IAC-25,D1,1,2,x95594

3xE: Energy, Economy, Environment. A space perspective case: Big Data Farms in Space

A.V. Autino[a], Alberto Cavallo[a], Werner Grandl[b], Ghanim Alotaibi[c], Stefano Antonetti[d], Marie-Luise Heuser[e], Gary P. Barnhard[f], Bernard Foing[g].

[a] *Space Renaissance International, Italy*
[b] *Space Renaissance International, Austria*
[c] *Space Renaissance International, Kuwait*
[d] *D-Orbit SpA, Italy*
[e] *Space Renaissance International, Germany*
[f] *Xtraordinary Innovative Space Partnerships, Inc., United States*
[g] *ILEWG "EuroMoonMars", The Netherlands.*

Abstract

Energy is rapidly achieving a primary position as a factor of sustainability. An increasing demand for energy supply already characterized industrial society, and it was satisfied by traditional fossil sources, which were the most convenient when environmental requirements were limited to polluting agents, with unevenly distributed levels of restriction. The fast-growing economy of China and later India mostly relied on coal to increase electrical production. During the last decades, general concerns about climate change have started the so-called "energy transition", pushing the phase-out of all greenhouse gas (not to be confused with pollutants!) emitting technologies. More recently, the development of the electronic society – based on the global communication infrastructure – brought a very large spread of new technologies, such as electronic money, mass video communication, electric mobility, and now artificial intelligence, supported by supercomputers, big servers, and big data farms. All of these technologies require a very huge energy supply and bigger storage capabilities. Such a development is seriously questioning the green transition strategies, conceived by most governments to contrast climate change. The global energy demand – supposed to be decreasing by the above policies – is instead rising, very much more than expected. Renewable sources are growing, but fossil sources are growing too, and the two of them, together, cannot pair with the quickly increasing demand. In fact, overall GHG (Green-House-Gases) emissions are increasing despite all the declared efforts to reduce them. The energy market is also heavily impacted by the geopolitical situation, which is playing an uneven role in different areas of the world, especially for the natural gas market, whereas natural gas is the fossil fuel with the lowest GHG impact, and gas-fired plants can be built very quickly. Innovative solutions are dramatically needed, or the energy bill will necessarily grow uncontrolled, with critical social impacts, in a gloomy scenario where the benefits of the electronic society and freedom of mobility will be progressively restricted to privileged classes.

It must be noted that after years of stagnation due to opposition by some environmentalist groups and wrong choices about the size and typology of the plants, nuclear fission energy is now recognized as a non-GHG emitting technology and it is fastly moving towards innovative solutions like small modular reactors (SMR) to reduce costs and the so-called fourth generation of fast reactors to solve once for all the "nuclear waste" problem, allowing as well a substantial reduction of the need of new mining for uranium.

In the energy sector, Civilian Space Development can propose a wide range of solutions. As a short-term enterprise, new big data farms could be shifted from Earth into orbit, in the Cislunar region and on the Moon. This would reduce their environmental impact avoiding producing and dissipating huge amounts of energy on Earth. From a mid-term perspective, important industrial settlements might be installed at Earth-Moon Lagrange Points. All of these settlements will benefit from solar power directly collected in space, 365/365 days, 24/24 hours, without seasonal limitations and without the energy absorption of the atmosphere.

Moon facilities can use small nuclear reactors to keep the energy flowing during the 14 Earth days of the lunar night, keeping the advantage of removing the impact of these facilities on the earthly environment. This paper explores the case for big data farms in Earth Orbit, on the Moon, and the Cislunar region.

Acronyms

Artifical Intelligence (AI)
Electric Vehicle (EV)
Geostationary Orbit (GEO)
Green House Gas (GHG)
International Energy Agency (IEA)
Information Technology (IT)
Light Emitting Diode (LED)
Large Language Model (LLM)
Low Earth Orbit (LEO)
Photo Voltaic (PV)
Space Based Solar Power (SBSP)
Small Modular Reactors (SMR)
Sun Synchronous Orbit (SSO)
United States of America (USA or US)
Variable Renewable Energy (VRE)

1 The rationale for Big Data Farms in space

1.1 The world energy scenario is changing: electricity demand

There is no doubt that the need of reducing and possibly eliminating greenhouse gas emissions is still there and is confirmed by all studies, even if currently there is a political backlash against it, probably due to some wrongly planned and publicized policies which have caused public disapproval.

