Farming Sustainably

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ABSTRACT:

Hydroponic containerized farming is an innovation which has emerged in recent decades, capable of growing organic food with minimal land and water usage within the urban environment. The design of the containerized model needs to be adapted to incorporate renewable energy to minimize its operational footprint, whilst maximizing the models ability to operate sustainably. I gathered energy usage data on existing hydroponic containers, determined the baseline energy demand and calculated renewable energy solutions capable of meeting this energy usage. Both wind and solar energy are renewable sources that, if sized correctly, are viable for powering this food supply model. Overall my research concluded that we should draw inspiration from this application of renewable energy to a food supply model as it is just one of many designs that will dramatically improve the world's window of survivability in the face of climate change and population growth.

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INTRODUCTION:

Thanks to the emergence of the internet we are now, better than ever, able to shape a collective understanding of the toll we take on the planet. During this era we have greatly expanded our technological abilities, but our cities still fail to meet the minimum standards of self reliance. Continuous urbanization is increasing pressure on policy makers to better prepare infrastructure and equip the cities of today to handle the surmounting population growth of tomorrow, and for this reason food production is a critical area in need of attention. There is good evidence that supports the production of food crops in mass quantities within local environments, as a means of reducing the C02 emissions and energy wastage of the existing supply chain responsible for the food grown conventionally, in rural environments. Vertical hydroponic containerized farming offers a unique, globally relevant and game changing innovation, which in theory, provides a blueprint for solving the global food supply and at the same time solving many grave factors that are contributing to climate change. The crux of this model is the large electrical energy input required for its operation. Little thought has been given towards the ability to solve this problem through renewable means.

Thesis Question:

Knowing the potential benefits of vertical hydroponic farming, is it possible to power these systems from renewable energy sources? What renewable sources are available? Which are the most viable? Finally, do the benefits outweigh the costs? This capstone intends to analyze the costs and benefits of using renewable energy to power vertical hydroponic containerized farming technology.

Literature Review:

Global population is projected to rise above 9.7 Billion by 2050 (UN DESA, 2019). This alarming projection is a daunting reality for our already strained food supply system.

The conventional U.S. food supply system has come under scrutiny for the adverse impacts it is having on the environment.

Agricultural consequences have been examined in a case study in a state called Haryana India. (Singh, 2000) The study analysed the impact of westernized farming methods on the physical and chemical degradation of soil. It discussed major limitations to mechanical soil farming which relied on genetically modified crops that necessitate chemical inputs. Identifying several major physical, hydrological, chemical and biological constraints relating to soil and ecosystem health. The study concluded that over time the overuse of irrigation, fertilizers and pesticides resulted in increased levels of phosphates, nitrates and other heavy metals in groundwater tables. This study also addresses declining nutrient use efficiency and storage capacity which is an indirect result of soil depletion (waterlogging, salinity and alkalinity) which over time if left untreated will lead to flooding, crop loss and desertification. It summarizes that arable land and natural ecosystems are simply unable to adjust to the chemical inputs required for this farming process. Productivity is limited and animal, plant and crop diversity diminish as a result. The study also highlights the fatal crux that comes along with population growth and increased land usage - that the scope of productivity for this kind of system lies on further intensification which is crucially dependent on more energy-intensive inputs. Rising water tables are also another factor affecting soil salinity.

According to recipient reports from (NOAA, 2020) “Global mean sea level has risen about 8–9 inches (21–24 centimeters) since 1880, with about a third of that coming in just the last two and a half decades. The rising water level is mostly due to a combination of meltwater from glaciers and ice sheets and thermal expansion of seawater as it warms” (NOAA, 2020) which will result in spots of increased salinity further complicating the issue of soil degradation.

Having noted the projection of population growth and having established the crippling limitations of conventional agriculture, it is equally important to factor in other global pressures that have emerged due to increased human activity. In 2009 the World Water Assessment Program formally recognised in a report that “Alongside the natural forces affecting water resources are new human activities that have become the primary ‘drivers’ of the pressures affecting our planet's water systems” (WWAP, 2009) The report summarized that global collective requirements for water to meet our fundamental needs and our collective pursuit of higher living standards, coupled with the need for water to sustain our planet's fragile ecosystems, makes water unique among other natural resources."

In 2011 Columbia professor Dr. Dickson Despommier wrote a visionary book called '*The Vertical Farm: Feeding the World in the 21st Century*'. This book provides insight into how vertical farming technology is a globally relevant, game changing innovation, which in theory, provides a blueprint for securing the global food supply and at the same time solving many grave factors that are contributing to climate change written prior to the actual construction of any of the urban vertical farms that exist today. Professor Despommier comprehensively approaches many of the serious yet largely disregarded ecosystemic, pollution, and health related issues caused by conventional agriculture, before suggesting how vertical farming offers a ground-breaking tool for architects, scientists and politicians worldwide. Despommier argues that the greatest harm caused by westernized agriculture stems from our failure to adequately handle the effluents caused by crop irrigation (Despommier & Carter, 2011). With almost 70% of all Earth's available fresh water being used for crop and livestock irrigation, the agricultural runoff is responsible for more ecosystem disruption than any other kind of pollution. Harmful irrigation effluent is laden with toxic substances like pesticides, herbicides, fertilizers, and silt. Despommier reasons that irrigation effluents have wreaked the most havoc on ocean-based ecosystems and are the leading cause behind coral and reef habitat loss (Despommier & Carter, 2011). This is due to Ammonium Nitrate pollution, the chemical used in fertilizer. This widely used farming input is destructive down-stream because the chemical properties of Ammonium Nitrate cause the effluent to absorb oxygen from water. This toxic cycle starves the sea life of the oxygen needed to survive and is causing a gradual disconnection in the world's oceans. This problem is further compounded by deforestation. Thousands and thousands of acres of forestry have been cut down and bull-dozed to make room for the continuously expanding land usage of modern agriculture. More farming acreage leads to more pollution from chemical inputs, and fewer forests mean fewer trees are available to aid the carbon cycle, leading to a dwindling ability for our planet to sequester carbon from the atmosphere (Despommier & Carter, 2011).

