IS VERTICAL FARMING AN EFFECTIVE SOLUTION TO FOOD SUSTAINABILITY IN ISRAEL

POLICY PROPOSAL

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Abstract

The world in the 21^{st} century is faced with unprecedented environmental challenges. In order to adapt to the ever-changing landscape, new technologies are needed more desperately than ever. This paper examines how vertical farming technologies can be used to increase agricultural productivity in a truly sustainable way. By exponentially increasing agricultural land, vertical farming can dramatically increase production. Firstly, in order to show the effect that increased land has on agricultural production, a regression analysis was conducted using agricultural data from 187 countries in 2016. Agricultural production was used as the dependant variable, while cropland and irrigation were used as independent variables, in addition to several control variables which were used. The analysis shows that increased land has a significant and positive effect on production. Secondly, in order to prove the viability of vertical farming in Israel, an in-depth SWOT and NPV analysis were conducted. The analysis showed that vertical farming is a financially viable venture and can be implemented effectively in Israel. We make several policy recommendations to the Israeli government, including: agricultural subsidy reform; freeing up of agricultural land in the south of Israel; investment in vertical farming research and development; utilizing abandoned buildings in the centre of Israel for vertical farming; and finally, that the Israeli government launch a pilot vertical farming project in the Negev.

Introduction

As drastic environmental changes and scarcity of resources are driving nations and economies inexorably towards a global crisis, many scientists, agriculturalists, economists and environmentalists have begun to propose sustainable technological alternatives to current economic systems. If the well-being of a modern society is to be sustained, governments need to transform their economies and invest in efficient and sustainable technological solutions. Governments need to "think green" and invest in technological solutions that can revolutionize their economies, converting "economic growth" into "economic sustainability". This paper will explore investment in vertical farming as such a solution for the agriculture industry in Israel.

Background and Significance

Thomas Robert Malthus predicted in 1798 that persistent population growth worldwide would lead the global economy into a premature catastrophe. (Malthus, 1999) According to Malthus, although technological developments had caused a significant increase in food production and general well-being, this increase in well-being would lead to increased population growth, eventually resulting in overpopulation and thus a decrease in welfare. (Galor & Weil, 2000; Malthus, 1999) However, history has proven that technological growth has exceeded population growth. (Galor & Weil, 2000). The catastrophe that Malthus predicted has failed to materialize.

However, in light of the modern environmental changes and increasing scarcity of resources, the "Malthusian Trap" has become relevant once more. The 21st century is expected to undergo unprecedented levels of climate change, putting serious pressure on the planet's resources, especially the global food supply (Al-Chalabi, 2015). Moreover, the global population is expected to reach 9 billion by 2050. (Al-Chalabi, 2015; Despommier, 2013; Kalantari, et al., 2018) Urban populations will be affected the most, as 80% of the world's population is predicted to live in urban areas. (Despommier, 2013; Islam & Siwar, 2012; Kalantari, et al., 2018) Particularly, strain will be felt in agricultural industries, as approximately 80% of the Earth's total arable land is already being utilized (Despommier, 2013; Kalantari, et al., 2018). Therefore, the agricultural industry will need to dramatically increase their yield per capita in order to match the increasing global demand for food. (Beacham et al., 2019; O'Sullivan et al., 2019)

Vertical farming has been proposed as a technological solution for the agricultural industry. (Al-Chalabi, 2015; Beacham et al., 2019; Kalantari et al., 2018; O'Sullivan et al., 2019) Vertical farming is an agricultural concept in which vegetables and crops are grown in vertical stacks, converting horizontal space into vertical space. (Beacham et al., 2019; Despommier, 2013). Vertical farms are built indoors, using LED lights and hydroponic technologies to create controlled environments for vegetable and crop production. (O'Sullivan et al., 2019; Beacham et al., 2019; Despommier, 2013) Such controlled environments are able to generate far higher yields than traditional farming methods. (O'Sullivan et al., 2019; Beacham et al., 2019; Despommier, 2013). In summary, vertical farming has the potential to bridge the gap between shortage of supply and increasing demand within the agricultural industry.