Here we focus on electricity, which is the single most important type of energy vector. Transportation is also important but it has a much more rigid structure and the effort to shift away from fossil fuels is not proceeding with the pace some expected. It is essentially based on direct electrification of transportation vehicles and systems or on the use of the so called e-fuels, that is synthetic fuels based on the use of electricity for their production. Therefore, in the countries (essentially western and northern Europe) where it is actually taking place, it directly influences the demand of electricity.

This summary is based on the yearly report by the IEA – for the current year, "Electricity 2025" [1].

Global power demand is rising faster and faster every year. Most of the increase is due to the fastest growing economies, and more than half of the total to the People's Republic of China (54%), whose power demand is growing faster that its economy (7% vs. 5%). This is due to rapid growth in electricity intensive manufacturing of "clean energy technologies", rising use of air conditioners, increasing diffusion of electric vehicles and expanding data centers. India is also significant but it accounts only for 10%. Advanced countries (USA, Europe, Japan) experienced a flat power demand in recent years, or even a decline, but now they are facing a restart of the increase: the declining power demand by industry and the increased efficiency of electricity use (e.g. the use of LED lighting) is now overridden by electric vehicles, air conditioners, heat pumps and data centers.

The manufacturing of PV modules, batteries and EVs in China consumed in 2024 a total of 320 TWh of electricity, roughly as much as the total electricity use in Italy. The increase due to new energy products in China accounted for 35% of industrial electricity demand and 16% of total demand. Therefore, the main driver for electricity use in China, which is more than half the increase in the world, is due to electrification of transport.

While industry accounts for 50% of the increase, non industrial demand sees air conditioning at 8% of the total increase of electricity use, while data centers and telecommunications account for 3%. Data about the latter are anyhow somewhat inconsistent. The estimation by IEA is 70 to 130 TWh for data centers only in 2023.

The United States is the second largest electricity consumer in the world after China, but its growth was slow until recently. In 2024 it rebounded to 2% yearly. The situation is completely different, compared with China: industry plays a limited role while buildings (which means air conditioning, mostly) and data centers give the highest contributions to the increase in demand, see fig. 1.

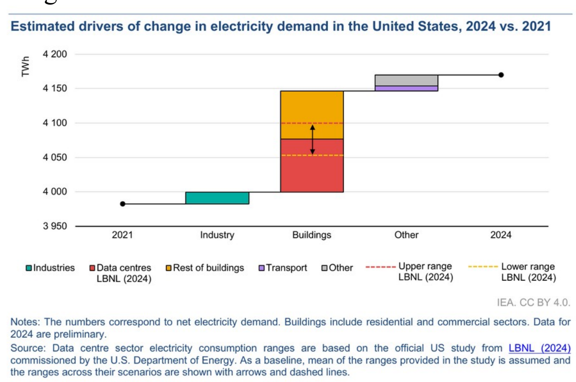

Fig. 1. Increase in electricity demand in the USA (IEA Electricity 2025 report)

Therefore, the big change in the overall scenario concerns the explosive growth of consumption for cooling and data centers, which reversed the trend in the USA. In the European Union the situation is comparable with the US, except that in recent years there was a significant fall in demand, which just restarted growing in 2024.

1.2 The world energy scenario is changing: electricity supply

Low emission sources, that is renewables and nuclear, are expected to meet all global demand growth out to 2027, according to IEA [1]. But for several years this implies a further growth of the use of fossil fuels, whose replacement can take place only in a longer term interval.

Renewables are growing fast and they are covering most of the new demand. Nuclear energy is ramping up, where France and Japan are recovering from the maintenance and revamping phase and a large number of new nuclear production is under construction in China, India and Korea (and Europe).

Fossil fuel is still growing, at a lowering rate. Coal is still growing in China, but it is slowing down, as gas is preferred for the reasons explained below.

Coal is still growing in India, Indonesia and other Asian countries, compensating the reduction in US and Europe. In the latter, gas use was reduced by the limited availability due to political reasons, which slowed the decline of coal.

The increasing role of solar and wind is starting to strain energy grids, especially when weather conditions cause a significant reduction in their generation. Several events of "VRE droughts" took place, for instance in Germany. These events caused increases in price of electricity and an increase of production from fossil fuels.

All activities that are not flexible in their power demand are ready to pay higher prices for energy temporarily – and in the long run move to places where electricity is cheaper.

The remedy to VRE droughts is based on higher interconnection, availability of a significant base generation, energy storage – specifically hydro pumping storage – and quick reacting peaker generators, essentially gas turbines. Longer droughts can only be managed through the availability of dispatchable generation. The quick solution is based on gas fueled gas turbines, which have high efficiency and low emissions, even if they still use a fossil fuel, and can be deployed very fast.