Despommier addresses how vertical farming in the urban center can provide several readily achievable and highly desirable benefits. He explains that vertical farm systems can improve food security by enabling farmers to grow food in an entirely new way - indoors instead of outside. Well monitored indoor climate conditions allow vertical farmers to ensure optimal year-round growth rates for carefully selected crop species by controlling important variables like temperature, humidity, C02 concentration, and water/nutrient supply (Despommier & Carter, 2011). Because vertical farms combine hydroponic technology with an indoor environment, they use substantially less water than conventional farming. They are entirely immune to weather and other natural phenomena that often cause debilitating crop spoilage for regular farmers. This soilless approach also eliminates the use of pesticides, herbicides, and fertilizers, which means it will lend itself towards solving pollution from agricultural irrigation. “The efficiency of a vertical farm one acre in footprint could be equivalent to as many as ten to twenty traditional soil-based acres” (Despommier & Carter, 2011).

Locational benefits also allow farmers to save huge amounts on fossil fuels otherwise used for transportation, refrigeration, plowing, applying fertilizer, seeding, weeding, and harvesting. Despommier completes his argument by concluding that by adopting these vertical farms in urban centers, we can convert significant amounts of farm land back into whatever ecosystems were there originally and cease any further destruction (Despommier & Carter, 2011). As outlined in this book, the benefits that vertical farms embody, allow the modern agrosolution to serve as a potential tool that will enable humanity to achieve an important and mutually exclusive goal of providing healthy food to the world growing population, whilst repairing the environment.

Piggybacking off Despommiers research, a peer review study conducted three years - later, explored how Vertical Farms also can strengthen and create more sustainable food supply chains (Gruner et al., 2013). The authors of this study reviewed current perspectives on the benefits of global versus local supply chains. They synthesized arguments to show how vertical farms can act as an operational model of a more local supply chain with significant practical and theoretical implications that can be emulated beyond the agricultural sector. “A shift toward more local supply chains can save resources, reduce waste and emissions and improve productivity.”. The study concluded that Vertical farms can be ‘ecosystemic’, in that they integrate all elements of a supply chain in one location, producing, refining and selling organic food under one roof. To the extent that all elements of the supply chain work as one cohesive whole (Gruner et al., 2013.). Overall the study suggests that vertical farming offers a local supply chain model of production and distribution which can take advantage of unique spillover effects and opportunities. Because industries beyond the agricultural sector can emulate this model, it can be applied to the broader supply chain context;

offering further economic, social, and environmental benefits beyond the defined operational efficiencies.

Research conducted locally in Arizona (Barbosa et al., 2015) sought to test hydroponic farming’s suitability as a replacement for conventional lettuce farming already in operation within the region. This study clearly identified hydroponic agriculture as an approach that reaps numerous benefits which “when practised in a controlled environment, can be designed to support continuous production throughout the year” (Barbosa et al., 2015) . The study concluded that this technology would improve operational efficiency within the future. Currently, it cannot be deemed a more sustainable alternative to conventional lettuce farming techniques due to the high electrical energy consumption required for its application. In summary, hydroponic agriculture could be a strategy for sustainably feeding the world’s growing population whilst reducing the demand of freshwater supplies, as long as the models high energy consumption can be overcome through improved efficiency and cost effective renewable energy application.

Data Collection, Results & Discussion
Theme 1: Transparency About The Rising Cost of Food.

Background:

In the United States the truth is simply that the majority of our population does not operate on a level playing field. Social inequality has risen as the wealth gap has continued to expand.Our society's wealthiest members share the bulk of profits generated from economic growth, and a disproportionate amount is distributed amidst the majority. The reality is that this system allows 1% of society to make enormous profits over the backs of less fortunate people and the planet.

A general question has been raised globally in consensus over the past decade regarding the question of how and why so many people in the world's most economically prosperous nations lack adequate access to enough healthy food to eat every day.This observation rings especially true in the United States. Having maintained our position as the world's largest economy, we spend substantially more than any other comparable country on health care, 8.8% of GDP in the U.S., compared to 2.7% on average for other nations.At the root of this problem is how we have learned to measure economic success and our current definition lacks and externalises an evaluation of social capital and natural capital. In this initial research section, I aim to provide transparency about our economy's critical failures and relevant social issues that highlight a need for change in our food supply chain structure.

