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Exploring Microsoft Data Center Innovations: From Earth to Outer Space, Unveiling Transformations and Corporate Social Responsibility

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Abstract

In the evolving landscape of Corporate Social Responsibility (CSR), this report meticulously examines Microsoft's CSR practices, with a particular focus on its data center innovations and their implications for the environment and society. The report identifies issues such as water scarcity and carbon emissions in data centers, proposing an innovative solution that involves launching a space data center powered by solar energy and vacuum cooling.

The paper assesses the feasibility, costs, benefits, and challenges associated with this solution and discusses its impact on Microsoft's stakeholders and sustainability goals. In light of the aforementioned research, this contributes to our further exploration and study of space data centers.

Keyword： ***Microsoft, Corporate Social Responsibility, Water Scarcity, Carbon Emissions, Space Data Center, Arizona***

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1. Introduce the target firm's current CSR

1.1 Vision / Core Value

Microsoft's overarching vision and fundamental values center around the promotion of responsible business practices, the facilitation of increased accessibility and connectivity, the advancement of fair and inclusive societies, and the empowerment of communities. These pillars serve as the guiding principles that underpin Microsoft's commitment to making a positive impact on a global scale, fostering a world where technology not only drives innovation but also contributes to the betterment of society by fostering ethical and inclusive business practices, fostering digital inclusion, promoting social equity, and empowering diverse communities.

1.2 Strategies

Their conviction rests on the principle that economic growth and opportunities should not merely be confined to specific segments but must be inclusive, extending their benefits to every individual, organization, community, and nation. Concurrently, there is a steadfast commitment to upholding the fundamental rights of individuals and fostering a climate of trust. Integral to this ethos is the acceptance of responsibility for the operational footprint, accompanied by a proactive endeavor to accelerate strides in sustainability through the application of cutting-edge technology.

A prominent embodiment of this commitment is exemplified in Microsoft's Cloud for Sustainability, a sophisticated platform crafted to assist clients in the meticulous recording and analysis of activities related to emissions. Through such innovative solutions, they aspire not only to drive operational efficiency but also to spearhead transformative change, forging a path toward a more sustainable and equitable future for all.

1.3 International Standards Achieved

1.3.1 SASB

Most sustainability reports share a lot of information with the public, but what investors really want are clear numbers that make it easy to compare different projects. The Sustainability Accounting Standards Board (SASB) steps in to help by sharing specific numbers related to sustainable projects. What makes SASB special is that it focuses on numbers that have a big impact on how much money investors can make. So, instead of overwhelming investors with too much information, SASB gives them the key numbers they need to make smart decisions about investing in sustainable projects.

Microsoft is categorized within the Software & IT Services sector, one of the 77 industry classifications established by SASB. This particular industry is characterized by a strong emphasis on innovation and a significant reliance on human and intellectual capital. In obedience to the SASB standard applicable to this sector, Microsoft is required to address six distinct disclosure themes and incorporate thirteen accounting indicators. These themes and indicators collectively contribute to a comprehensive and standardized reporting framework that enables stakeholders to assess Microsoft's sustainability performance within the Software & IT Services industry.

1.3.2 TCFD Report (Task Force on Climate-related Financial Disclosures)

- **Strategies**
  - **Short-term (0~3 years): Steady Reduction of Carbon Emissions**

    With the ambitious goal of achieving zero carbon waste by 2030, Microsoft has implemented a series of measures aimed at mitigating its environmental impact. Its comprehensive approach involves not only minimizing its own operational carbon footprint but also leveraging technology to empower others in their sustainability journeys. The company has invested in renewable energy projects, such as underwater data centers, enhanced energy efficiency in its data centers, and pioneered initiatives to advance a circular economy. Through these ongoing initiatives, Microsoft exemplifies a steadfast dedication to combating climate change and fostering a more sustainable future.
  - **Medium-term (out to 2030): Zero Carbon Waste**

    Microsoft has set a target to achieve zero carbon waste by 2030, exemplifying its unwavering commitment to environmental sustainability. This comprehensive goal reflects the company's determination to minimize its ecological footprint and advance towards a circular economy. Microsoft's strategy involves not only reducing its direct emissions but also addressing the entire lifecycle of its products and services. The company is actively working to eliminate single-use plastics in packaging, enhance recycling efforts, and innovate in materials sourcing to create products with a more sustainable lifecycle. By embracing a holistic approach to waste reduction, Microsoft aims to contribute significantly to mitigating climate change and fostering an eco-friendly business model by the end of the decade.
  - **Long-term (out to 2050): Remove All the Carbon**

    In the long term, Microsoft plans to eliminate all carbon emissions. It is also investing in carbon removal technology and nature-based solutions to proactively remove an amount of carbon equivalent to all of its historical emissions. Through short-, medium-, and long-term planning, the plan for 2050 can finally be realized.