Nuclear energy is now moving towards the SMR (Small Modular Reactors), which solve the issue of long construction times. Fourth generation reactors, meanwhile, will ensure that little new uranium is needed since they use spent fuel from older generation reactors, which also solves much of the issue of "nuclear waste". In summary, fuel is not an issue for nuclear, and the problem of the "waste", always highlighted as a crucial downside, can be solved.

But, as mentioned at the beginning of this paragraph, the overall picture shows that even if in the long run global demand may be covered with low emission sources, fossil fuel generation is still required and growing. Natural gas is expected to cover a significant part of the needs, because gas fired plant can be quickly built, have high performance and efficiency and can start fast and cover the production slumps caused by the renewables.

1.3 Data centers as energy users

In the global energy scenario, industrial use prevails as the main cause of increase of electricity demand, and the "green transition" is, somewhat ironically, the main cause, since the production of batteries, EVs, heat pumps and other "clean" equipment is the main driver of the increase. Moreover, the "energy transition" is mostly based on electrification, that is on using less fuels and more electricity for the final users of energy, and an extensive use of e-fuels, that is synthetic fuels produced through an intensive electric energy input – in fact, the energy value of e-fuels is created by using electricity for their production.

If we come down to the use of electricity by economic area and by country, we can appreciate that all that was said above applies to China and south-eastern Asia, while in USA, Europe and Japan the scenario is quite different. In these latter countries energy demand was flat or decreasing a few years ago, and it is now growing due to a larger use of air conditioning and to data centers. While at a global level this affects only about 1-2% of total demand, in these countries it is very significant.

The current size of data centers, being built for companies like Google, Amazon, Microsoft and several others, can easily reach a nominal energy capacity in the range of 132 to 250 MW per site and GW scale is envisaged. This means that they have a large local impact on availability and cost of power. By comparison, a typical single unit combined cycle is nowadays around 800 MW of capacity, being able to feed 3 to 6 of those data centers.

Each data center must rely on a local emergency power source, to avoid data loss in case the main power source fails. Therefore each data center comes with a set of emergency generators, typically diesel engines, with a capacity comparable with the total capacity of the data center. Since data centers are put in service stepwise, during the initial phase power can be supplied by local generators that are going to stay as emergency units for the future, or by temporary, trailer mounted generators.

After the initial start up phase, electricity feed usually comes from the local high voltage grid, which eliminates the need of local generation besides emergency. In areas where a a strong interconnected grid is available and the price structure of electricity is nation based, like in Europe, local impact on other users is manageable, while of course there is always a significant one on power producers and on transmission grid operators, which must plan their development in accordance. Just consider that the whole of continental Europe, save only some eastern areas still connected to Russia, constitutes a single interconnected power grid, managed in coordination by national grid operators.

In areas where the grid is weakly interconnected and grid operators and power producers have a narrower base, like in the USA, the impact on the other local users may be significant in terms of price and availability of electricity. This is even more significant since in the USA the level of interconnection and coordination is lower than in Europe.

But this is not different from what happens when a large size industrial plant is built. The reason why data centers are perceived as heavily impacting is that, especially in Europe, there is not anymore the habit of having new large industrial sites being built. Newer ones, when they are constructed, just replace old dismissed ones.

In any case, data centers need a firm power supply available 24/24, 7/7, which implies that they add to base load, and non-dispatchable power sources like wind or solar are not suitable to support them, whereas hydro, nuclear and of course combustion are. This requirement can be well satisfied by gas fueled combined cycles, which combine a short construction time with high efficiency and relatively low emissions – of course they still emit GHG but it must be considered that the emission by a gas fueled combined cycle is one third the emission of a coal fired plant for the same electricity production. While Europe still clings to the idea of not allowing new fossil fuels plants of whatever type, the US with the current administration seems to have no issue. In the state of Texas alone, 130 new combined cycles have been proposed, for a total of 58 GW of total power [2]. On another side, the current reluctance of European countries towards natural gas is due to dwindling local production and the disappearance of Russia as a politically suitable supplier, while the US can rely on a robust local production and is a net exporter.

Non GHG emitting base load generators mainly means nuclear. As we noted above, nuclear is ramping up everywhere, even with innovative solutions. The example of some ideologically adverse countries like Germany is not significant, while China, India, USA and several European countries fully embrace the nuclear resurgence [1].

1.4 Energy from space?

The current scenario of electricity production and use, as it is summarized above, does not bode well for space based power generation, of course based on solar.

