is processed. Market segments that require high speed to serve events and low reaction times are most likely only interested in the final product, if their real-time response requirements can be met, but not in storing the data itself.

While the satellite communication provider market is not seen as decent market segment for SDCs, space-to-space communication is. Currently the communication costs between satellites are very high. Data ingress is becoming a large problem. Additionally, no standards for satellite-to-satellite communication exist. SDCs could fill this gap as they are able to manage data traffic, implement a distributed architecture, and offer constellations with repeatable space and ground track. They could even prepare the fundament for a de-facto standard for space-to-space communication.

Also, cybersecurity of data was mentioned as potential market segment for SDCs. Putting data in orbit could increase the security of data, but it is also seen that threats could be different in space.

The last identified but very important aspect that could push the implementation of SDCs is sustainability. So, industries that must comply to strict environmental rules, might be forced in the future to put infrastructure that is not carbon efficient into space to push sustainability on earth.

5. BUSINESS MODELS

5.1. BUSINESS MODEL – A DEFINITION

In 1994 Peter Drucker in [34] proposed a universal theory of the business. He suggested a business paradigm based on organizational assumptions about performance, structure, operation, value creation, and how organizations "get paid for what they do" [35] , that was meant as template for business development. While he did not coin the term business model, his assumptions build the fundament of the current definition of business models that can be found in Gartner's Finance Glossary [36] :

"A business model is a description of how an organization creates, delivers, and captures value. It has a formal structure that consists of four basic components: the value proposition, customers, a financial model, and capabilities."

5.2. CLASSICAL CLOUD BUSINESS MODELS

The System Analysis Report RD-3 listed in chapter 2 states that in the context of this study SDCs provide "in-space on-demand compute, storage/buffering and communication services through a unified access/interface scheme and many redundant access points". So SDCs exhibit a lot of common, as well as essential characteristics of the NIST Cloud Computing Definition Framework [30] as shown in Figure 1.

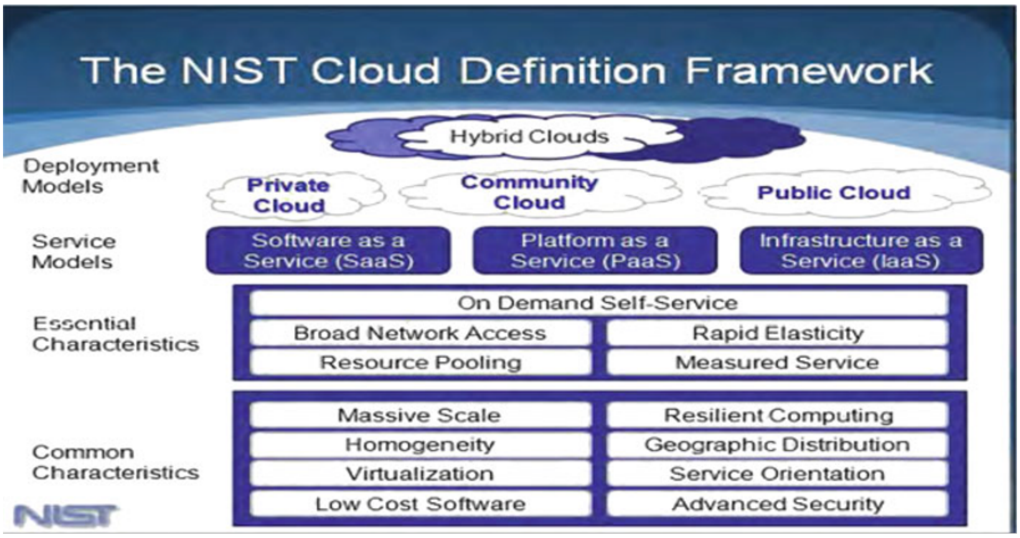

Figure 1: NIST Cloud Computing Definition Framework [27] [30]

This Framework identifies also the three most common layers or service models for the deployment of cloud computing as depicted in Figure 2. Each layer provides a set of dedicated services to the succeeding layer, and the layers purchase specific services, not necessary the full set of offered services, from the preceding layer.