- **Implemented Goals and Activities**

1. Carbon Negative

Microsoft aims to remove more carbon from the atmosphere than it emits. To achieve this goal, Microsoft has implemented a multi-faceted approach. The company is focused on ensuring that its cloud platform is not just carbon neutral but actively carbon negative, harnessing renewable energy sources and investing in energy-efficient technologies. Microsoft has also introduced a carbon fee, encouraging its business divisions to be accountable for their carbon emissions and incentivizing them to adopt sustainable practices. Furthermore, the company is investing significantly in research and development, particularly in artificial intelligence, to develop innovative solutions for carbon removal and enhance overall energy efficiency. Through these strategic initiatives, Microsoft is not only aligning itself with a sustainable future but also driving positive change across industries by integrating environmental considerations into its core business practices.

2. Water Positive

Microsoft's second goal is water positive. They reduce water intensity through water circulation systems. As of 2022, Microsoft has helped add 928 million liters of water around the world, and that number is rising every year.

However, although Microsoft has increased the amount of water replenishment, they expect the value to increase even more in the future, so they hope to reduce the amount of water shortage. For example, the water consumption of liquid cooling technology in undersea data centers can be avoided. But new technology is needed to replace it, and Microsoft is thinking about this issue.

3. Zero Waste

Microsoft is actively pursuing a comprehensive zero-waste initiative, with a strong focus on sustainable packaging practices. The company is committed to reducing its environmental impact by prioritizing recyclable packaging materials and eliminating single-use plastics entirely. Microsoft's strategy involves designing packaging solutions that are not only functional but also environmentally responsible, emphasizing the principles of a circular economy. By transitioning to recyclable materials and steering away from single-use plastics, the company aims to minimize the waste generated throughout its product life cycles. This commitment underscores Microsoft's dedication to fostering a more sustainable and eco-friendly approach to its operations, aligning with broader global efforts to reduce plastic pollution and promote responsible consumption and production practices.

- **Positive Influences on the Target Firm’s Stakeholders**

Microsoft has set a target to achieve zero carbon waste by 2030, exemplifying its unwavering commitment to environmental sustainability. This comprehensive goal reflects the company's determination to minimize its ecological footprint and advance towards a circular economy. Microsoft's strategy involves not only reducing its direct emissions but also addressing the entire lifecycle of its products and services. The company is actively working to eliminate single-use plastics in packaging, enhance recycling efforts, and innovate in materials sourcing to create products with a more sustainable lifecycle. By embracing a holistic approach to waste reduction, Microsoft aims to contribute significantly to mitigating climate change and fostering an eco-friendly business model by the end of the decade.

1.3.3 GRI

GRI recognized as a tool to help organizations improve analysis and decision-making, GRI has influenced 450 policies in 80 countries around the world, of which 120 policies were formulated based on GRI standards.

The GRI guidelines are divided into universal standards (GRI 1~3) and topic-specific standards. The topic-specific guidelines are divided into economic (GRI 201~207), environment (GRI 301~308), and society (GRI 401~419), so GRI The guidelines consist of 4 series.

Here are three examples of Microsoft using GRI standards to write sustainability reports. For example, Microsoft lists GHG emissions in environmental compliance. As for energy, it lists the energy consumption within the organization, such as electricity, gasoline, etc. Finally, in terms of water, surface water, groundwater, etc. are listed.

2. Three theaters

This chapter delves into the classification of Microsoft's corporate social responsibility (CSR) programs, categorizing them into three theaters: Theater 1 - Philanthropy, Theater 2 - Operational Improvement, and Theater 3 - Business-Modal Transformation. The analysis centers on Microsoft's initiatives addressing waste reduction, carbon emissions, and water conservation, highlighting their impact on data centers and the broader community.

2.1 Waste Reduction Program

In Theater 2 - Operational Improvement, Microsoft has prioritized waste reduction, particularly in the context of data centers. Initiatives involve minimizing company waste and responsibly disposing of decommissioned assets. Moreover, in Theater 3 - Business-Modal Transformation, Microsoft has established a recycling cloud system and "Circular Centers" within data centers to efficiently manage the processing of old equipment. The "Hands-on"

labs program in Theater 1 - Philanthropy repurposes retired equipment to support educational institutions, showcasing Microsoft's commitment to sustainability across various sectors.

2.2 Carbon Emissions Program

Recognizing the need for collaboration to achieve net-zero emissions, Microsoft focuses on involving suppliers and manufacturers in carbon reduction. In Theater 2 - Operational Improvement, a capacity-building tool has been released for suppliers to report emissions and develop clean energy strategies. In Theater 3 - Business-Modal Transformation, Microsoft collaborates with the International Finance Corporation (IFC) to provide technical support and financing for greener operations. This multifaceted approach highlights Microsoft's dedication to addressing carbon emissions throughout its supply chain.