Space based solar is not considered in the plans of those who actually manage the electrical systems of the planet for the simple reason that it is not on the market yet. The electricity market is very conservative and it needs to plan everything in large advance. In the current situation, long term planning includes nuclear and renewable generation together with energy storage and better interconnection. The first fourth generation pilot nuclear generators are planned for the first years of the next decade (one of the authors was directly involved until recently), while improved third generation plants are currently being built in large numbers.

Ground based renewables are still growing fast, even if in some areas they are reaching the maximum allowable level before making the grids too unstable; in the meanwhile, energy storage and better interconnections are being built to cope with this problem.

Gas fired combined cycles are based on a fossil fuel, but their emissions are one third those of coal fired plants, they have improved very significantly in recent years in terms of unit capacity and efficiency and they can be built very quickly. As we indicated above, they are planned in large numbers.

SBSP is still in the conceptual demonstration phase. In some years we may have the first demonstrators operating, and some pilot plant in the next decade, in the most optimistic hypothesis.

But building it without a space based industrial infrastructure means that all the materials must be launched from Earth. The only suitable location is GEO, which reduces the payload of launchers significantly. An evaluation of costs comparable with the available solution is simply not possible today, considering the scale that is actually required to have an impact on electricity demand, besides some niche requirements.

As correctly predicted by Gerard O'Neill about 50 years ago [3], SBSP can be competitive only if the materials come from space – specifically from the Moon – and the most suitable use is in space itself.

Beaming gigawatts from GEO to Earth is something that does not exist today and its development is not predictable until a suitable experimentation is conducted, starting from demonstrators up to pilot plants. Discussing the difficulties in theory is not the point here: we can only say that this solution is not on the market and it will not be presumably for a couple of decades. We are talking of gigawatts, that is 6 orders of magnitude more than the kilowatts that can be achieved in some years. As SpaceX is constantly showing us, you never know the real problems of a new technology if you do not test it in real scale, even if you know – or believe you know – all the theoretical issues.

An additional point is worth to be weighted in. If energy is beamed from space to whatever user on Earth, the waste heat from that user stays on Earth. In the case of a data center, virtually all the received electrical power is converted into heat and dispersed on Earth. Therefore, beaming electricity from space avoids the impact of power generation on Earth, but the need for cooling is still there and it is huge: all the megawatts of the data center are converted into heat which must be dispersed in water or in air – Earth's water or air.

By the way, the impact of incoming energy is not exactly nil. A receiving antenna is needed, and its size must be huge to keep power density low enough not to make damage to living beings and things, and power must be collected and brought to the user – the latter point is always neglected in studies but it is significant.

It is therefore debatable if ever SBSP beamed to Earth can be competitive on the power market and advisable for users like data centers.

If the production of all materials is kept on Earth, all of its environmental impact is kept also here, and it is very significant. As we saw above, the largest part of the increase of electricity demand on Earth is due to this kind of productions.

Using electricity beamed from space keeps all the environmental burden of cooling the user systems on Earth anyway.

1.5 Data centers in space?

The advantages of collecting solar power in space, anyway, are still there and we do not deny them. The point is using it in space, not down on Earth. We can propose this motto:

Rather than moving energy from space to Earth, move energy users from Earth to space.

A system in space, like a data center or any other resource consuming activity, removes all the impact on Earth: power production, waste heat emission and even soil occupation (a data center of 132 MW may occupy 35 hectares, including its cooling system).

More than that, all technology is already available, some crucial components have already been tested in space and some pilot systems are already in orbit. This will be documented in the last part of this paper.

It must be clear that data centers in space may not be competitive for all uses in a short time, and launch cost is still the decisive element.

The will not probably replace their equivalent on Earth but just complement them, and in the longer run they can be the base of an industrial ecosystem in space.

It is also essential that the production of most materials, after the initial phase, can be progressively moved to space (in orbit or on the Moon).

2 Feasibility and technical problems of Data Centers in Space

2.1 Space activities and data processing

Space economy is growing and several activities are performed in space, besides exploration and scientific research. Our purpose here is to focus on the former and find out how they can evolve towards a full industrialization in space, by using data processing and management as a driver for development.

All activities currently performed in space and not relevant only to research consist in services for the Earth. They include mainly:

1. Earth observation
2. Telecommunications
3. Positioning

Earth observation includes a constantly growing amount of data collected by optical and radar systems for the most various purposes, from meteorological data collection and forecast to detection of fires, surveillance of environmental conditions and many other – of course military reconnaissance as well.

The processing of these data takes place mostly on Earth, but it is becoming feasible to start some preliminary treatment and even analysis directly in space, equipping the satellites with more and more computational power.