Literature Review

Galor & Weill (2000) offer a convincing paradigm with which to assess the need for persistent technological innovation in modern economies. Their work begins by considering the theoretical "Malthusian Trap". (Galor & Weill, 2000) Contrary to Malthus' prediction, modern growth trends have been characterized by increasing technological growth and decreasing population growth, which have resulted in an ever-increasing GDP per capita and social welfare. (Galor & Weill, 2000) Their work suggests that constant technological innovation is required to maintain GDP per capita and societal welfare in the future. Therefore, in the face of increasing global populations, aggressive technological innovation is needed in order to continue to increase societal welfare across the world.

The work of Emerick, De Janvry, Sadoulet, Dar (2016) further strengthens the argument for technological innovation in agricultural industries. According to their work, technological innovation can greatly increase land productivity and can eliminate the effects of environmental volatility on production. (Emerick, et al., 2016) Moreover, they contend that, "increased investment is an important channel through which improved agricultural technologies lead to substantial gains in productivity." Therefore, their works proves that investment in agricultural technologies can create a substantial increase in agricultural productivity.

The twenty-first century is projected to experience ever increasing environmental challenges on an unprecedented scale. (Hornbeck, 2012) Hornbeck's work contends that, in a time of environmental instability, agricultural producers need to adapt to maintain productivity. (Hornbeck, 2012) Moreover, technological innovation should not be solely used to mitigate environmental disadvantages, but should focus on using technology to capitalize on any advantages offered by the environment instead. (Hornbeck, 2012

Research Hypothesis

This paper aims to show how vertical farming can increase the agricultural productivity of a country by increasing total arable land. By farming vertically instead of horizontally, vertical farms allow for the exponential increase in farming surface area. In other words, 1 square meter of arable land can be converted into 5 square meters of arable land, or more. In this way, vertical farms will increase agricultural productivity.

We hypothesize that the total amount of arable land in a country will be significant to the total agricultural output of that country. We further hypothesize that irrigation will be a significant factor in agricultural output. We predict that total arable land will have the largest effect on agricultural output, followed by total irrigation. This will lead us to conclude that increasing total arable land and total irrigation is the most effective way to increase agricultural output in a country.

Research Methods

Our regression will analyze the effect of arable land and irrigation on agricultural output. In our analysis, we will use agricultural data from 187 countries in the world. The data will be taken from the year 2016, as this is the most recent year with sufficient available data for our purposes. The data has been sourced from the United States Department of Agriculture.

For the purposes of our analysis, we will use Ordinary Least Squares (OLS) regression analysis, which will be conducted using *Stata*. To begin our OLS regression analysis we will conduct a qualitative evaluation of the data. This will be followed by running our initial regression model (see below). After some initial results have been achieved, we will conduct regression diagnostics and significance tests for all variables. Finally, we will augment the regression model by testing several combinations of variables and regression transformations in order to find the optimal model.

Our initial regression model is outlined below:

output = β_0 + $\beta_1$cropland + $\beta_2$irrigation + $\beta_3$fertilizer + $\beta_4$machinery + $\beta_5$labor + $\beta_6$gmo + e

It should be noted that our model reflects the Cobb-Douglas production function:

$$Y = AL^{\alpha}K^{\beta}$$

where $\alpha+\beta = 1$

Therefore, we will use the Cobb-Douglas production function as the theoretical framework for our analysis.

The effect of arable land on agricultural production has been assessed using regression analysis in previous academic work (Rudra, 1968). The conclusion reached indicates that an increase in farming land has a positive impact on yield. Similarly, the effect of irrigation has also been studied using regression analysis (El-Mohsen et al., 2013). Likewise, the results indicated that irrigation increases agricultural production. These previous studies have given us the basis to include total arable land and total irrigation as variable in our regression analysis.

