From Earth to Space: The future of Data Storage

1946 saw the completion of the ENIAC, built by John Presper Eckert and John Mauchly, it is considered the first data centre. It was 8 ft tall, 2 ft deep and 80 ft long, occupying 2,880 square ft and consumed an estimated 150 kW of electricity. (Hewlett Packard, 2023) In comparison, today, a small data centre might be 5000-20000 square ft and consume up to 5 MW of electricity. (Data Center Knowledge, 2024)

The rapid advancements in Artificial Intelligence (AI), Internet of Things (IOT) and Cloud Computing have led to exponential growth in data generation, requiring increasingly sophisticated processing and storage solutions. Concurrently, the power requirements for operating and maintaining modern data centres have risen dramatically (Thangam et al., 2024). Efficiency has improved, however, despite technological advancements significant challenges persist in power consumption, cooling systems, scalability and environmental sustainability.

Current terrestrial data centres are increasingly strained by these demands, with rising costs and the growing need for expansion. To address these problems the concept of space-based data centres has emerged as a potential solution. Leveraging recent innovations in reusable rocket technology, satellite communication, and hardware miniaturisation, space-based data centres offer a promising pathway to overcome the constraints of terrestrial infrastructure.

This essay will explore the current use of terrestrial data centres and examine how space-based alternatives, driven by advancements from organisations such as SpaceX and the Ascend Project, are becoming feasible. It will also evaluate the potential of space-based data centres in comparison to terrestrial systems, focusing on efficiency, scalability, and reliability.

Terrestrial and subsea data centres currently form the backbone of global data storage infrastructure. Data centres refer to a facility housing interconnected computers that work together to store, process and manage large amounts of data. Terrestrial data centres rely on extensive cooling mechanisms to manage the heat generated by their high-performance systems. These data centres are critical to today's infrastructure and supports the growth of technologies such as AI, IOT and Cloud Computing. However, they require vast amounts of resources, with the power they consume and the cooling system being the most significant costs.

As of March 2024, there is an over 10,000 data centres worldwide. (Statista, 2024) With over half of those in the United States, followed by Germany and the UK with 521 and 514 data centres respectively. In 2023 these data centres used 7.4 GW of power, over a 50% increase from 2022 (Data Center Knowledge, 2024). With the increased growth this can be expected to continue to increase.

In 2018 Microsoft launched project Natick, an innovative subsea data centre prototype. The prototype was deployed of the coast of Scotland at a depth of 117 ft and was run for a period of 2 years. Using the cold water environment for cooling and a nitrogen filled atmosphere, the two year experiment found the prototype to use less energy and was more reliable that land-based data centres. However, subsea data centres face logistical and maintenance challenges, including the difficulty of accessing systems for repair and upgrades. William Chappell, vice president of mission systems for Azure, said “a pretty compelling vision of the future.” (Microsoft, 2020). Yet today only a few subsea data centres exist.

One significant issue with subsea data centre is the ownership of the data stored within them. Each country has its own laws surrounding data protection and the land-based data centres come under the rules and regulation of the country it is in. The law around subsea data centres still depend on where it is deployed: territorial waters, exclusive economic zones or international waters. Subsea data centres are likely to come to be subject to the laws of the country that owns the equipment but there may also be other concerns relating to data privacy, environmental protection and telecommunication law that could be applied. Countries with stringent data sovereignty laws, like the European Union's General Data Protection Regulation (GDPR), may impose additional compliance requirements, even if the subsea data centre is in international waters. This can lead to complex legal challenges in the operation of subsea data centres.

Both land and subsea solutions are constrained by scalability and environmental concerns. Increasing data demands place pressure on land-based centres, while the energy required for cooling and operational inefficiencies contribute significantly to global CO2 emissions. These limitations underscore the need for alternative, sustainable data storage solutions.

The rapid advancement in technology is opening possibilities for space-based infrastructure. In particular SpaceX's, Falcon 9 and Starlink.

SpaceX's Falcon 9 has changed the economics of reaching orbit. The falcon 9 and the merlin rocket were designed to be launched into orbit and return, landing and being relaunched on the next mission. So far there have been 424 missions, 380 landings and 353 relaunches (SpaceX, 2024). This has dramatically reduced the cost of the launch expense making large scale deployments to orbit possible.

SpaceX's development of Starship, a fully reusable rocket designed for long duration missions, is expected to further reduce the cost of sending large payloads into space. This could potentially allow for large scale deployments of space-based data centres by further reducing the cost of regular access to space, simplifying maintenance and expansion.

The Starlink project is a satellite constellation project with the goal of providing high speed, low latency internet access. Starlink utilises thousands of small satellites deployed in low earth orbit (LEO). SpaceX started the deployment in 2019 and as of 2025, they have already launched over 6900 Starlink satellites and plans for a complete constellation of 12,000 satellites with a potential increase to 42,000 in the future (Space.com, 2025). This would make bringing hi speed connectivity a global utility rather than reginal or national. This could influence the law governing data storage and could alleviate some of the issues with space data centres. Starlink's global communications infrastructure could enable space-based data centres to operate more effectively by providing low latency communication between satellite clusters, ground stations, and space-based data processing hubs. This would enable seamless transmission of data across the globe, reducing bottlenecks associated with terrestrial data centres and improving efficiency.