Telecommunications is another traditional use of space, dating back from the beginning of space era. Now telecommunication through space does not include only specialized data links and TV broadcasting, since LEO constellations to give high speed Internet access have stated and are growing fast: Starlink has opened the way and now some competitors are showing up.

Starlink already uses laser for satellite to satellite cross link, exploiting the fact that in a void laser beams can reach long distances with no substantial loss.

In summary, high speed connection to and from space is a current technical reality, while the presence of computational power on satellites is constantly increasing.

Placing more and more computational power and data storage in space is something that is already happening, and it may ramp up moving to space some functions currently performed by data centers on Earth, like:

- Data processing and analysis
- Cloud computing
- Data storage
- AI training

Before delving into possible applications, it is appropriate to examine some general requirements and potential difficulties that may arise.

2.2 Requirements and criticalities for data centers in space

In this conceptual study, we have selected a short list of requirements and criticalities that must be dealt with in order to place data centers in space. There are also other requirements and criticalities, but this short list summarizes the main topics that are relevant in this phase.

Requirements and criticalities include:

1. Energy
2. Cooling
3. Connection
4. Security

5. Environmental threats
6. Latency
7. Maintainability

2.2.1 Energy

In the first chapter the topic of energy was extensively discussed. Here we go into some specific details relevant to energy for data centers in space.

A free floating data center in space can enjoy 24/24, 7/7 availability of solar power. If we consider possible Earth orbits, some limitations arise.

GEO is a location endowed with several advantages: hovering above a specific point on Earth and being exposed to sunlight for most of the time, with only short shaded time at the equinoxes. On the other side, its distance from Earth requires more power for transmissions and causes an unavoidable delay of transmission, or better said latency.

In LEO equatorial or inclined orbits the satellite is shaded by the Earth for a significant time during each orbit, which means that batteries are needed to sustain power – the rated power of the batteries must be enough for the full capacity of the user systems – and the solar panel must be sized for twice the total power, allowing to accumulate all the energy in half the time.

The most favorable orbit is a sun synchronous orbit over the terminator, which ensures constant exposition to the sunlight. Large size data centers shall arguably be put in such orbit.

If we consider data centers placed in other locations in the Earth-Moon system, the Lagrange points are suitable, and they do not create issues about sunlight availability (again, with the exception of short time eclipses). The surface of the Moon, on the contrary, is unfavorable for solar power, since almost all is affected by 14 consecutive Earth days of darkness during the lunar night. Studies about how to power lunar installations are oriented towards nuclear energy.

2.2.2 Cooling

The only cold pit available in space is a very good one, the cosmic background at 2,7 K, but of course heat transmission must take place by radiation. The current solution for large cooling systems in space is based on a a cooling system running a refrigeration cycle with radiative units conveniently placed to disperse heat towards the cosmic background.

The size of the radiator for a data center shall be about 1/3 the size of the solar panels, which is fairly good.

The environmental advantage of placing data centers in space is largely linked to cooling, since on Earth a significant water or a huge air flow is needed, which makes a large impact, and is required even if the energy input is sourced from space itself.

2.2.3 Connection

The development of the LEO Internet constellations like Starlink has already put in place high speed connectivity in space. The same technologies can be applied to data centers, which makes the connection issue just an engineering task based on proven technology. Connection between data centers in space can be accomplished by optical laser, which is an already tested and applied solution.

2.2.4 Security

Security is essential whenever data are to be managed, due to the possible impact of information leaks, malicious use or denial of service.

Space based data centers are secure from terrorist or criminal attacks conducted by small groups or individuals. They are anyway exposed to the actions of any organization – currently only some nations – possessing antisatellite weapons. Large systems are the most vulnerable, while a constellation of smaller satellites is much more resilient to physical attack.

From the cybersecurity point of view space is no different from the surface of the Earth: all threats not based on direct physical access are substantially equivalent.

2.2.5 Environmental threats

Space based data centers are immune from earthquakes, storms and hurricanes, floodings and forest fires. On the contrary, they are exposed to the constant pounding of radiation (solar and cosmic) and occasionally to solar storms.

Unfortunately microelectronics is sensitive to radiation. Ionizing radiation can cause memory alteration and computational errors by flipping the status of single bits and it can even physically damage the microchips.

The hardware used for the control of space vehicles is based on specifically hardened chips and circuits, redesigned to survive very stringent specifications, including the mechanical solicitations during launch. The process for certifying flight hardware is complex and lengthy, which impairs any possibility to follow the quick advancement of microelectronics.

While strict requirements are justified for hardware to be used for flight control, the experimentation of more relaxed conditions is the only way to keep up with the quick pace of commercial hardware evolution.

