Data Farms and Seaforestation – Final Paper

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Global demand for large language models, generative AI, cryptocurrencies, and cloud services continues to increase each year, and with it comes the demand for places to operate with and store that data. For those tasked with building the data centers of the future, sustainability becomes a priority as limited natural resources and land continue to diminish. The socio-environmental problems of data centers in the continental United States include rising high energy consumption, land usage, and significant carbon emissions. These are some of the many visible byproducts data centers produce, but there also exist social injustices in where they are placed, where resources are taken, and who is affected by these externalities. While many data centers are located in tech-based urban areas such as coastal California and the Virginia-D.C. area, rural communities, small towns, and farmlands have become prime locations for development. This results in a disproportionate amount of noise pollution, resource siphoning, and ecological disturbances, among other problems (Monserrate, 2022). These issues are important because data centers in the US are rapidly growing and consuming energy from nonrenewable resources as well as taking up significant portions of land, further reducing usable land people or wildlife could sustain themselves with.

We can relate these issues with the **Tragedy of the Commons** problem. The constant growth of data centers requires sizeable tracts of land, but the locations that would benefit from having them in close proximity, such as urban cities, are already packed. The Increased demand for data center development, increasing population, and decreasing amounts of land to use for sustenance would bring us closer to that reality. Innovation can only take us so far; buildings can only get so packed full of servers before building expansion is required. To tackle these problems, I propose a solution to continue the development of data centers in a more sustainable manner: underwater data farms.

Before we discuss our proposed solution and its implications, some general background knowledge on US energy sources and data centers is required. Since 2008, energy produced from coal has significantly gone down, from 30% to 12% by 2022. 60% of US energy production is generated by petroleum or natural gas, an increase from 42% (EIA, 2022). In terms of consumption, coal has decreased significantly from 23% down to 10%, while petroleum and natural gas consumption has gradually increased to almost 70%. Renewable energy consumption slowly increases its share, from 7% to 13%. We can see from these statistics that the **market response model** is at play. Sustainable energy production has led to a cost reduction in energy, resulting in the waning of coal usage, which continues to become more expensive to mine. Petroleum, however, has not yet been phased out due to the unreliable nature of energy grids in colder climates. In these climates, diesel is the tried-and-true method for keeping critical components running.

Data centers are predicted to consume 6% of the total US energy demand, half of this energy consumption for cooling (Buckley, 2024). Data centers are rooms, buildings, or entire facilities whose purpose is to provide and store data. These buildings are filled with data storage systems and computational servers. One unique attribute of data centers is that they are built upon levels of redundancy. Many critical processes are performed using these data centers, such as communication platforms, company and personal storage, and keeping the internet stable and online. Data centers have become essential for **globalization** efforts by connecting people worldwide to communicate and share ideas. It would cost people and corporations thousands, sometimes millions, in lost revenue should their online processes fail to function; therefore, data centers are built to stay online if one component fails. As a result, many servers go unused and remain idle as a failsafe. This redundancy is the primary cause of the high energy and resource usage. As a further precaution, many data centers use diesel generators, which cause long-term harmful environmental effects. Additional energy is required to keep the interiors cool. Servers located inside data centers generate copious amounts of heat. Air cooling, using large fans and kilowatts of electricity, keeps interiors cool. This heat is discarded out onto the atmosphere, contributing to a warmer climate. This heat is very difficult to recover for sustainable energy production, and is discarded in many places, although some data centers in Norway are able to use the heat to keep nearby locations warm (Ebrahimi et.al., 2014).

Proponents of a greener data center propose the use of water-cooling, as liquids are able to transfer heat more efficiently than air. Much like a water-cooled computer, these systems generate less exhaust heat, keep the components cooler, and require less energy to maintain. However, for liquid cooling to be efficient, potable water must be used. Saltwater cannot be used to cool these components, as the alkaline from the water hastens the deterioration of metals. Data centers such as the NSA's Utah center, built in an arid and dry climate, are water cooled with millions of gallons of water per day (Hogan, 2015). One solution to this wasteful usage of a valuable resource would be to recycle the used water throughout the data center more than once, in what is known as a "closed-loop system". Thousands of gallons will still be used and peak efficiency will diminish, but it puts less of a strain on our natural resources.