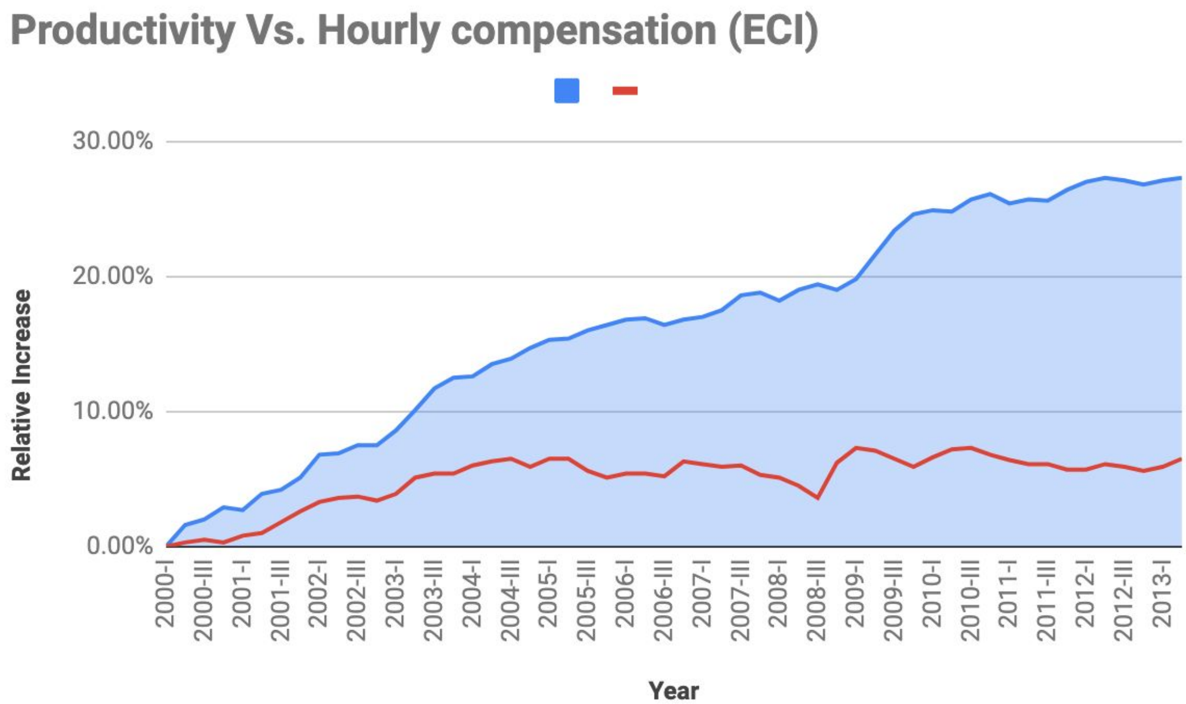
Research Methodology:

I began by reviewing tabular data collected from reports published by the U.S. Bureau of Labour Statistics (viewable in the appendix). This data demonstrates how the changes in compensation across U.S. workers over time has mainly been unequal. I looked at the relative increase of U.S. gross domestic product compared to the relative increase of hourly compensation for U.S. workers over the last two decades.

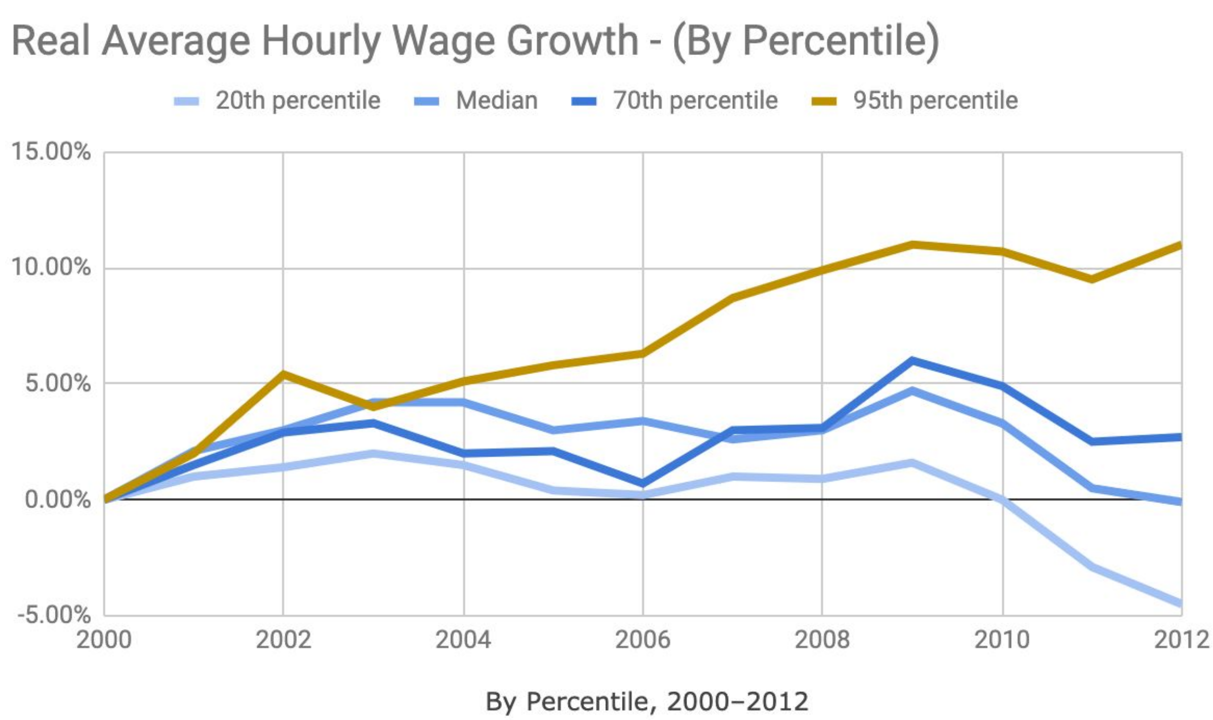
It is important to zoom in and analyze how wage growth gets distributed across the U.S. population's varying income percentiles. The purpose of diving deeper into this economic data is to contextualize the social factors contributing to consumers having less money to afford healthy food. I collected and synthesized additional tabular data made available through the Bureau of Labour Statistics. This data focuses on the relative increase of average hourly wages across four economic percentiles; The lower class (20 th percentile), the middle class (Median percentile), the Upper class (70th percentile), and the wealthiest class (95th percentile). The line chart shows the relative hourly wage growth of each percentile in a color index. The results of this data analysis are visible below.