NASA and HPE have been conducting this kind of experimentation on board the ISS since 2017. A solution mostly involving standard hardware with a dedicated software layer to correct radiation-induced errors has been developed by HPE (Hewlett Packard Enterprise) and tested on board the ISS. The Spaceborne Computer program had a first iteration which started in 2017, a second in 2021 and has been running the third iteration since January 2024. The purpose of the first iteration was mainly to test how the hardware behaved in space, while the second one already included real tasks and even the implementation of AI with the LLM created by Booz Allen Hamilton [4, 5].

The experiments by HPE have already shown the advantage of placing edge computing in space: the amount of data to be transmitted to Earth is much less, since raw data are digested in space and the result, much smaller in size, is sent to Earth, with substantial gain in total time. Moreover, with appropriate software solutions, and shielding where required, off-the-shelf computers can operate in space. Specific criticalities have been identified and corrected: the most affected hardware systems were solid state discs, while microprocessors and DRAM have performed satisfactorily, thanks to the provisions devised by HPE and NASA.

2.2.6 Latency

Computers placed in space may be far enough from Earth to experience a significant latency in data communication. In GEO the round trip delay is about 0.24 s, while on the Moon is about 2.5 s, which may cause difficulties for some applications in GEO and substantially limits computers on the Moon to a data storage function.

Large data centers in SSO can anyway be used for several tasks, including AI training, cryptocurrency mining and massive data analysis. All important studies on data centers in space, in fact, are focused on SSO, while the Moon has been considered for backup data storage. Specific examples are described in the following chapter.

Even real time applications can run in space if they are placed on well connected constellations of smaller units, instead of large satellites mimicking Earth based data centers. This follows the same concept adopted for Internet connection by Starlink: a large number of small units instead of a smaller number of more powerful ones.

But in the long run, in consideration of the perspective of the industrial development in space, data centers will be needed to support activities that take place completely in space. From this perspective, the situation flips over: if for instance there is an industrial activity on the Moon, the relevant data must be managed on the Moon itself, because if would make little sense to send everything to the Earth and back.

The development of data centers in space can be considered as a continuous process, where initially the Earth is the main customer of the service, but the presence of computational power and data storage in space facilitates the installation of more activities in orbit and on the Moon, fostering the start up of a complete industrial ecosystem in cislunar space.

2.2.7 Maintainability

All systems need maintenance and this may appear as a hindrance to putting them in space.

But servicing satellites is a new field that has already started to develop. Several solutions for space maintenance and logistics are already on the market or under advanced development by companies like D-Orbit [12].

Data centers in space shall be designed for quick and easy maintainability, to be performed mostly by robotic spacecraft. This is essentially accomplished through the use of swappable modular units, designed to be accessible by robotic manipulators.

As the industrial ecosystem in space develops, human presence will increase, allowing intervention where complex and critical tasks are required.

This will be the propulsive force of the real expansion of humanity into space.

3 Ongoing Studies and Projects

3.1 ASCEND: European Data Centers in Orbit

ASCEND (Advanced Space Cloud for European Net zero Emission and Data sovereignty) is a feasibility study led by Thales Alenia Space, for the European Commission as part of Horizon Europe programs [6].

It is based on the assumptions we have mentioned above: use of energy, cooling towards space and in general reduction of the environmental footprint. The idea is fundamentally the same described above: creating data processing facilities in space as a natural development of the increasing amount of data collected in space.

Avoiding to increase GHG emissions on Earth is seen as one of the main purposes, as per the EU general environmental policy. The project includes definining the requirements and developing an architecture, including the evaluation of relevant costs and business targets, in order to define a road-map leading to an operational system between 2030 and 2035.

The project is organized in four phases:

1. Needs and Context Analysis
2. System Architecture Trade-off and Optimisation
3. European Space Data Centre Definition
4. Feasibility Assessment (on-going)

Without going into details of each phase, it is significant to give a look at the definition they have already reached, while the feasibility assessment is going on.