2.3 Water Conservation Program

In Theater 1 - Philanthropy, Microsoft's water conservation program is centered on the data center located in Arizona. This critical initiative involves recharging Arizona's groundwater and implementing Drought Contingency Planning to ensure a sustainable water supply for the data center. The comprehensive water conservation efforts not only benefit the data center but also contribute positively to communities facing water shortages.

3. Issues

3.1 Issue Introduction

The issue we are rectifying will be distributed into several sections and discussed singly. Firstly, revenue growth from the 2022 annual report of Microsoft. We will discuss the growing revenue from the cloud service, and building a new data center in Arizona. Secondly, we take Open AI and Google, for example, to explain how the data center is water-consuming. Finally, we noticed that some of the people from Arizona did not come to more data centers to build in Arizona.

According to the 2022 annual report Microsoft, the revenue grew by 25% from FY2021. The report points out that this growth mainly comes from Microsoft Azure and other cloud services with a growth of 22%. To meet the growing demand from clients for Microsoft cloud services, they launched a data center in Arizona in 2021. (Walsh, 2021)

In the 2022 CSR report of Microsoft, it disclosed that water use has increased by about 34%. The reason for this is the significant investment in Artificial Intelligence (AI) and collaboration with OpenAI. (Singh, 2023) More and more people using Chatgpt, but they

don’t know that is a water-consuming system. According to the paper from Shaolei Ren, a researcher at the University of California, Riverside. He points out that 500 milliliters of water are needed to run 10–50 queries using GPT-3 inference. (Ren, 2023) At the same time, as a tech giant providing cloud services, Google disclosed the water-consuming data for the data center. In 2021, there will be 43.3 billion gallons of water consumed by all Google data centers. They pointed out that 43.3 billion gallons of water is equal to 29 golf courses’ water usage in the southwest U.S.

Although Microsoft's data center will bring great commercial advantages, job opportunities, and other benefits to the community, there are still local officials in Arizona who oppose the data center. (Solon, 2021) Worrying that the data center will cause harm to the natural environment of the area, thus affecting the lives of the residents.

3.2 Evidence

3.2.1 Drought Conditions in Arizona

For more than 20 years, the southwestern United States has been experiencing severe droughts, with Phoenix, Arizona, experiencing extreme drought conditions for nearly a quarter of that time. This situation has put serious pressure on the state's water resources, particularly challenging the water needs of data centers for technology companies like Microsoft.

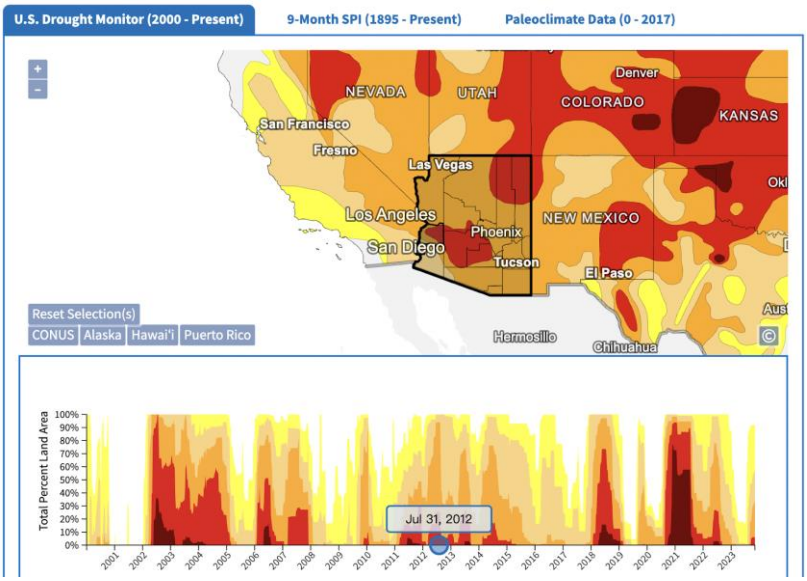


Fig. 1. Drought Conditions in Arizona

(Source: U.S. Drought Monitor)

3.2.2 Colorado River Water Resource Restrictions

The Colorado River, Arizona's second-largest source of water, has experienced a long-term decline in its flow. In 2021, the federal government announced cutbacks to the

Colorado River and reached a corresponding agreement with the states along the river. This decision maximizes Arizona's access to Colorado River water and poses a threat to the sustainability of the state's water resources.