Definition of variables

Variable	**Explanation**	**Measure**
output	Gross agricultural production	Total agricultural production per country measured in $1,000
cropland	Arable land used for agriculture	Total arable land used for agriculture, measured in 1,000 hectares

irrigation	Arable land equipped with irrigation	Total arable land equipped with irrigation, measured in 1,000 hectares
fertilizer	Synthetic fertilizers used in agricultural production	Total N, P2O5, K20 used in agricultural production, measured in metric tonnes
machinery	40-CV tractor equivalents used in agricultural production	Farm machinery in 40-CV tractor equivalents, measured in single units
labor	Persons employed in the agriculture industry	Persons employed in agriculture, measured in 1,000 persons.
gmo	Ban on "genetically modified organisms" in each country	Dummy variable, measured either as 1 or 0

Control Variables

In order to reduce the error term *e*, we have included several control variables that could also affect agricultural output. We have decided to control for fertilizer, machinery, labor, and GMO bans. These variables have been defined above.

The effects of fertilizer on agriculture have long been documented. We chose to include fertilizer as a control variable as fertilizers have been shown to have a significantly positive effect on fruit and vegetable yield (Montagu & Goh, 1990). Furthermore, regression analysis studies evaluating the effect of fertilizer use on production have been conducted in previous years (Ricker-Gilbert & Jayne, 2012). Fertilizer was found to be a significant variable. Therefore, the fertilizer variable should be useful in our regression for the purpose of reducing the error term and should further prove to be a significant variable.

The variable machinery has been chosen as a proxy variable for capital. The amount of capital expenditure in agriculture will surely have an effect on production. However, in our research we were unable to find suitable data on capital expenditure. Therefore, we selected machinery as a proxy variable, as 40-CV tractors[1] are highly expensive pieces of equipment. Purchasing a new 40-CV tractor or its equivalent would require heavy capital expenditure. Thus, machinery is a suitable proxy variable for capital.

Labor has been included as a control variable in our analysis because of the Cobb-Douglas production function, in which labor is a key variable. Additionally, it is reasonable to assume that a strong labor force in the agriculture industry should increase production. This assumption has been studied using regression analysis (Mugera et al., 2011). The studies showed that increased labor productivity increased agricultural output. Labor as a control variable in our regression should prove to be a significant variable and thus decrease the error term.

The debate over genetically modified crops has become an increasingly relevant topic in the agriculture industry worldwide. Genetically modified crops offer myriad benefits to farmers, including higher productivity and higher quality products (Nielsen et al., 2020) Despite its clear agronomic benefits, the practice has been held under intense scrutiny and has garnered significant controversy (Nielsen et al., 2000). Several countries across the globe have banned the use of genetically modified crops. Therefore, we have decided to include gmo (genetically modified organisms) as a control variable in our analysis, as GMO's have become a major factor in world agriculture.

Descriptive Statistics

Variables	Observations	Mean	Std.Dev.	Min	Max
output	187	15,097,302.10	55,423,591.85	4,744.19	623,444,322.44
cropland	187	9,881.50	27,635.17	1.36	212,180.72
irrigation	187	1,855.48	7,625.25	0.00	70,400.00
fertilizer	187	1,046,312.90	4,430,759.00	15.49	47,771,600.00

[1] See appendix for 40-CV tractor image.

machinery	187	271,175.17	1,161,859.28	4.86	12,349,632.98
labor	187	5,278.49	22,705.19	2.00	217,575.00
gmo	187	0.20	0.40	0.00	1.00

Below is a summary of all variables

```
. summarize output cropland irrigation fertilizer machinery labor gmo
```

Variable	Obs	Mean	Std. Dev.	Min	Max
output	187	1.51e+07	5.54e+07	4744.19	6.23e+08
cropland	187	9881.498	27635.17	1.36	212180.7
irrigation	187	1855.484	7625.248	0	70400
fertilizer	187	1046313	4430759	15.49	4.78e+07
machinery	187	271175.2	1161859	4.86	1.23e+07
labor	187	5278.491	22705.19	2	217575
gmo	187	.197861	.3994562	0	1