Advancements in hardware miniaturisation have been fundamental in allowing space-based systems, like the Starlink Constellation, to become feasible. There is a current trend towards making hardware smaller, more powerful and more energy efficient. This has allowed for the development of compact satellites, such as the Starlink.

These advancements in technology led the European Union to commission the Advanced Space Cloud for European Net zero emission and Data sovereignty (Ascend) Project. The project's primary aim is to investigate the viability of establishing data centres in space, as a solution to these growing challenges (Ascend, no date). These challenges include issues related to energy consumption, cooling requirements, and limited scalability. It explores the potential use of solar power and highlights that cooling is unnecessary in the vacuum of space, eliminating the need for energy intensive cooling mechanisms through natural heat radiation.

One of the most compelling advantages of space-based data centres identified by the project is the use of solar power. Space offers an almost unlimited supply of solar energy, unlike terrestrial systems where energy generation can be intermittent and dependent on weather conditions (Kang et al., 2024). The Ascend Project explores how data centres in space can tap into solar energy for constant power, without the concerns of grid reliance.

Another key benefit of space is the natural cooling environment. In space, the extreme cold of the vacuum of space eliminates the need for elaborate, energy-intensive cooling systems that are necessary for land-based data centres to manage heat dissipation. The lack of an atmosphere means that heat can be dissipated through radiation into the surrounding space, which reduces both operational costs and the environmental impact of cooling systems.

The Ascend Project has shown that from a technological standpoint, deploying data centres in space is a feasible concept (SataliteProMe.com, 2024). The study assessed the technical, economic, and environmental factors involved in building and operating such facilities. The key findings suggest that solar-powered systems in space could provide a reliable and sustainable energy source for the data centres, and that space offers the necessary conditions for energy-efficient operations, particularly through natural cooling.

However, the Ascend Project also highlighted several challenges in deploying data centres in space. These include the high initial cost of deployment, the complexity of maintaining equipment in space, and the need for robust data communication systems between space-based centres and ground stations. The project also emphasised the need for the development of space habitats capable of housing and maintaining these systems, including radiation protection and long-term reliability of space systems.

Terrestrial data centres consume substantial energy. Cooling systems account for a large amount of the total energy consumption. These centres typically rely on grid-based electricity generated from non-renewable sources. This dependence significantly increases their environmental footprint. Although many centres are transitioning to renewable energy sources, their reliance on local power grids still limits sustainability and energy efficiency. Solar farms require a substantial footprint to provide sufficient energy (NASA.gov, 2024). In contrast, space-based data centres offer a new approach to energy management. Satellite-mounted solar panels provide continuous and uninterrupted power generation without weather-related disruptions. The natural cooling environment of space eliminates the need for energy-intensive cooling systems. The combination of renewable energy and passive cooling has the potential to reduce energy consumption compared to current solutions.

As data storage demands grow, terrestrial data centres are constrained by physical space, rising land costs and increasing infrastructure requirements. Expanding these centres requires substantial investments in building infrastructure, power management and cooling systems. Space-based data centres overcome these terrestrial constraints. The orbital environment offers virtually unlimited deployment potential. Satellite-based centres can be seamlessly added to existing constellations as computing and storage demands increase. However, practical challenges remain, including the high cost of deployment and the complexities of maintenance.

Terrestrial data centres consume large amounts of energy and contribute to carbon emissions through their reliance on current non-renewable energy sources. The construction of these centres consumes extensive land and resources, while outdated infrastructure generates substantial electronic waste. Space-based data centres provide a more sustainable alternative. By harnessing solar energy and eliminating traditional cooling systems. Reusable rocket technology further alleviates environmental concerns by reducing launch waste (SpaceX, 2024).

Terrestrial data centres require continuous financial investment. They involve ongoing expenses for setup, maintenance and operation. In contrast, space-based data centres offer a potentially transformative economic model. Although initial setup and maintenance costs are likely to be significantly higher due to the logistical challenges associated with space-based infrastructure, once deployed, they could achieve near self-sustaining operations.

The future of data storage is at a pivotal moment driven by increasing data demands and the limitations of current data centres. While terrestrial systems have long been the backbone of global data storage, their rising energy consumption scalability issues and environmental impact call for alternative solutions. Although subsea data centres are an innovative option, they encounter logistical and legal challenges leaving room for more transformative approaches to be explored.

Space-based data centres which were once the realm of science fiction are now becoming a feasible solution. Advances in reusable rocket technology satellite communication and hardware miniaturisation have significantly lowered the barriers to deploying infrastructure in orbit. Initiatives such as the Ascend Project highlight the potential of space-based systems to harness solar energy eliminating the need for energy-intensive cooling systems while providing options for scalability.

Despite their promising advantages challenges still exist, high initial costs, maintenance complexities and the need for strong legal and regulatory frameworks. However, the environmental and operational benefits of space-based data centres make them an attractive alternative to traditional systems especially as global priorities shift towards sustainability.

As technology continues to progress, the integration of space-based data storage into global infrastructure could redefine the future of data management. By overcoming terrestrial limitations these systems could lead the way, reaching beyond terrestrial limitations and into the vastly unexplored potential of space.

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