Findings:

Line Chart Showing the Relative Stagnation of Wages in comparison to U.S. GDP



Line Chart Showing The Distribution of Relative Wage Growth Across Various Income Groups.



Discussion:

There are a few evident trends. This productivity vs. hourly compensation chart shows a steady increase in the gross domestic product over a decade - highlighted in the chart's blue area. This is not particularly surprising, however, it is surprising to see how disproportionate the relative increase of compensation appears to be in comparison. The data shows how despite a constant increase in economic activity and growth - the U.S. economy fails to provide wage & benefit growth to the vast majority of workers. With the real median weekly earnings for U.S. workers decreasing (-0.2 percent) since 2008, it is evident that the fruits of this collective economy are distributed disproportionately with the wealthiest families enjoying a majority of the overall growth.

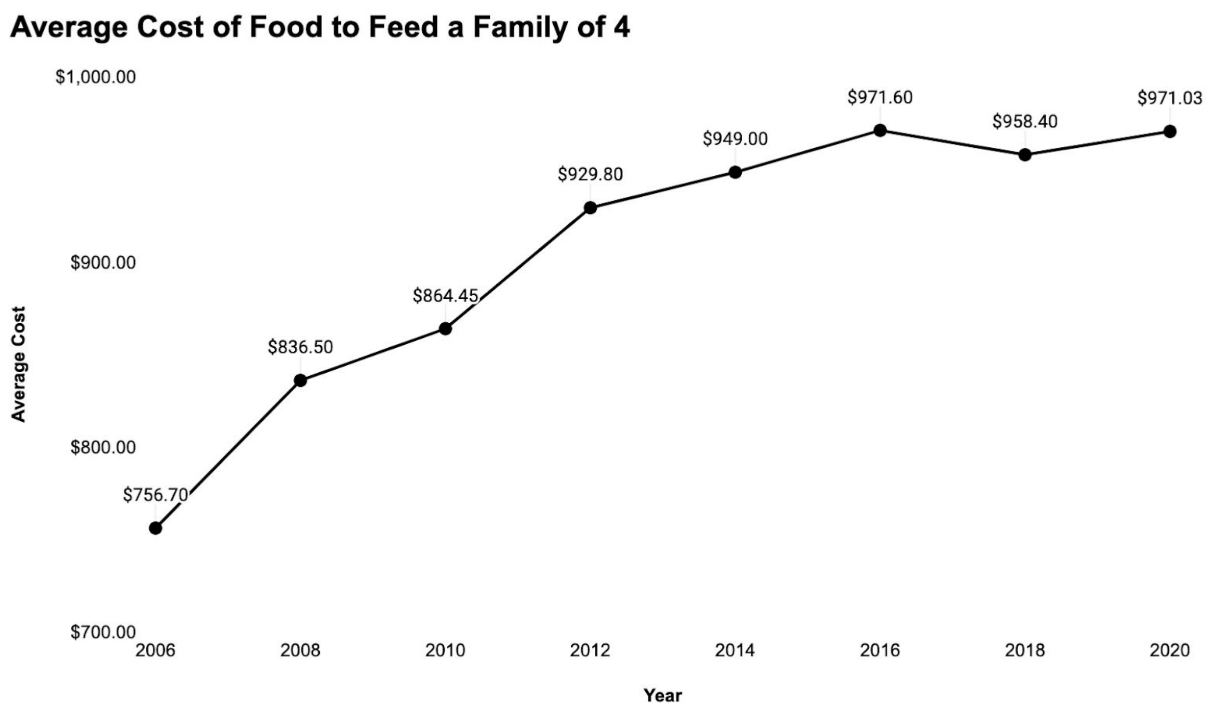
In the Real Average Hourly Wage Growth chart, the first and most prominent trend is that the 95th percentile (indicated in gold on the line chart) experienced the most significant relative increase in hourly compensation. The second most notable trend is a steady decline in hourly wage growth for the vast majority, visible in the various shades of blue (70th percentile, median and 20th percentile). This data provides evidence that the rich are getting richer, and most lower-income earners in the United States are experiencing a loss of earning potential. These findings further lend themselves to the theory of wage stagnation and the social consequences which are partly to blame for why many people in the most prosperous nations lack adequate access to healthy food every day.

Research Methodology (continued):

Another area of economic data involves looking at food costs. The USDA collects and examines data about the weekly and monthly costs associated with feeding a family of four, across four variations of diet; a thrifty plan, a low-cost plan, a moderate cost plan, and a liberal plan. The data that I reviewed was from the years 2006 to 2020. The following graph shows the relative increase in food prices over the past 14 years.