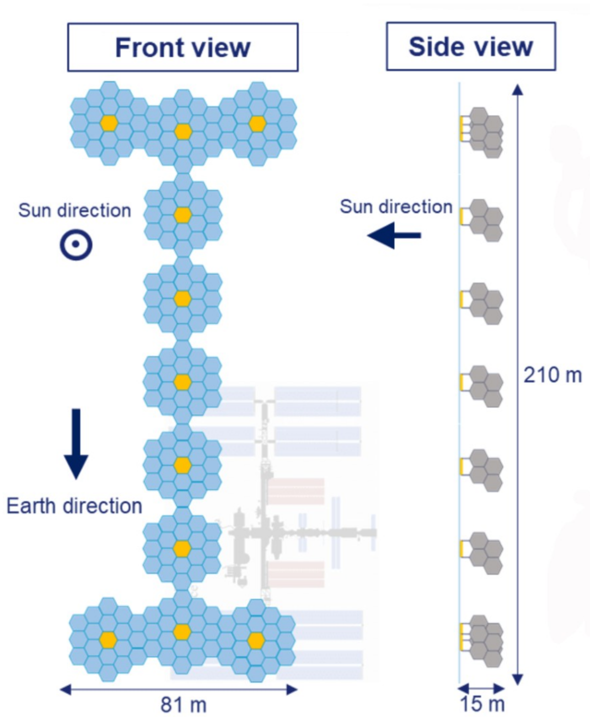

Fig. 2. ASCEND architecture (ASCEND website [6])

The total power is 800 kW, weight is 32 tons and it is designed to fit in the fairing of just one super-heavy launcher. Each yellow hexagon comprises IT hardware, communication, control and heat pumps for cooling. Each light blue hexagon includes 6 kW of solar panels, while each light gray one hosts the radiators for cooling. The in-space assembly is performed robotically.

3.2 *Starcloud: AI in orbit*

Starcloud is a US company proposing their project of data centers in space, following the path we have outlined above: first serving edge computing tasks and then evolving into high power data centers [7]. Their orientation is essentially aimed towards AI training.

A first demonstrator is slated to be launched on a rideshare mission by SpaceX in July 2025, while the Starcloud-2 pilot should be ready next year.

They claim that they can make a 40 MW data center with a design life of 10 years for 8.2 million US$, see figure 3, taken from their white paper [8].

Table 1. Cost comparison of a single 40 MW cluster operated for 10 years in space vs on land.

Cost Item	Terrestrial	Space
Energy (10 years)	\$140m @ \$0.04 per kWh	\$2m cost of solar array
Launch	None	\$5m (single launch of compute module, solar & radiators)
Cooling (chiller energy cost)	\$7m @ 5% of overall power usage	More efficient cooling architecture taking advantage of higher ΔT in space
Water usage	1.7m tons @ 0.5L/kWh[10]	Not required
Enclosure (Satellite Bus/Building)	Approximately equivalent cost	
Backup power supply	\$20m (commercial equipment pricing)	Not required
All other data center hardware	Approximately equivalent cost	
Radiation shielding	Not required	\$1.2m @ 1kg of shielding per kW of compute and \$30/kg launch cost
Cost Balance	**\$167m**	**\$8.2m**

Fig. 3. Starcloud cost comparison (Starcloud WP [8])

It is easy to notice that the true enabling factor is launch cost, which is fast reducing with the already available solutions of reusable launchers and all the further developments that are going on.

According to Starcloud, their project is scalable up to GW size data centers, mostly dedicated to AI training.

3.3 *Lonestar: Data Storage on the Moon*

Lonestar is another US company which is focusing on placing data center on the Moon or around it [9].

As we mentioned above, the latency induced by the distance of the Moon limits the applications that can be performed there, if they have to serve the Earth. Lonestar proposes the Moon and its surroundings as the best place for data storage and backup, ensuring a high level of security.

They tested small demonstrators on the surface of the Moon twice, on board the Intuitive Machines landers IM-1 (February 2024) and IM-2 (March 2025). Even if both missions encountered problems, unrelated with the Lonestar payloads, they claim that they were able to perform their scheduled tests and now they are planning to move the first deployment of their systems to an orbit around the Earth-Moon L1 point.

Later on, they plan to place large data backup centers in lunar lava tubes, to ensure a high level of protection from all outside risks.

3.4 *Xingshidai: a constellation of data processing satellites*

A Chinese joint venture composed of ADA Space and Zhejiang Lab is already deploying a constellation of data processing satellites, implementing AI and dedicated to perform edge computing for space based data collection [10,11].

The full constellation will comprise 2,800 satellites, each one capable of performing 744 one trillion operations per second (TOPS).

The satellites will communicate at high speed with each other using lasers, as in other constellations.

This solution is very interesting since it leverages on the concept of creating large data processing capacity by building large constellations, instead of concentrating computational power on a smaller number of large units. For edge computing this solution is clearly advantageous, while other may require bigger units. It is also suitable for quick deployment, in fact this phase has already started: the first batch of 12 satellites was launched on 14th May on board a Long March 2D rocket from China's Jiuquan Satellite Launch Center.