(See Table 3 in Appendix for Correlation Table)

<u>Log transformation of Regression</u>

In order to transform the Cobb-Douglas production function into a linear equation, a log transformation is required. Therefore, the Cobb-Douglas equation will be transposed into:

$$Ln(Y) = ln(A) + \alpha ln(L) + \beta ln(K)$$

This transformation will be mirrored in our OLS regression model. We will take the natural log of all variables. After this transformation, our new model will look as follows:

$$ln(output) = \beta_0 + \beta_1 ln(cropland) + \beta_2 ln(irrigation) + \beta_3 ln(fertilizer) + \beta_4 ln(machinery) + \beta_5 ln(labor) + \beta_6 gmo + e$$

Once this transformation is completed we can begin our regression analysis in earnest.

Variable	Obs	Mean	Std. Dev.	Min	Max
ln_output	187	14.63703	2.086948	8.464676	20.25077
ln_cropland	187	7.23812	2.288403	.3074847	12.26519
ln_irrigat~n	179	4.90159	2.612035	-2.040221	11.16195
ln_fertili~r	187	11.02428	2.756544	2.740195	17.68194
ln_machinery	187	9.347554	3.046799	1.581038	16.32914
ln_labor	187	6.315644	2.262209	.6931472	12.2903
gmo	187	.197861	.3994562	0	1

Regression Results

Using the log transformation described above, we ran a preliminary OLS regression on *Stata* to test if the data satisfied the Gauss-Markov Theorem. The results from the regression are presented below.

```
. reg ln_output ln_cropland ln_irrigation ln_machinery ln_fertilizer ln_labor gmo
```

Source	SS	df	MS
Model	699.740906	6	116.623484
Residual	39.6682266	172	.230629224
Total	739.409132	178	4.15398389

Number of obs	=	179
F(6, 172)	=	505.68
Prob > F	=	0.0000
R-squared	=	0.9464
Adj R-squared	=	0.9445
Root MSE	=	.48024

ln_output	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln_cropland	.2924999	.0447561	6.54	0.000	.204158	.3808417
ln_irrigation	.0970366	.0253497	3.83	0.000	.047	.1470732
ln_machinery	.0714	.0242378	2.95	0.004	.0235581	.1192418
ln_fertilizer	.3054685	.0348068	8.78	0.000	.236765	.3741721
ln_labor	.1015886	.0319179	3.18	0.002	.0385873	.1645899
gmo	-.0523822	.0953514	-0.55	0.583	-.2405917	.1358274
_cons	7.397485	.1832196	40.37	0.000	7.035836	7.759133

As can be seen above, all variables are highly significant and have positive a co-efficient, except for gmo. Our regression includes 179 observations, and the F-test score for the regression is very high at 505.68. Similarly, the R-squared stands at 0.9464, indicating that a high proportion of the variance in the dependent variable is explained by the independent variables.

The results of the regression confirm our hypothesis that cropland and irrigation are significant factors in agricultural production, and that an increase in both will increase production. From the table above we can see that a 1% increase in total cropland will increase agricultural production by 0.29%. Similarly, a 1% increase in total land irrigated will increase agricultural production by 0.097%.

Fertilizer proved to be more substantial than expected, with a coefficient of 0.305. This indicates that a 1% increase in total fertilizer used will increase agricultural production by 0.3%. This proves to have a nominally more significant impact than total arable land. From this result, we can conclude that fertilizer is as important as arable land and even more important than irrigation.

The insignificance of gmo indicates that a ban on genetically modified crops does not prove to be a substantial factor affecting output. This result was to be expected, as GMO's are a new phenomenon in global agriculture, and only a select few countries have the technology available to implement such growing methods.