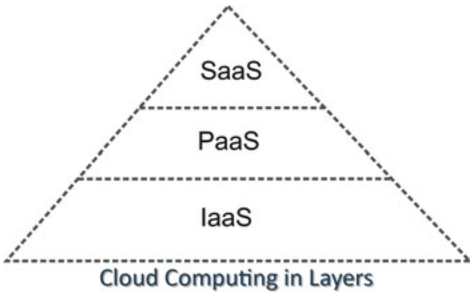

Figure 2: Common Cloud Computing Layers [27]

The service or product of Infrastructure-as-a-Service (IaaS) is basically the hardware itself and the according services that are related to it. This includes storage, servers, devices, etc. that can be offered "as-a-Service" to the clients. When relating this business model to SDCs, this would include satellites, whole nodes or even pods of the SDC, or maybe parts or whole constellations. The investments to run such a deployment model with SDCs are huge and might be commercially not viable for a lot of businesses as no standards for satellite infrastructure yet exist.

Platform-as-a-Service (PaaS) is the layer where applications can be developed, designed, and tested that run on the IaaS [27] . In this service model, the hardware is basically outsourced, but it offers a complete and traditional software development environment. This business model is quite attractive for businesses that develop new applications. They do not need to maintain own hardware and can customize the IaaS service according to their current needs.
Software-as-a-Service (SaaS) is according to the NIST Framework the last layer of classical cloud computing. This layer hosts only applications or software services that are used on-demand by the end user.

While IaaS might not be viable, PaaS, as well as SaaS could be suitable business models in the SDC context. Those two allow to build up an ecosystem in orbit that offers on-demand scalability, as well as a huge variety of different space-applications on top of the same infrastructure.

5.3. EMERGING CLOUD BUSINESS MODELS

Emerging business models in the cloud space are either data- or AI-based. Specifically, the growing area of foundation models, machine learning, and artificial intelligence generate new business models on top of cloud-based platforms. AI-as-a-Service (AIaaS) is one of the new models that allows businesses to incorporate artificial intelligence in their service offering and products without having the need to build up the associated expertise [28] . With these new AI/ML capabilities it is even possible to offer Insights-as-a-Service (Insights-aaS) where actionable analytical results are provided for a diverse set of market sectors [8] .

The most common data-driven model is Data-as-a-Service (DaaS). In this business model central organizations are collecting data from users mainly via digital platforms. The collected data is anonymized and commercialized either raw or slightly pre-processed on a certain marketplace. Companies that can collect massive amounts of data are usually successful with this business model. DaaS can be either offered on-demand with a “pay-per-data” revenue generation model or via subscription or flat-rate model [29] .

Another data-based business model is Information-as-a-Service (Info-aaS). In this model either self-collected data or third-party data is used, analyzed, and visualized. It’s focus is to generate analytical reports and distribute them either in a B2B or B2C fashion. The revenue generation can be done on-demand through selling individual reports or analyses, or through a subscription model [29] . However, deep know-how of the specific industry is required to operate such a model successfully.

The third data-driven business model is Answers-as-a-Service (AaaS). It requires deep know-how of their client base and is therefore suitable for businesses with close contact to their customers. The basic idea is that this service provides answers to questions that are asked by their clients. Revenue generation can be like in any data-driven business model pay-per-answer, or via subscription services [29] .

Those emerging business models are enabled by massive amounts of data, the ability to store that data, as well as capabilities to process these data sets. These enablers match the value proposition of SDCs identified during the workshop [33] . Therefore, it is expected that these kind of emerging business models can be directly translated to space, leveraging the capabilities of SDCs.

5.4. SPACE AS-A-SERVICE

The trend to move to "as-a-Service" business models has already started in the new space economy. While in the past, owning space infrastructure was the key, nowadays more and more businesses move to a leasing model. So according to [10] Ground Segment-as-a-Service (GSaaS) emerged to offer ground segment operations to a variety of satellite operators. This model increases flexibility, offers more cost-effectivity, and can be easily adapted to the needs of the new space economy.

Also, Satellite-as-a-Service (SataaS) and Payload-as-a-service (PalaaS) are emerging business patterns that address a customer base that does not want to own or operate a satellite. SataaS allows to lease capacity on a satellite for the full mission, but also leasing capacity for a particular window in time or a specific imaging site or area of interest are offered [10] . PalaaS includes hosted payload concepts for in orbit testing, as well as condosats [10] . Both models are expected to minimize costs and shorten time to market due to the simplification of access to space.