Findings:

Line Chart / Graphic Showing the Increase of Food Prices:



Discussion:

The USDA data shows a continuous increase in food cost over the past fifteen years. In 2006, it cost only $756 to feed a family of 4, today the cost has risen to over $958. These results pair nicely with the results of stagnating wages. Coupled together they provide context towards the struggle that most workers face, it is getting harder to feed our families healthy food. This information provides valuable scope towards an otherwise obscure issue. Transparency is critical towards holding the economic systems accountable for these failures. This is a large part of why I think finding innovative solutions that increase the variety of healthy food while developing solutions to cut down on production costs are so important. As in theory, it will lend itself to solving this problem.

Theme 2: Understanding the Features, Benefits and Energy Use of Vertical Farming.

Background:

The literature review provided context on the global food and fresh-water crisis and the noteworthy conventional agriculture failures in tackling the related challenges and issues. Despommier & Carter, 2011;Gruner et al., 2013; and Barbosa et al., 2015 provided an introduction into the innovative world of vertical farming and provided insight into the benefits of this futuristic technology, which lend themselves as a useful tool for fixing the global food crisis. Although there are many sustainable farming techniques available to consider for this capstone, I found particular interest in containerized vertical hydroponic farming due to the farming model's versatility as a growing food method in a built-up urban environment. Prefabricated in the form of a retrofitted shipping container, this model allows farmers to essentially 'plug and play' in the urban environment. Land availability is limited in the urban space, and organic food suppliers are scarce. This research section aims to analyze and explain two aspects; what features and benefits of this kind of vertical farming model make it sustainable and what environmental costs are externalised through its operation.

Methodology:

The first thing I did was reach out to an urban farmer at Freight Farms in Brooklyn, NY. Freight farms is a ten container urban farm located in the rear parking lot of the repurposed Pfizer chemical plant in the Bronx. I had a wonderful experience interviewing the farm team. They provided me with all of the necessary documentation that I would need to understand each container's operational efficiencies and provided me some useful insight into some of the growing pains they had experienced since starting the farm. I transcribed my interview with the Square roots team and used the information that i had collected to summarize the benefits of this farming technique in comparison to conventional farming. I also calculated the total amount of electrical energy used by a single container to grow food over a 24 hour period. I then used local utility rates to quantify the total amount of energy one of these containers would require to operate in Tucson, AZ and how much this would cost. With this information I broke down the externalised environmental costs of running this model off of grid power (like they do at the Square Roots farm) to highlight a dilemma that this farming solution fixes one problem while creating another.

Findings:

Table of The Comparative Benefits Provided by Vertical Farming

More efficient fresh water usage - 5 gal a day (10% of conventional agriculture)
Higher crop yields - 5% of crops lost to spoilage (conventional agriculture loses over 40%)
No fertilizer, pesticide or herbicide use - prevents loss of ecosystem biodiversity
No conventional irrigation required - massive savings in fresh water and water table pollution.
Soilless technology - prevents deforestation and desertification from overfarming.
Reduces global impact on climate change - by minimizing the footprint of agriculture.
Increased food security - less susceptible to political, geological and seismological events.
Localized model - versatility and scalability enables a more sustainable food supply chain.

Table showing Calculations of Monthly Operational Energy Use of a Single Container:

Total usage	**4791 kW**
Total cost	**$402.03**
Cost per kWh	**0.0839 $/kWh**
Energy in Btus	**16,351,683 BTUs**
Energy in Therms	**163.51 Therms**

3 Important factors to take into account for the following calculations:

1. For every kWh of electricity that is consumed on-site, a utility company must generate 3.3kWh in the power plant.
2. To generate 1 kilowatt-hour of energy by thermoelectric means typically consumes ⅔ of a gallon of water
3. The generation of 1 kWh of electricity releases 2.3 pounds of Carbon Dioxide into the atmosphere.

Table of Calculated Externalized Environmental Costs from this Energy Use:

Carbon Dioxide Released into the Atmosphere.	**16.49062 Metric Tons / monthly**
Fresh Water Consumed	**10,540 gallons of water monthly**

Discussion:

Two of the most constant farm expenditures include land tenure (lot space rent) and monthly electricity bills. A container needs between 150kWh to 165kWh (depending on the climate region) to operate and grow food daily. When put in perspective, the energy use of a single container would equate to roughly three domestic households in comparison. This extremely intensive energy use comes as no surprise. The container model heavily relies on LED lighting and HVAC equipment to ensure optimal interior growing conditions year-round. Little thought was given regarding the externalized environmental costs of plugging one of these containers into the socket and running it off the national grid. Having completed the calculations. It was shocking to see how high the externalized environmental costs are. Using non-renewable sources, the electricity required to power a single container over one day would draw an additional 346 gallons of fresh water and emit a whopping 0.54 Metric Tons of C02 in the atmosphere. These environmental costs are significant when brought into perspective. Still, conventional agriculture's character faults are equally disappointing because this system fails to internalize and account for the entire “true” cost of production. This realization leads to the final section: an analysis of renewable energy solutions’ potential to solve this problem.

Theme 3: Net Zero Farming with Renewables.