3.5 D-orbit: from space logistic to space IT services

D-Orbit is a fast growing Italian company that originally proposed devices to deorbit satellites that have reached their end of life but has become a full fledged "space logistics company", with 19 accomplished missions already under their belt. Their ION satellite carrier has already safely delivered more than a hundred satellites to their destination orbits, within rideshare missions [12].

The ION already has on-board computers capable to host applications to be deployed and tested in space. Moreover, they propose Intelligent Logistics, which means an orbital infrastructure that enables a distributed network of space-based data collection and processing. All along the lines we have described, of putting more and more data processing in space to satisfy demand for processing data gathered in space as well as helping applications that are still down on Earth.

They also propose solutions for in-orbit services, that are an essential part of the space industry ecosystem that we have outlined.

4 Conclusions

Energy demand is rising on Earth at a pace that is not allowing the reduction of pollution and GHG emissions as desired. While solutions on Earth may be found in the long run, nothing arguably can stop a further environmental degradation, including global warming but several other important impacts as well.

Just importing energy from space is problematic, for several reasons. The solution for beaming energy to Earth in the quantities required is not really available yet, and the sheer production of all the needed equipment would anyway have a huge impact, as exactly the production of solar panels and other "green" equipment is de facto the main driver of the increase of energy use in industry.

Just producing energy in space and keeping all the rest on Earth would only solve a part of the problem. All the other effects of human activities on our planet would stay there.

Therefore, the correct solution for reducing the global impact of human activities on Earth is not collecting energy, or raw materials (not treated in this paper but obviously connected) in space and bringing them to Earth, but moving these impacting activities to space, where they can use solar power as well as lunar or asteroid materials and release waste heat and other emissions directly to space, without any harm for our precious planet.

Data centers have been singled out as an energy intensive application that is already having a significant impact at local scale in some areas of the Earth and is beginning to have some effect at global scale. Data processing and other IT applications, including especially AI training, is something that can be moved to a space infrastructure in a reasonable time frame. Requirements and difficulties have been described and it has been pointed out that there are in-depth studies as well as some applications already starting.

Transferring data centers to space would zero out their impact on Earth from all points of view, except for now the production of all the relevant devices.

Having such an IT infrastructure in space would respond in the short term to the demand of edge computing for data that are originated in space, just later developing into other applications from data storage to AI training, and ultimately enabling the start of the industrialization of cislunar space, which is the perspective that SRI has been supporting since its beginnings.

The conundrum of allowing economic growth without damaging the planet where we live can be solved by moving out of the planet all the activities that can reasonably be transferred. This will also allow, in the long term, a healthy growth of human communities in space, which we at SRI consider philosophically essential for the survival of civilization, keeping it based on sound economic and industrial principles.

References

[1] International Energy Agency, Electricity 2025 – Analysis and forecast to 2027, February 2025, https://www.iea.org

[2] Sean Wolfe, Over 100 new gas-fired power plants have been proposed in Texas, https://www.power-eng.com/gas/over-100-new-gas-fired-power-plants-have-been-proposed-in-texas, June 17, 2025

[3] Gerard K. O'Neill, The High Frontier, 2019 reprint by Space Studies Institute Press North Hollywood, California

[4] Amelia Williamson Smith, On the Edge of the Edge: Taking Supercomputing to Space, https://issnationallab.org/upward/hpe-supercomputing-return-space/, May 7 2021

[5] Press release by Booz Allen, https://www.boozallen.com/menu/media-center/q2-2025/booz-allen-deploys-the-power-of-generative-ai-in-space.html, August 1 2024

[6] ASCEND website, https://ascend-horizon.eu/, (accessed July 12, 2025)
[7] Starcloud website, https://www.starcloud.com/, (accessed July 12, 2025)
[8] Starcloud (formerly Lumen Orbit), Why we should train AI in space, White Paper v1.03, September 2024
[9] Lonestar website, https://www.lonestarlunar.com/, (accessed July 12, 2025)
[10] Laurence Russell, China's Adaspace orbits first 12 AI-cloud satellites of 2,800-strong constellation, https://www.datacenterdynamics.com/en/news/chinas-adaspace-orbits-first-12-ai-cloud-satellites-of-2800-strong-constellation/, May 20 2025
[11] Ben Turner, China is building a constellation of AI supercomputers in space — and just launched the first pieces, https://www.livescience.com/technology/computing/china-is-building-a-constellation-of-ai-supercomputers-in-space-and-just-launched-the-first-pieces, June 2 2025
[12] D-Orbit website, https://www.dorbit.space/, (accessed July 12, 2025)