As already mentioned in chapter 5.3 it is expected that emerging cloud-based business models will be adopted by the new space economy. Space Data-as-a-Service (SDaaS) is already a fast-growing market [13] . So, it is only a matter of time until companies will adopt other emerging data- and insights-based business models for their applications, leading to a commodification of space data and insights [10] .

But how do SDCs fit into the Space-as-a-Service trend? SDCs offer on-demand compute and storage capacity, as well as bandwidth to adapt for peak loads. SDCs are envisioned to aggregate and consolidate data from different satellites allowing for the emergence of new, complex real-time applications. They can accommodate small, highly efficient satellites at reduced costs that provide better performance and offer flexible, low-latency ground connections in real-time. Therefore, SDCs have the potential to foster current and generate completely new "as-a-Service" business models within the new space economy, leading to a commodification of space.

5.5. WORKSHOP RESULTS

The question if it is possible to match traditional cloud business models to SDCs was heavily and controversially discussed during the workshop [33] . Particularly Infrastructure-as-a-Service was considered as not feasible yet due to the missing standardization of the space infrastructure.

Additionally, IaaS would contradict the basic idea of opening space for everyone, as only a few big clients, such as large insurance companies, would be able to afford such a bare-metal model in the context of SDCs. However, if organizations such as ESA, would push for and facilitate common standards in this area, IaaS could work and it would have a positive effect on the accessibility of space. Specifically, because there are already companies, operating in the merged ground/space market, and would be interested in offering IaaS. For them IaaS is the combination of data centers on the ground with data centers in space that work closely together. These players are thinking of opening their satellite systems for the purpose of data relay to other space-related businesses, even allowing to do some preprocessing on the data, and passing it on to the next node or the next ground station.

The workshop attendees agreed that PaaS and SaaS are likely to be useful for clients in the space industry. Particularly because it is expected that the revenue generation models that come with it will be extended so space. Revenue generation in general is considered as a very important question, because depending on the value proposition, users and payers are not necessarily the same.

So, on-demand revenue models like Pay-as-you-go or Pay-as-you-use, as well as subscription or licensing models are expected to be available in the context of SDCs and could be even extended to infrastructure services. For larger clients and larger constellations, these revenue generation models might not hold, and 1-to-1 long-term arrangements are envisioned.

With respect to the NIST Cloud Definition Framework [30] the workshop participants stated that it also could be applied to SDCs, as it brings the world of datacenters, cloud, and telecommunication together. The framework fits perfectly fine as long as flight operations for SDCs are understood.

Also new and emerging business models were intensively discussed during the workshop. The opinions, particularly regarding “as-a-Service” (aaS) were manyfold. The main drivers for aaS models in space are the demand for significantly more data types as well as real-time data, the demand for insights, dynamically changing mission requirements, as well as short deployment cycles implying quite some mission uncertainty. While these business models seem to be very attractive for commercial players in the new space economy, military and government clients are not interested that much in aaS. According to Euroconsult government space budgets have increased from 2022 to 2023 by 15%, reaching $117 billion [37] . $59 billions of this budget went directly into defense expenditures, surpassing investments in civil programs for the first time in this sector [37] . It is expected that this specific market segment will use SDCs not in combination with “as-a-Service” models, but either own their own SDC or leverage full bare-metal options.

Besides the classical and emerging “as-a-Service” models also Resilience-as-a-Service (ResaaS) was suggested. As the generation of data and insights is done outside of earth, it is not possible to rely on fully functioning systems all the time. In case of a system crash the generated data and insights should not be lost. So, SDCs could provide this feature “as-a-Service”.

As a result of the workshop [33] the following business models are considered as viable for SDCs:

- Classical – IaaS / PaaS / SaaS
- Emerging – DaaS / InfoaaS / AaaS / AIaaS / Insights-aaS
- SDC specific – SDaaS / ResaaS

6. COMMERCIALISATION ANALYSIS

6.1. RISK ANALYSIS

The SWOT analysis in Table 2 shows that SDCs have a lot of benefits and offer strong opportunities.