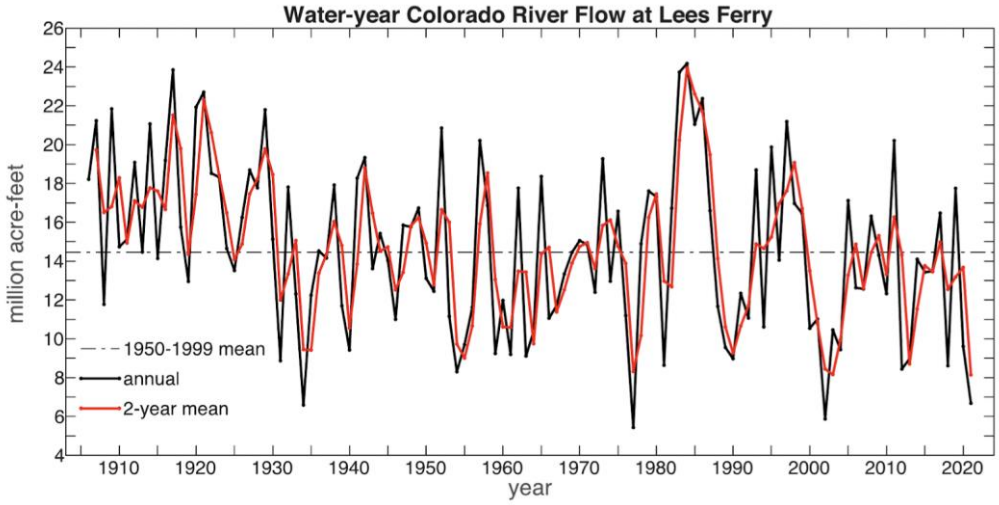


Fig. 2. River flow from the upper basin of the Colorado River

(Source: U.S. Bureau of Reclamation)

3.2.3 Relationship between water pricing and water sustainability

Despite the relatively low price of water in Phoenix, Arizona faces serious risks to water sustainability. Technology companies may choose to build data centers in areas where water is scarce to reduce costs, yet this simultaneously increases environmental damage, raising questions about the balance between cost and environmental impact.

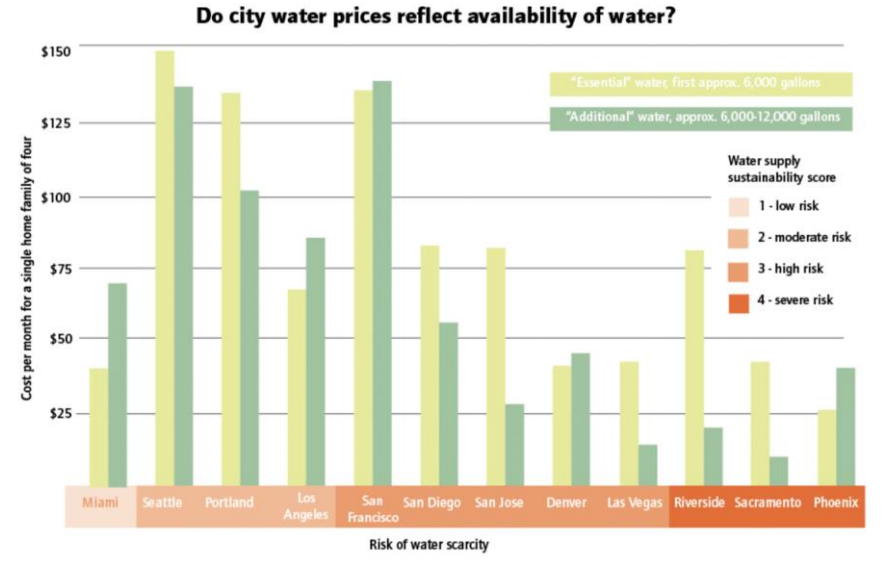


Fig. 3. Unjust water prices

(Source: Ian H. Luby, Stephan Polasky, Deborah L. Swackhamer. Infographic by Luna Anna Archey)

3.2.4 Impact of Data Center Construction on Water and Carbon Footprints

As can be observed from the data in Fig. 4., building a data center in Arizona will result in a larger water footprint while facing severe water scarcity and some degree of carbon footprint. Considering the large amount of water consumed by data centers in the state, it becomes a question worth deeper study and reflection on whether this is an appropriate place to build data centers in the region.

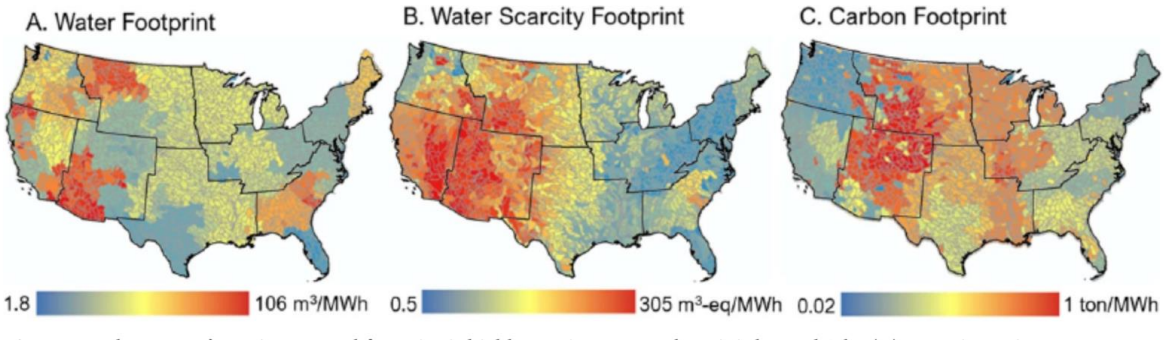


Fig. 4. A data center's environmental footprint is highly contingent on where it is located

(Source: The environmental footprint of data centers in the United States)

4. Proposed New Solutions

4.1 New Solution for Microsoft Data Center

An innovative program conceived to address regional water scarcity and the carbon footprint of data centers while advancing Microsoft's 2030 carbon emissions goals: Let the DC fly in the universe.