One is inclined to ask why data centers are developed in dry climates, far from the general population that would use these services. Companies are influenced by rural area's low energy costs, opting to build data centers on farmland or commercial zones. Farms that are no longer able to profit from large-scale crop production sell or lease portions of their land to contractors for data center use (Starner, 2024). This results in multiple **externalities**, felt unevenly between the United States based on class and income levels. Noise pollution, local temperature increases, reduction of water resources are all noticeable externalities of populations in close proximity to a data center. We can categorize this disproportionality between three groups: rural and small towns, tech-based cities, and suburban areas. Rural and small-town populations are impacted the most from data center noise, resulting in some cases of hearing loss and psychological effects. Suburban areas remain mostly unaffected by these externalities.

Tackling the problems of energy consumption, land usage, and emissions reduction, my proposal stems from the practice of creating data centers on farmland to instead create underwater "data farms." Submerging data servers underwater reduces energy consumption for cooling while preserving our limited drinking water resources. This energy transfer from cool water to outer casing is more efficient, as more surface area is coming into contact with the liquid. Land development creates permanent ecological impacts, while data farms can be relocated/removed for the restoration of ocean ecology. Since there is no need for infrastructure such as roads and buildings to house the server components, it also produces less physical and chemical waste.

The general structure of an underwater data farm is simple: Servers, storage units, and computers are stored inside a series of metal containers, whose components are in direct contact with the cold metal. The casing keeps the components watertight, while also acting as the medium for the heat transfer of the heating computer parts and the chilly water that surrounds the container. Cables power the data farms using renewable energy sources, as well as connect their components to an inland server to allow its users to connect with the underwater servers.

Although the size and scale of underwater data farms would produce miniscule impacts to ocean carbon density and overall temperature increases, the development rate of new data centers would produce alarming changes to ocean temperatures if unchecked. These data farms would still produce excess carbon gases, only this time they are absorbed by the waters, a far more alarming alternative than to remain in the atmosphere. Carbon-offsetting practices must be used in conjunction with these data farms. The most optimal solution to this problem is "Seaforestation", or the development of kelp farms in or near the data farms (Li et.al., 2022). Although data farms would benefit the most by being placed in arctic climates, ideally, they can be kept in temperate waters or below, such as those on the California coast. Likewise, kelp grows well in waters between 40-72 degrees Fahrenheit. The role of kelp farms close to the data farms would result in improved **carbon sequestration**, a reduction in total oceanic carbon density, as well as a potential biofuel source for other applications.

The United States is the frontrunner in data center development. From 2020, the US is the largest developer of data centers; over 50% of all data centers worldwide are in the US (Statista, 2024). The introduction of underwater data farms leads by example to improve certain **Sustainable Development Goal** indicators. SDG seven, "renewable energy share in total final energy consumption," is improved both by the reduced dependence on coal and petroleum as well as the generation of kelp as a potential fuel source. Building materials and the ensuing pollution construction produces are also reduced and improves SDG twelve, "production-based emissions" as server casings replace buildings as the housing of servers. Prototypes of underwater data farms have been met with moderate success. Similar ideas have been implemented by Microsoft under Project Natick (Simon 2018). Data centers running on renewable energy were dropped underwater for a period of 2 years, resulting in uninterrupted services while performing with a significant reduction in energy consumption. According to their analysis, Ecological impacts were minimal, with restoration efforts underway after data centers were removed from the ocean floor. Subsequent drops could remain underwater for as long as 5 years with minimal impacts. They do not provide any information about the long-term impacts on the ocean environment, nor do they disclose the amount of pollution emitted; however, the ecological impacts are miniscule when compared to the impacts land-based data centers have on their surrounding communities.

Underwater data farms are a sustainable method of reducing our dependence on nonrenewable generation of electricity while keeping up with the demand for cloud computing, Artificial intelligence, and large language models. The Unites States is a global leader in the development of sustainable data center policy. To lead by example is the ideal method of influencing other countries with data centers to follow sustainable practices. The impacts of "Seaforestation" to offset carbon emissions helps preserve our natural resources, both oceanic and inland, and furthers development of sustainable biofuel production. Our dependence on technology does not have to come at the cost of wildlife habitats, farmlands, or our rural communities. Through innovative development of our data infrastructure, we can develop a path towards a greener, sustainable computing future.

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