More and more European countries are in the top 10 list of the largest space deals. So, for example Germany, France, Spain, and Denmark saw large investments in their national space industry during 2023 [21] .This shows that European countries are willing to foster and grow a space ecosystem. However, a common European space investment strategy is still missing.

Strengths	**Weaknesses**
Simplified access to space Democratization of space Increasing scalability & velocity of resources Accelerated profitability Enablement of new applications Fostering experimentation [26] Process data where it is generated	Cybersecurity in space [4] National space investments [21]
Opportunities	**Threats**
Promoting of on-demand business models Strengthen a united European space program Increased sustainability on earth Profit from data center capacity shortage Boost value creation [25]	Complex international & national regulations Missing open accessible standards Bankruptcy of IaaS providers [23]

Table 2: SDC SWOT analysis

The pricing of data center capacity has steadily increased in European markets, due to the growing demand, as well as the rising operational costs. This effect is paired with a shortage in data center leasing availability, leading to significantly higher rental rates specifically in Frankfurt and London, and creating significant issues for Hyperscalers that need to secure their expected demand for their digital services [22] . This effect prevents that data generated in space can be entirely processed in data centers on earth, which could foster the need for SDCs in the projected timeframe of this study.

It can however also be observed that SDCs are facing some challenges. The two biggest threats to their success are complex and sometimes also contradictory national and international regulations [4] for space access, as well as missing open accessible technical standards for space infrastructure and platforms, space-to-space communication, or APIs, just to name a few.

6.2. BUSINESS MODEL FEASIBILITY

While in chapter 5.5 suitable business models for SDCs were identified, Table 3 investigates the feasibility of those business patterns with respect to the three selected use-cases of this study. When looking at the value proposition of SDCs that have been collected in chapter 4.3, the first use-case focusing on the mothership and scout formation, can be seen as representative for the real-time delivery requirements of processed data. The second use-case featuring a combination of GEO SDC and various data-producing LEO satellites covers the data-related value propositions, like data generation, storage, processing, as well as combination & consolidation. The last use-case featuring an SDC in combination with a lunar lander represents an edge computing example including space-to-space communication. The feasibility is categorized with low, medium, or high, estimating the likelihood that that specific business model is used for this use-case.

Business Model		**Use-Case 1**	**Use-Case 2**	**Use-Case 3**
Classical	Infrastructure-aaS	low	medium	low
	Platform-aaS	medium	medium	medium
	Software-aaS	high	high	medium
Emerging	Data-aaS	medium	high	high
	Information-aaS	medium	high	low
	Answers-aaS	medium	high	low
	AI-aaS	high	high	medium
	Insights-aaS	high	high	medium

Business Model		Use-Case 1	Use-Case 2	Use-Case 3
SDC specific	Space Data-aaS	medium	high	high
	Resilience-aaS	medium	high	high

Table 3: Matching Business Models with Use-Cases

6.3. PLAYERS IN THE FIELD

Even though SDCs featuring the capabilities envisioned in this study do not exist yet, several important players in the space economy are either evaluating the ability to put data centers in space or are already planning it. ASCNED [14] for example is a European project led by Thales Alenia Space with the goal to achieve carbon neutrality by 2050 by installing data centers in orbit that are powered by solar power plants. While the government of UAE is not planning a data center in space it announced to build a Space Data Center as digital platform that will provide scientists, the public, public and private entities, as well as start-ups with full access to space data [15] . The overall goal of this initiative is to build an ecosystem utilizing data that is harvested in space and develop innovative technologies to “address global sustainability challenges, promote space-related solutions to overcome national challenges, and boost the number of companies and patents in the space industry” [15] . Also, NTT, a Japanese telecom and technology company, announced a collaboration with SKY Perfect JASAT Holdings to launch a data center into space already by 2025 [17] . This small SDC is envisioned to be a satellite that collects data like images or video, preprocesses that data in orbit and sends only precious data to earth.

An example for the merged space and ground market segment is the startup Tilebox [20] . This company offers a platform that integrates data processing in-orbit with data-processing on the ground, as well as efficient downlinks to ground stations.