4.1.1 Solution Inspiration

The program's name is inspired by the acclaimed film series DC Extended Universe, which complements the data center acronym. In this innovative program, we analogize satellites and the International Space Station to multiple characters in the movie, and now we're planning to introduce an entirely new character into this vast universe: the Space Data Center.

There are few places other than the earth's land, seabed, and sky that are suitable to house such a highly water- and energy-intensive facility. However, a possibility exists in the vast universe of outer space.

The idea is motivated by the need to overcome many of the problems faced by data centers operating on Earth. Outer space, as an uninhabited environment, offers a unique solution. By building on the success of the space station, we can establish a stable and unoccupied data center in space to avoid further pressure on Earth's resources, especially given its high water- and energy-intensive nature.

4.1.2 Principle of operation of the Space Data Center's cooling system

Only thermal radiation can transfer heat in a vacuum environment, and any object above zero can produce thermal radiation in the form of electromagnetic waves, the higher the temperature the greater the total energy radiated. （志盛威华邵，2022）

We plan to install radiators at the Space Data Center with liquid ammonia flowing through their internal piping. The ammonia acts as a refrigerant to transport waste heat to the radiators, where it is transferred by heat conduction to the high-emissivity material, which then dissipates the heat into space by thermal radiation.

4.2 Short-term/ long-term goals

Data centers in space are designed to reduce reliance on power and water resources while accelerating Microsoft's goal of negative carbon emissions by 2030. By transferring data centers to space, we are able to significantly reduce land use while removing the water resources needed to dissipate heat through thermal radiation and the low-temperature environment of space, effectively reducing the environmental impact of data centers.

In the near future, we will set up a complete solar power generation and vacuum cooling system and conduct practical tests. At the same time, we plan to work with space exploration organizations such as SpaceX to reduce the cost of space transportation and to ensure that the data center in space project can be realized smoothly. This set of short-term goals will provide a solid foundation for realizing the long-term goals of the Data Center in Space as a sustainable solution.

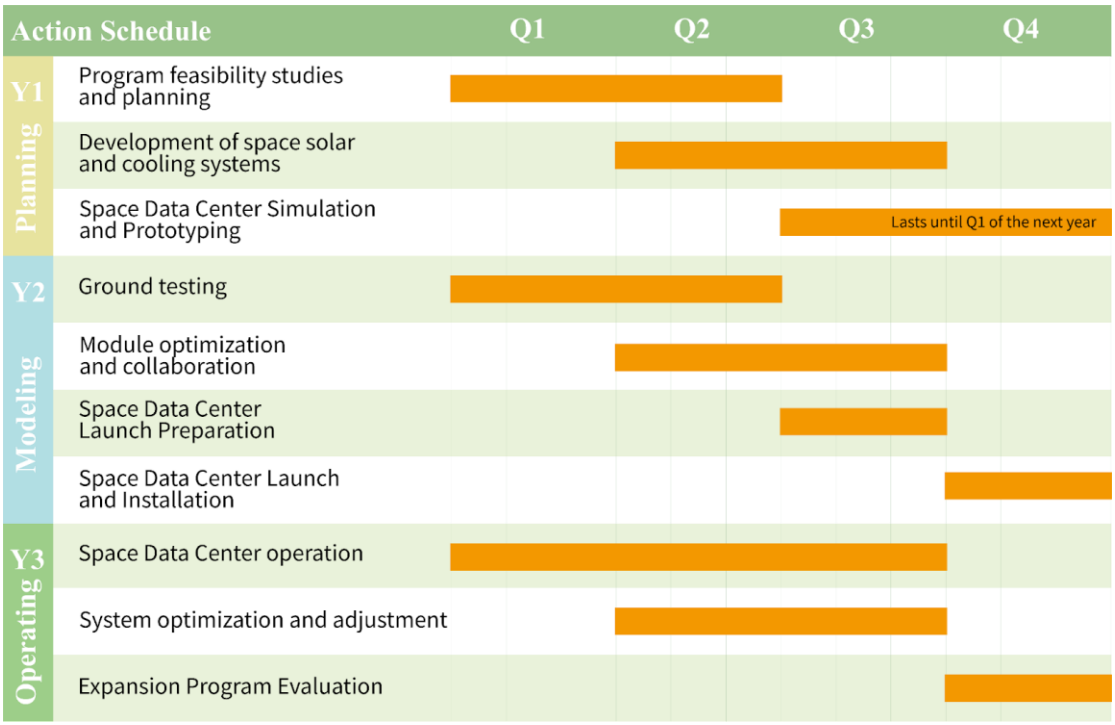
4.3 Important for which stakeholders

This program involves a wide range of stakeholders, whose interests and degree of impact may be different, and we have conducted a stakeholder analysis via the following table.