Background:

In the previous section, the amount of energy required to power a vertical hydroponic container was calculated. This farming model's design needs to change, noting the consequences of drawing this power from non-renewable sources. The change that I am suggesting is to incorporate renewable energy sources to solve externalized environmental costs, while simultaneously giving hydroponic containerized farming the capability to become NetZero. Having already applied the electricity usage to the metrics associated with Tucson, AZ, I will also be using these renewable energy solutions in the context of a Sonoran Desert Climate. With the list of renewable options available, including; water (hydroelectric), geothermal, solar, and wind, I selected both Photovoltaic and Wind generation as the most viable renewable solutions. I did not explore geothermal or hydroelectric as the two options' rigidity does not align with the containerized urban farming model's versatility. I opted to start this section by studying solar power because the abundance of sunlight in Tucson made it the most apparent option. I then conducted a similar analysis of wind turbine generation and compared the results with one and other to analyze the various costs and benefits of either option. The section's ultimate goal is to determine the feasibility of either solar or wind electricity to power containerized vertical hydroponic farming and to determine its environmental benefits.

Methodology: Sizing a PV array

The first part of this section is dedicated to sizing an appropriate photovoltaic array. The second part of this section is dedicated to determining the cost of such an array, and lastly, the third section analyzed a return on investment. I started by accessing the PVWatts© solar program. I then pulled up data on the climate and geographic location of my home address in Tucson. I then set the program to default system values to find a sample quantity of kWh produced per year by a PV Array in Tucson. I then viewed the results of this sample array, and determined the total kWh produced per year. I also noted that the average solar radiation received by the sample collectors. I then used a proportion ratio equation to calculate the sufficient size of a kW PV Array that would be capable of meeting the energy demand of a vertical hydroponic container in Tucson. I then entered the resultant kW PV Array in the PVWatts© software and did not change other parameters concerning: geographic location, module type, array type, tilt or collector orientation. Once the appropriate kW size PV array was confirmed I conducted an online search to see what available options were for sale. I found 10kWh panels sold online which required 600 sq ft of free space to install (images of this array are visible in the findings sections below). I then calculated how many of these arrays would be necessary to power a container and the cost associated with purchasing them. Once I understood the costs, I conducted a cost-benefit analysis to determine if this renewable option is a financially viable alternative to vertical farmers' grid power.

Methodology (continued): Sizing a Wind Turbine

The first part of this section is dedicated to calculating how many containers a commercial wind turbine would be capable of powering. The second part of this section is dedicated to determining the cost of such a turbine, and lastly the third section analyzed a return on investment. I accessed the General Electrics website and viewed various specifications about 2MW Wind Turbines with a rotor diameter of 116 meters. Using a capacity factor of 25% I calculated the total amount of kWh a turbine of this size can generate per year. I then divided the total yearly amount of kWh produced by the amount of kWh each container demands, to determine how many containers a single 2MW container would hypothetically be able to power. Once I had confirmed the scale of this renewable option, I conducted an online search to see how expensive the upfront cost of a single 2MW commercial turbine would be. This was difficult as commercial wind towers are not as easily sourceable as solar panels, but I was successfully able to find a general consensus on the average price of purchasing and installing one of these gigantic systems. Once I understood the costs, I conducted another cost-benefit analysis to see if wind power is more or less financially viable in comparison to solar.

Findings:

Table of Results for Sizing an Appropriate Photovoltaic Array

Size of Array	**40kW**
Upfront Cost	**$52,628**
Annual kWh Demanded	**57,487 kWh**
Annual kWh Produced	**69,839 kWh**
Annual kWh Surplus (buy back electricity)	**12,352 kWh**
ROI (over 25 years)	**$93,858**
Net Monthly Profit	**$312.00**
Comparative Fresh Water Savings (over 25 years)	**3,162,000 gallons**
Comparative C02 Emissions Savings (over 25 years)	**4,950 Metric Tons**

*25 year Warranty Period

Table of Results for Sizing an Appropriate Wind Turbine:

Size of Turbine	**2MW**
Upfront Cost	**$4,000,000**
Annual kWh Produced	**4,380,000 kWh**
# of Containers Capable of Powering	**83**
Annual Savings from Utility Company	**$400,309**
ROI	**10 years**
Comparative Annual Fresh Water Savings	**10,542,660 Gallons**
Comparative Annual C02 Emissions Savings	**16,359 Metric Tonnes**

Image of 10kW solar array (¼ of array required for one container)

(https://www.gogreensolar.com/products/10000-watt-10kw-solar-ground-mount-kit)

Image of a 2MW Wind Turbine

(https://en.wind-turbine-models.com/turbines/963-w2e-wind-to-energy-w2e-93-2.0)