But there are also startups that plan to build data centers on the moon. One of them is Lonestar Data Holdings Inc. [16] . This project is not targeting the generation of data on the moon, such as done in use-case 3 of this study, but to store data from earth on a non-terrestrial location for disaster recovery purposes.

There is also a growing number of startups that offer satellite edge computing solutions with the overall goal to process data in-orbit in real-time. Examples of those companies are i.e. Little Place Labs [18] that allow to use machine learning algorithms on satellite constellation for data analysis. Another startup that offers solutions in the EO space is Sidus Space [19] . With the acquisition of Exo-Space and its AI technology in 2023, they expanded their EO business segment to provide actionable solutions for their clients in this area.

While not all these players in the new space economy are willing to invest in own more intelligent space infrastructure, their solutions could be part of an ecosystems that is fostered and developed by the implementation of SDCs.

6.4. CONCLUSIONS & RECOMMENDATIONS

Space-based Datacenters offer an excellent way to push ESA's agenda 2025 [1] , specifically in the areas of boosting „commercialization for a green and digital Europe"[1] , as well as „strengthen space for safety and security" [1] . It can be expected that SDCs will stimulate commercialisation in space, as they fosters simpler access to space, and push therefore it's democratisation. It is also expected that by 2040 „as-a-Service" will be the most dominant business model in space [7] . This in turn attracts new players and establishes an ecosystem including new markets. However, to make SDCs the most used platform of the new space economy, new open and open accessible standards for space infrastructure, platforms, software, and services, as well as open APIs and standards for space-to-space communication need to be established. Even open source business models [28] , as well as open arhcitectures and open access to SDCs could be a way to foster a space ecosystem.

While open accessible standards are the drivers for a technological boost of SDCs, the complex and sometimes even contradictory regulations on international, as well as national level, still slow down efficient access to space [4] . A harmonization of these regulations would make space operations much simpler and safer specifical for commercial entities [4] . Multi-government organizations, such as ESA, should take the lead and push for such a harmonized regulatory framework at least on the European level.

From a profitability point of view, studies already show that satellites with more processing power as well as more capabilities are more cost effective then a large number of satelllites with low complexity [3] .This can also be exptected for SDCs, as they allow to generate real-time actionable information and insights due to their high performance compupte, massive storage, and AI/ML capabilities.

When looking at the socio-economic effects of space investments between 1972 and 2018, as depicted in Figure 3 [11] , it can be seen that investments in space have already a lot of impact on the overall economy, as well as selected market sectors.