Stackholders	Importance Level	Support Level	Concerns	Communication Cannels	Communication Frequency
Space Exploration Agency	High	High	technical support, space launch, project success	professional meetings, regular reports, technical exchanges	High
Enivronmental Groups	Medium	High	environmental impact, sustainable development, carbon footprint	open forums, environmental reports, social media	Medium
Technology and IT companies	Medium	Medium	technical collaboration, business opportunities, data security	techical workshops, clloaborative meetings, professional forums	Medium
Government Agencies	High	High	legal compliance, economic development, government support	government meetings, seminars, reports and recommendations	Medium

Stackholders	Importance Level	Support Level	Concerns	Communication Cannels	Communication Frequency
Local Community	Low	Low	community impact, employment opportunities, environmental concerns	community meetings, public forums, social media	Low
Inverstors	Medium	Medium	investment returns, business feasibility, risk management	investor meetings, financial reports, investor presentations	Medium
International Community	Low	Low	international image, collaboration opportunities, regulatory compliance	international conferences, collaboration project reports, diplomatic channels	Medium
Employees	High	High	working conditions, training opportunities, engagement	internal meetings, feedback channels, employee training	Medium

4.4 Action plan (schedule)



Program feasibility studies and planning

- Timeline: 1st year Q1- Q2
- Explanation: Analyze the technical, cost, and efficiency aspects of establishing a data center in space. Develop the basic framework of the program.

Development of space solar and cooling systems

- Timeline: 1st year Q2- Q3
- Explanation: Initiate the development of solar power generation and vacuum cooling systems, ensuring viability in space.

Space Data Center Simulation and Prototyping

- Timeline: 1st year Q3- 2nd year Q1
- Explanation: Designing a three-dimensional model, the space data center incorporates an integrated structure, energy systems with solar panels, and efficient cooling systems to create a prototype that optimizes sustainability and functionality.

Ground testing

- Timeline: 2nd year Q1- Q2
- Explanation: Conduct real-world testing of the space data center prototype on Earth, evaluating its functionality and performance.

Module optimization and collaboration

- Timeline: 2nd year Q2- Q3
- Explanation: Perform final system optimization based on test results and prepare for collaboration negotiations with space exploration agencies.

Space Data Center Launch Preparation

- Timeline: 2nd year Q3
- Explanation: Prepare for the launch of the space data center, including pre-launch mission preparations.

Space Data Center Launch and Installation

- Timeline: 2nd year Q4
- Explanation: Launch the space data center with the assistance of space exploration agencies and install it in space.

Space Data Center Operation

- Timeline: 3rd year Q1- Q3
- Explanation: Conduct operational tests of the space data center in space, monitoring its performance in the space environment.

System optimization and adjustment

- Timeline: 3rd year Q2- Q3
- Explanation: Optimize the system and adjust performance based on operational test results to achieve optimal operating conditions.

Expansion Program Evaluation

- Timeline: 3rd year Q4
- Explanation: Assess the feasibility of the expansion plan, considering increasing the number and scale of space data centers.

4.5 Three Theaters

Talking about the theaters for our newly implemented solutions, as mentioned in the previous sections of Chapter 4, we've recognized the challenges associated with installing a new data center in outer space. In this section, we will discuss the implications and opportunities that this idea/solution will bring to the company.

First, launching our data center in space could resolve the current issue of relying on a traditional cooling system, especially considering the extreme temperature of 3K (or -270 Celsius) in outer space. For a data center, maintaining a temperature range of -12 to 17 degrees Celsius (10.4 to 62.6 degrees Fahrenheit) is crucial. By siting the data center in outer space, we can address the issue of reducing water usage and further minimize carbon emissions associated with other cooling systems.

Second, harnessing solar power could serve as our main activation system. By utilizing solar power, we can significantly reduce electricity consumption, as the data center (station) would be self-sufficient in meeting its electric demands. This energy efficiency could prevent the data center from facing shutdowns due to a lack of electricity.

Thirdly, Low Earth Orbit Satellites, also known as LEOS, have emerged as a significant technological innovation during the Ukraine and Russia wars. LEOS could transport data centers and launch them into orbit around the Earth, potentially reducing the cost of sending individual data centers into outer space.

Lastly, we consider maintenance fees to be lower than those on Earth. While one might assume that maintenance costs would increase due to the need to launch parts into space and hire professional astronauts to solve problems, the fact is that being in space makes it less susceptible to external factors. Taking a long-term perspective, there will be a substantial difference in the total cost of the data center on Earth compared to in space.