Discussion:
Solar:
According to the program, the results for my estimates proved accurate. A 40 kW PV array would collect 69,839 kWh of electricity annually; this would generate more than enough electricity to offset the 57,487 kWh of electricity used by a container on an annual basis, allowing the design to become ‘Net Zero’. I was at first shocked by how expensive the price of these photovoltaic panels are online, but was pleasantly surprised to conclude that by making this purchase, an investor can get a return on investment during the duration of the solar panels 25-year warranty. Having assumed the utility companies would pay an identical amount to what they charge for buying back the surplus energy, an investor would net more than $300 a month in profit. This conclusion means that Solar is not only a financially incentivized option but can enable a container farm to be grid-independent (more versatile) and Net Zero (preventing additional fresh water wastage and greenhouse gas emissions).
Wind:
According to these results, I was able to show that wind power has a much greater impact on a larger scale. I discovered that a 2MW wind turbine can supply the electrical needs of 83 hydroponic containers year-round. This large economy of scale does however, comes with an equally large price tag. With the cost of a single turbine averaging 4 million dollars, this option appears too pricey for most start-up farmers. For a much larger commercial operation with the financial capital to afford this infrastructure - this would be the most feasible option for one critical reason. This reason is centered around the lack of available land in urban centers. Today, urban cities are already incredibly dense, with many overlapping functions and boundaries. Open and undeveloped space in the urban center is usually hard to come by and often incredibly expensive. This is the partial reason why conventional farming has continued to expand into rural regions where land acreage is bought at its cheapest. Despite the enormous upfront cost of erecting a commercial wind turbine, there is little to no land use required as the structure of a turbine is vertical in nature and therefore believe wind power has the most utility. When powering a single container via photovoltaic means, 2,400 sq ft of space is required to install a 40 KW system. When considering this on an identical scale to the 83 containers a wind turbine can power, I quickly realized a vertical farm using solar on this scale would require 4.5 acres of undeveloped land to install the photovoltaic array. Therefore solar is less tenable than wind power towards solving the issue of powering vertical hydroponic farms in urban centers, sustainably.

Conclusion, Recommendations & Limitations

Conclusion:

Current data trends indicate the cost of food and global population growth will continuously increase. In contrast the quality of food and the land & fresh-water resources required to grow it will continue to diminish. Technological innovations have emerged in recent decades that enable new farming approaches, such as intensive farming, aquaponics, and hydroponics, which will expand the global window of survivability and reduce the footprint on climate change created by conventional agriculture.

Containerized hydroponic farming is a unique approach to the urban food dilemma, which solves many of the problems attributed to conventional agriculture. However, a design that does not incorporate renewable energy causes a significant sustainability failure because of the power generation required. Such a system still results in vast amounts of fresh water usage and greenhouse gas emissions from power generation; one problem is fixed while another is created. Fresh-water consumption, greenhouse gas emissions, deforestation, and public health are all directly affected by how we grow the future of food.

As demonstrated in this paper, wind and solar energy are renewable sources that, if sized correctly, are viable alternatives for powering a containerized vertical hydroponic farm in Tucson, Arizona. Although either option requires vastly different upfront costs and installation requirements, they both would lend themselves to fixing these issues presented by conventional farming. We should draw inspiration and unquenchable enthusiasm from this application of renewable energy to a food supply model. It is just one of many designs that will increase the world's window of survivability.

Limitations:

There are few limitations involved with this study that need to be considered. To begin, the calculations for the energy demanded by containerized vertical hydroponics assumed that the container was being operated in Tucson, Arizona. While this is relevant, there are significant variations in climate in different regions of the world, which will affect differing water and energy requirements. Additionally, the container model data I used for energy estimates were assumed to be commercial scale and optimized for the maximum production of a single crop type, instead various available crop types. In addition, this research focused only on the direct energy inputs required to power containerized hydroponic food production and did not consider energy embodied in chemical or material inputs. Performing a full life cycle assessment of the containerized hydroponic model might produce alternative results, with material and chemical inputs potentially figuring prominently into the true cost equation. Lastly, this study did not discuss additional factors that might inhibit the successful implementation of hydroponic farming in the urban environment, such as the expenses involved in land tenureship.

Recommendations:

It is essential to take these suggestions and apply them to a real-world environment. Implemented renewable energy into an already existing containerized hydroponic farm would bring the notion of Net Zero Farming into the light of day and the realm of reality. This model would lend itself to the future development of more substantial urban farming models that embody Net Zero energy principles in their operation. If this innovation gained enough momentum, it could shift the path of climate change while increasing the quantity and variety of healthy food to the increasing global population of the near future.

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APPENDIX

Real average hourly compensation and productivity growth, 2000–2013 from from U.S. Bureau of Labor Statistics

	Productivity	Hourly compensation (ECEC)	Hourly compensation (ECI)
2000-I	0.00%	0.00%	0.00%
2000-II	1.60%	0.30%	0.30%
2000-III	2.00%	0.70%	0.50%
2000-IV	2.90%	1.00%	0.30%
2001-I	2.70%	1.30%	0.80%
2001-II	3.90%	2.10%	1.00%
2001-III	4.20%	2.80%	1.80%
2001-IV	5.10%	3.50%	2.60%
2002-I	6.80%	4.20%	3.30%
2002-II	6.90%	4.00%	3.60%
2002-III	7.50%	4.30%	3.70%
2002-IV	7.50%	4.20%	3.40%
2003-I	8.60%	4.30%	3.90%
2003-II	10.10%	5.50%	5.10%
2003-III	11.70%	5.70%	5.40%
2003-IV	12.50%	5.70%	5.40%
2004-I	12.60%	6.40%	6.00%
2004-II	13.50%	6.10%	6.30%
2004-III	13.90%	7.00%	6.50%