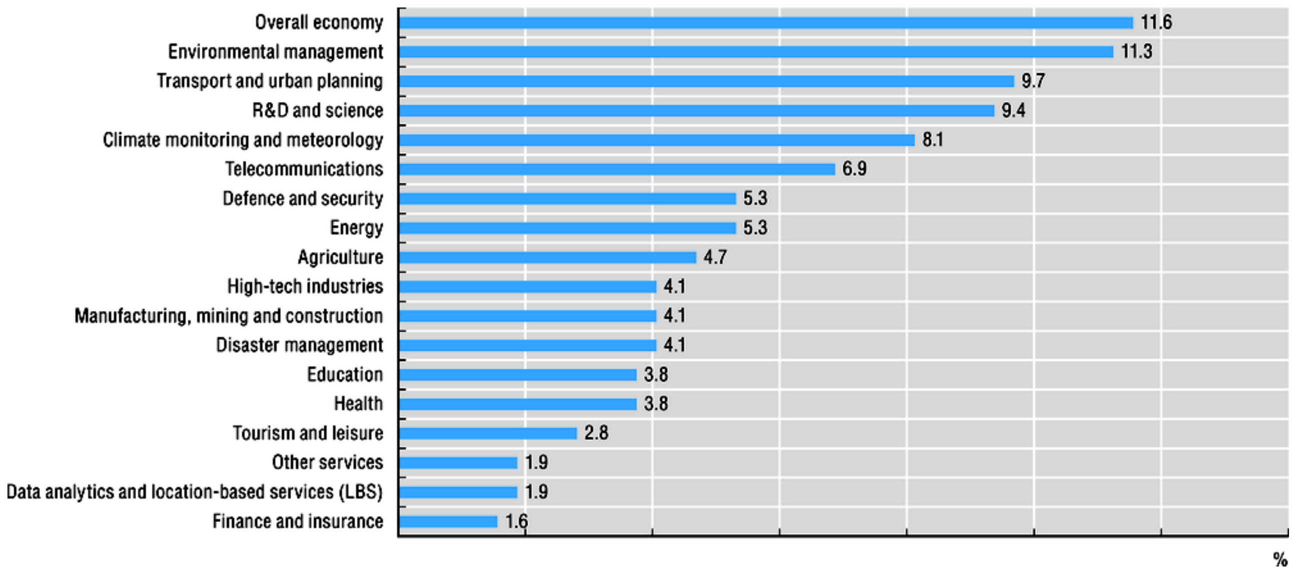

Figure 3: Selected sectors benefiting from socio-economic effects from space investments (OECD) [11]

Also in 2018 a study conducted by Deloitte [26] evaluated the economical and social impact of Google cloud. This study showed that cloud technology is a major driver of revenue growth and cost savings for any type of business. Due to the on-demand accessability of resources and tools a net return of $10 for each $1 spent on cloud computing are reported on average by large Google Cloud users [26] .

Combining these two effects and projecting them towards the benefitial trends of SDCs, then the socio-economic impact of data centers in space can be exptected to be huge. So, SDCs will not only boost the new space economy, but will also have a large positive impact on non-space related marekt segements, as well as on society.

7. SUMMARY

This commercialization analysis report describes the main characteristics of markets for Space-based Datacenters. It identifies the main trends, as well as market segments of the space economy, lists classical, and emerging cloud business models, as well as new space-based business models. Market segments and business models, as well as the value propositions for SDC were validated with experts in the space-tech field during an on-line workshop. The workshop results build an inherent part of this analysis. In a next step these findings will be part of the final dissemination of the project.

8. LITERATURE REFERENCES

[1] ESA Agenda 2025 Executive Summary, https://esamultimedia.esa.int/docs/ESA_Agenda_2025_final_EN_executive_summary.pdf

[2] ESA Agenda 2025, https://esamultimedia.esa.int/docs/ESA_Agenda_2025_final.pdf

[3] I. del Portillo et al., Architectural Decisions for Communications Satellite Constellations to Maintain Protitability While Serving Uncovered and Underserved Communities, International Journal of Satellite Communication and Networking, Wiley, October 18, 2022, https://doi.org/10.1002/sat.1464

[4] Sean Ludwig, How the Space Industry Is Taking Off in 2023, U.S. Chamber of Commerce, August 29, 2023, https://www.uschamber.com/space/how-the-space-industry-is-taking-off

[5] The space economy is booming. What benefits can it bring to Earth, World Economic Forum, October 19, 2022, https://www.weforum.org/agenda/2022/10/space-economy-industry-benefits/

[6] Falling launch costs are making the space economy more accessible, Verdict, September 27, 2023, https://www.verdict.co.uk/space-economy-reduced-costs/?cf-view

[7] Space 2040 – The Future of the Global Space Economy, Foresight Study, 2bAHEAD, June 2023, https://2bahead.com/downloads/space-2040

[8] What are Space Economy Business Models?, New Space Economy, https://newspaceeconomy.ca/2023/06/10/what-are-space-economy-business-models/

[9] OECD (2022), OECD Handbook on Measuring the Space Economy, 2nd Edition, OECD Publishing, Paris, https://doi.org/10.1787/8bfef437-en

[10] Main Trends & Challenges in the Space Sector, 3rd Edition, PWC, July 2022, https://contents.pwc.com/main_trends_challenges_space_sector_22

[11] OECD (2019), The Space Economy in Figures: How Space Contributes to the Global Economy, OECD Publishing, Paris, https://doi.org/10.1787/c5996201-en

[12] What is the Value Chain of the Space Economy?, New Space Economy, https://newspaceeconomy.ca/2023/01/19/what-is-the-value-chain-of-the-space-economy-a-quick-overview/

[13] Riding the exponential growth in space, Deloitte, March 22, 2023, https://www.deloitte.com/global/en/our-thinking/insights/industry/defense-security-justice/future-of-the-space-economy.html