For the third theater, Business Model Transformation would be achieved by launching the data center into space. This approach would minimize future errors, as factors like temperature, earthquakes, and other external elements would not affect the performance of the data center. Consequently, a significant change in operation is necessary. The current

operation would not be feasible since we would be sending our data center into space. Most employees would be laid off, with only a few working at the headquarters to monitor data center performance. Additionally, the company would require more tech professionals involved in data analysis and maintenance. It is possible that Microsoft would need astronauts to perform maintenance in space, and the company would have to collaborate with other space organizations.

4.6 Expected KPI (Key performance index)

From Microsoft's 2022 Environmental Sustainability Report Data Facts, it is evident that GHG is divided into three scopes, as mentioned in the report. For GHG, scope 1, 2, and 3 account for 0.5%, 26%, and 73.5%, respectively. It is nearly impossible to address the issues in scope 1 and 2. Therefore, for our Key Performance Indicators (KPIs), we would like to focus more on scope 3.

Regarding our KPI, we aim to achieve a decrease in GHG emissions. According to Microsoft's GHG annual report, the distributed categories are as follows:

1. Purchased Goods & Services
2. Capital Goods
3. Fuel- and Energy-Related Activities
4. Fuel- and Energy-Related Activities (market-based)
5. Upstream Transportation
6. Waste
7. Business Travel
8. Employee Commuting
9. Downstream Transportation
10. Use of Sold Products
11. Use of Sold Products (management's criteria)
12. End-of-Life of Sold Products
13. Downstream Leased Assets

From the report, it is evident that most emissions from scope 3 are attributed to Categories 1, 2, and 11, which are Purchased Goods & Services, Capital Goods, and Use of Sold Products, respectively. For our newly implemented strategy, we aim to address all three categories with our new goals for the company. Next, we will discuss what and how we plan to solve them.

For our KPI in Chapter 4 regarding the solution for the company, using the data and information provided in the previous section, we notice that not only can we save more water

but also fully eliminate the electricity usage for the data center since it would be self-sufficient in the future.

From Microsoft's 2022 Environmental Sustainability Report Data Facts, we observe that Categories 1, 2, and 11 constitute over half of the emissions for scope three. If the solution is provided for the data center in space, it is possible to reduce most emissions in these categories.

Looking at just the three categories—Purchased Goods & Services, Capital Goods, and Use of Sold Products—all can be accountable for some of the data center and the data calculation or data calculation services according to the report. The number of each category increased/decreased by 1,210,000; -153,000; 1,151,000. That means for purchased goods and services, and use of sold products increased by almost 20% from 2021 to 2022.

Purchased Goods & Services account for the electricity purchased, and use of sold products for data processing, AI, and data racks established for the data center. It is significantly important for us to identify the increased amount and find ways to counteract it. In Chapter 4, we discussed the short and long-term goals for the company, as well as the solution for the space data center. According to the data analysis we have from Microsoft, the increased 1,210,000 and 1,151,000 in Category 1 and 11 can be resolved through our solution.

We assume that if we follow the timetable in Chapter 4.4, it is possible for us to reduce emissions in the next 2 to 3 years. Currently, the analysis for us (which will be mentioned and explained in the before and after analysis) is that a 2-year time frame can provide us with a 12-rack unit data center in space. This is the size of a small to medium data center. For Microsoft, if they would like to cut the third scope in half (stated in their report), then this is the action we suggest Microsoft to take, which can result in a 605,000 reduction in Purchased Goods and Services and also a 575,500 reduction in the use of sold products.

4.7 Before and After Analysis

The objective of enhancing the cooling process and efficiency of the data center is set to achieve a 12-rack unit (RU) data center within two years. Prior to implementation, the cooling process and efficiency were limited, resulting in larger data center footprints and potentially inefficient use of space. The plan is to optimize cooling systems, reduce the data center footprint, and standardize rack units to achieve the targeted 12 RU data center. Simultaneously, the goal is to save energy costs by transitioning to smaller, more energy-efficient data centers. The key performance indicators (KPIs) include deploying one 12 RU data center in the first year and two 24 RU data centers annually from the second to the

fifth year. Additionally, the aim is to improve the Power Usage Effectiveness (PUE) from the current average of 1.18 to 1.10, with a long-term objective of reaching a PUE of 1. Technological advancements, including the integration of efficient cooling systems, energy-efficient hardware, and intelligent power management, play a crucial role in achieving these objectives. This comprehensive approach ensures a more energy-efficient, cost-effective, and technologically advanced data center infrastructure.