2004-IV	14.70%	6.50%	5.90%
2005-I	15.30%	7.20%	6.50%
2005-II	15.40%	6.70%	6.50%
2005-III	16.00%	5.60%	5.60%
2005-IV	16.40%	6.20%	5.10%
2006-I	16.80%	7.20%	5.40%
2006-II	16.90%	6.60%	5.40%
2006-III	16.40%	7.10%	5.20%
2006-IV	16.80%	8.10%	6.30%
2007-I	17.00%	8.00%	6.10%
2007-II	17.50%	6.90%	5.90%
2007-III	18.60%	6.80%	6.00%
2007-IV	18.80%	6.80%	5.30%
2008-I	18.20%	7.10%	5.10%
2008-II	19.00%	5.80%	4.50%
2008-III	19.40%	5.40%	3.60%
2008-IV	19.00%	8.80%	6.20%
2009-I	19.80%	9.80%	7.30%
2009-II	21.60%	9.00%	7.10%
2009-III	23.40%	8.50%	6.50%
2009-IV	24.60%	7.20%	5.90%
2010-I	24.90%	8.20%	6.60%
2010-II	24.80%	7.90%	7.20%
2010-III	25.70%	8.40%	7.30%
2010-IV	26.10%	7.10%	6.80%
2011-I	25.40%	7.30%	6.40%
2011-II	25.70%	6.30%	6.10%
2011-III	25.60%	6.40%	6.10%
2011-IV	26.40%	6.70%	5.70%
2012-I	27.00%	6.90%	5.70%
2012-II	27.30%	6.60%	6.10%
2012-III	27.10%	6.50%	5.90%
2012-IV	26.80%	5.80%	5.60%
2013-I	27.10%	6.30%	5.90%
2013-II	27.30%		6.50%

Real average hourly wage growth, by percentile , 2000–2012 from U.S. Bureau of Labor Statistics

	20th percentile	**Median**	**70th percentile**	**95th percentile**
2000	0.00%	0.00%	0.00%	0.00%
2001	1.00%	2.10%	1.50%	2.00%
2002	1.40%	3.00%	2.90%	5.40%
2003	2.00%	4.20%	3.30%	4.00%
2004	1.50%	4.20%	2.00%	5.10%
2005	0.40%	3.00%	2.10%	5.80%
2006	0.20%	3.40%	0.70%	6.30%
2007	1.00%	2.60%	3.00%	8.70%
2008	0.90%	3.00%	3.10%	9.90%
2009	1.60%	4.70%	6.00%	11.00%
2010	0.00%	3.30%	4.90%	10.70%
2011	-2.90%	0.50%	2.50%	9.50%
2012	-4.50%	-0.10%	2.70%	11.00%

Rising Cost of Food Data - Retrieved from U.S. Department of Agriculture.

Year Average Cost

Year	Average Cost to feed Family of 4 $
2006	756.70
2008	836.50
2010	864.45
2012	929.80
2014	949.00
2016	971.60
2018	958.4
2020	971.03

Solar Panels Cost/ Savings Analysis:

-25x 400W tier-1 144-cell polycrystalline PV modules with 25 year warranties.

4 x 10KW kits available on the amazon.com.(require 600 square feet of space each)

40KW array is capable of producing 69,839 kWh annually

Overall Cost of Array = $52,628 - $25,908 = $26,720

Annual PV Ac output - Annual Use = 69,839 kWh - 57,487kWh
= 12,352kWh a year of Surplus Alternating Current

Mean annual cost of AZ energy

57,487.5 kWh/year x 0.0839 $/kWh = $4,823
x 25 years = $120,578
*this is what TEP energy would have cost

Return on Surplus Energy = 12,352 kWh x 0.0839 $/kWh = $1036.33year
25 years = $25,908
*assuming TEP would pay 0.0839 $/kWh

Net Zero Total Monetary Savings Per Container

Overall Cost - TEP Energy Savings Over 25 years
*25 year Warranty Period

25 years = $93,858
Yearly = $3,754
Monthly = $312.00

Net Zero Water Savings:
25 years = 3,162,000 gallons of water
Monthly = 10,540 gallons
Daily = 346 gallons

Net Zero Carbon Savings:

25 years = 4,950 Metric Tons
Monthly = 16.5 Metric Tons
Daily = 0.54 Metric Tons

Wind Turbine Calculations:

Specifications Table

2 MW Series	2MW - 116	2MW - 127	2MW - 132
Output (MW)	2.0 to 2.7	2.2 to 2.8	2.5 to 2.7
Rotor Diameter (m)	116	127	132
Hub Heights (m)	80, 90, 94	89, 90 (Brazil), 114	94, 130
Frequency (Hz)	50, 60	60	50
Vavg (m/s)	8.0	7.85	6.5
Vref (m/s)	38.0	40.0	35
Cut-in (m/s)	3.0	3.0	3.0
IEC Wind Class	IIS/IIIS	IIS/IIIS	IEC S

With a 25% capacity factor, a 2-MW turbine would produce

2 MW × 365 days × 24 hours × 25% = 4,380 MWh = 4,380,000 kWh

in a year.

Total AC current provided) 4.380,000 kWh / 4,791 kWh (Total annual energy use per container) = 83.4

1 turbine is capable of supplying 83 containers with their annual energy supply.

(mean annual cost of energy in AZ) $4,823 x 83 = $400,309 energy savings yearly

Cost

Most of the commercial-scale turbines installed today are 2 MW in size and cost roughly **$3-$4 million installed.**

Cost benefit Analysis:

10 year return on investment

$400,309 annual energy savings

Daily Water Savings 348 Gal x 83= 28,884 Gal

Daily Carbon Savings 0.54 Metric Tons x 83 = 44.82 Metric Tons