[14] ASCEND, November 14, 2022, https://www.thalesaleniaspace.com/en/press-releases/ascend-thales-alenia-space-lead-european-feasibility-study-data-centers-space

[15] UAE Space Agency blaunches Space Data Centre porject, November 17, 2022, https://www.timesaerospace.aero/news/space/uae-space-agency-launches-space-data-centre-project

[16] R. Shendar, Bui8lding a Data Center on the Moon, Wetern Digital BLOG, February 2, 2023, https://blog.westerndigital.com/space-data-center-moon/

[17] H. Menear, NTT and SKY Perfect are building data centres in space, DataCentre, May 21, 2021, https://datacentremagazine.com/technology-and-ai/ntt-and-sky-perfect-are-building-data-centres-space

[18] Little Place Labs, https://www.littleplace.com/

[19] D. Werner, Sidus Space acquires Exo-Space, SpaceNews, August 22, 2023, https://spacenews.com/sidus-space-acquires-exo-space/

[20] Tilebox, https://tilebox.com/

[21] M. Haverty, Investment Trends, M&A, and Operational Challenges for the Space Industry in 2023, Via Satellite, October 23, 2023, https://interactive.satellitetoday.com/via/november-2023/investment-trends-manda-and-operational-challenges-for-the-space-industry-in-2023/

[22] Global Data Center Trends 2023, CBRE Research, July 14, 2023, https://www.cbre.com/insights/reports/global-data-center-trends-2023

[23] E. Saykol, On the Economical Impacts of Cloud Computing in Information Technology Industry, International Conference on Eurasian Economies, 2014, https://www.researchgate.net/publication/281270698_On_the_Economical_Impacts_of_Cloud_Computing_in_Information_Technology_Industry

[24] P. Mell, T. Grance, The NIST Definition of Cloud Comuting, NIST SP 800-145, https://doi.org/10.6028/NIST.SP.800-145

[25] State of Cloud – How orgs are maturing in the cloud, Pluralsight, June 2023, https://learn.pluralsight.com/resource/offers/2023/state-of-cloud

[26] Economic and social impacts of Google Cloud, Deloitte, September 2018, https://www2.deloitte.com/content/dam/Deloitte/es/Documents/tecnologia/Deloitte_ES_tecnologia_economic-and-social-impacts-of-google-cloud.pdf

[27] Z. Mahmood, R. Hill, Cloud Computing for Enterprise Architectures, Computer Communications and Networks, Springer, London, https://doi.org/10.1007/978-1-4471-2236-4_1

[28] FourWeekMBA, What is a Business Model, https://fourweekmba.com/what-is-a-business-model/

[29] The characteristics of data-driven business model development and how to succeed, BMI Lab, November 23, 2022, https://bmilab.com/blog/2022/11/23/the-characteristics-of-data-driven-business-model-development-and-how-to-succeed

[30] T. Grance, The NIST Cloud Definition Framework, National Institute of Standards and Technology, Gaithersburg, MA, USA (2010), referenced in [27]

[31] T. Highfill et al., Preliminary Estimates of the U.S. Space Economy, 2012-2018, Survey of Current Business, The Journal of the U.S. Bureau of Economic Analysis, Volume 100, Number 12, December 2020, https://apps.bea.gov/scb/issues/2020/12-december/1220-space-economy.htm

[32] OECD (2012), OECD Handbook on Measuring the Space conomy, OECD Publishing, Paris, February 2012, https://doi.org/10.1787/9789264169166-en

[33] Space-bsed Data Centers – Market Segments & Business Models, on-line workshop with Advisory Board, ESA, and Thales Alenia Space, October 5th, 2023

[34] P. Drucker, Theory of the business, Harvard Business Review, September/October 1994 ,

[35] P. Daly, J.Walsh, Drucker's theory of the business and organisations: Challenging business assumptions, Management Decision 48(4), May 2010, http://dx.doi.org/10.1108/00251741011041319

[36] Gartner Finnance Glossary, https://www.gartner.com/en/finance/glossary/business-model

[37] Euroconsult, New historic high for government space spending mostly driven by defense expenditures, https://www.euroconsult-ec.com/press-release/new-historic-high-for-government-space-spending-mostly-driven-by-defense-expenditures/