5. Cost and Benefit Analysis

5.1 Associated Cost Analysis

Category	Items	Expected Price
Collaboration Cost	Launch company cooperation (SpaceX-Starlink plan)	SpaceX rocket launch cost per kg: US$1410 1410*4M=5.6B
Construction Costs	Hardware and Software equipment	US$650/sqft* 4M sqft=US$2.6B
	Solar panel construction costs	US3,400*750＝US2.55M
	Appearance design cost	US$80/sqft*4M sqft=US$320M
Electricity Cost	Machine operation	US$41.76M*60%＝ US$25.056M/month
Maintenance Cost	Maintain hardware, software, disaster recovery, continuous power supplies, and networking	US$20M/year
Labor Costs	R&D cost	US$4.5M*300=US$1.4B/year
	Technical operators	US$126,880*100=US$12M/year

Since space technology is not yet mature, Microsoft's process of building a space data center may be relatively risky and will cost a considerable amount of money. Microsoft has not implemented this plan yet, so all related costs are estimated based on the experience of

other companies that are embarking on similar plans, such as Google, Hon Hai, and Lonestar. The first is the cost of cooperation. If you cooperate with SpaceX, there will be rocket launch costs. Because they use recyclable rocket launches, the cost will be lower than other launchers, about 5.6B.

For the construction cost. First of all, hardware and software equipment are very important in the data center. Hardware includes buildings, racks, circuit systems, fire extinguishing systems, etc., while software equipment is mainly servers. The cost of this equipment is US$2.6B. Second, is the cost of building solar panels. Running machines in space requires electricity, which needs to be generated by 3,000 solar panels. However, since the electricity collected in space is 4 times that on land, the data center in space only needs 3000/4, which is approximately equal to 750 solar panels, and the total cost is US$2.55M. Third, the data center in space must be designed by a professional satellite designer, and its cost is 320M.

Data centers in space no longer need to spend electricity on cooling technology, electricity only needs to provide machines to maintain basic operations. The electricity cost of the original data center was US$41.76M, 40% of which was used for the cooling system. Therefore, the power cost in space was US$41.76M multiplied by 0.6 equal to US$25.056M per month. Although there are no natural disasters such as floods and earthquakes in space, it may be damaged by geomagnetic storms. Therefore, its repair and maintenance costs are relatively high, about US$20M per year.

Finally, the labor cost. According to information from Hon Hai Group, the space data center team has about 300 people invested in research and development. The annual salary of an R&D personnel is US$4.5M. So US$1.4B is required for R&D costs every year. And 100 technical engineers are needed every year to operate and monitor the operation of the space data center. The salary is approximately US$126,880 per year, so a total of US$12M per year is required.

5.2 Associated Benefits Analysis

Category	**Numerical Measurement**	**Expected Social or Financial Influence**

Liquid Cooling Technology	Electricity Bill	Total electricity bills: 5000x8352= US$41.76 M/ month Saved US$ 41.76Mx40%= US$ 16.704M/ month of electricity bills in total
	Water Bill	Saved 700 kLxUS$34 = US$ 23,800/ month of water bills in total
Construction	Price of Solar Panels	Price of solar panels: US$ 3,400/ unit Number of solar panels needed: 5000 units Number of solar panels needed: 5,000x60%x1/4=750 units Saved (5,000-750)xUS$3,400= US$ 14.45M in total
Carbon Credits	Reduction of Carbon Emission	Carbon Emission: 13M tons/ year Price of carbon credit in Florida (CCA): US$ 55/ ton Carbon emission saved: 13Mx40%= 5.2 M tons/ year Saved 5.2 MxUS$55=US$ 286M/ year

Regarding associated benefits, in the past Microsoft used an underwater data center to organize data. To cool the machine, they invented liquid cooling technology to keep the machine running. This technology uses a lot of water and electricity, accounting for 40% of the total electricity and water consumption of the underwater data center. Therefore, the emergence of the space data center can directly cool machines through the -270°C space environment, thereby achieving Microsoft's water and power-saving goals.

According to the table above, we can find that if the future space data center is implemented, the monthly electricity bill can be saved by US$ 16.704M, and the water bill can be saved by US$ 23,800. Even though the amount may not seem high now, you will save a lot over the years. Microsoft can also use the funds for other projects.

How does the space data center generate electricity? We will use solar panels to receive the energy provided by the sun and convert it into electricity. According to research, placing solar panels in space can produce four times more electricity than on the ground. This means that we can produce a large amount of electricity with a small number of solar panels. Currently, the electricity Microsoft needs on the ground is approximately the power provided by 5,000 solar panels. However, in the space data center, not only do we not need to produce the power required by liquid cooling technology, but we can also divide the number of solar panels by 4. Ultimately, we will only need about 750 solar panels to generate electricity, which means we can save 750 solar panels, which is about US$14.45M in total.

In addition, Microsoft is very concerned about carbon emissions because they are the second-largest carbon-emitting company on the planet. Therefore, they purchase a large number of carbon credits like other companies every year to maintain operations. The space data center can save electricity and water and indirectly reduce carbon emissions. The original underwater data center reduced carbon emissions and saved Microsoft US$700 million. After some estimates, it is estimated that the emergence of the space data center can save Microsoft an additional US$200 million. Furthermore, there will be a better chance of achieving the 2030 goal of "Zero carbon waste".

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