Discussion of Regression Results

Our regression analysis has confirmed our research hypothesis. Total arable land and total land irrigated are both significant and positive contributing factors in agricultural production. Fertilizer also proves to be a hugely significant variable. Therefore, increasing total arable land, total land irrigated, and total fertilizer used are the most effective ways of increasing agricultural production in a country. More specifically for Israel, a 1% increase in total arable land will increase the value of agricultural production by approximately $8,413. Increasing total land irrigated by 1% increases the value of agricultural production by approximately $2,814. Finally, a 1% increase in total fertilizer used will increase the value of agricultural production by approximately $8,703.

Description of a Vertical Farm

For the purpose of this paper we will create a theoretical design for a vertical farm.

The structure of our vertical farm is like that of any other building with multiple stories. However, the outside of the vertical farm building is fitted with an array of solar panels across the length and width of the building. Each floor on the inside of the vertical farm acts as a controlled environment grow-room. Each grow-room consists of six layers of hydroponic basins fitted on top of each other[2]. Each layer has a set of LED lights facing downward onto the fruits & vegetables growing in the basin. Nutrient rich water is pumped through these basins and the LED lights shine twenty-four hours a day. On the top floor of the building, there is a water tank which pumps the water throughout the building. (See appendix for illustration of Vertical Farm).

Our theoretical vertical farm can be built to match any specifications required. For the sake of this paper, we will assume the vertical farm is twelve stories high, that each floor contains 100 square meters, and that the plot of land on which the vertical farm is built will be 140 square meters.

SWOT analysis

Strengths:

- Vertical farming removes all dependency on weather conditions. Crop yields are not affected by changing weather conditions (Chirantan Banerjee at al., 2013).
- Vertical farming converts horizontal land into vertical land, thus increasing total surface area for farming dramatically.
- Vertical farming implements controlled environment indoor farming which significantly increases output per square meter: the yield of 1 indoor acre of land is equal to 6 outdoor acres of land. These figures can increase when different fruits & vegetables are grown. For example, 1 indoor acre used for the growing of strawberries is equivalent to 30 outdoor acres (Chirantan Banerjee at al., 2013).
- Vertical farming can be a source of relief in poverty-stricken areas, areas prone to natural disasters, or regions plagued by famine and drought. Vertical farming can serve as a stable source of food for these areas.
- Vertical farming does not require pesticides. Produce is grown in controlled environments with sterile laboratory conditions. The food produced is much healthier

[2] See Appendix for illustrations

and more organic. Furthermore, this will reduce the cost of farming, as pesticides are highly expensive.

- Vertical farming will greatly alleviate the demand for fossil fuels that regular farming techniques generate.
- Vertical farming can be built in urban areas, thus reducing transportation costs. This will help to drive down the price of food. Additionally, a reduction in transport means a reduction in CO_2 emissions.
- Vertical farming does not require deforestation or the destruction of natural land.
- Vertical farms are highly aesthetic and pleasing to the eye. These buildings will increase the greenery in urban areas and will have a positive psychological effect on urban residents.

Weaknesses:

- Vertical farms require huge capital costs for construction of the building and purchasing of growing systems: pumps, LED lights, and solar panels.
- Vertical farms rely upon constant energy supply to power the LED lighting systems and water pumps. Without a sustainable source of energy, operational costs may prove to be too high.
- LED lights have to be replaced every three years at significant cost.
- Lack of research in the field of vertical farming leaves many questions still unanswered.

Opportunities:

- With increasing populations worldwide and decreasing land supply globally, vertical farming offers an effective solution for increasing agricultural output for the same amount of land.
- Vertical farming allows for the growth of any form of fruits & vegetables in regions lacking the correct climate, terrain or weather conditions. With vertical farming, agricultural production will no longer be dependent on geography.
- With vertical farming, countries that were once highly dependent on other countries for their food supply can now become food independent.

Threats:

- Current stakeholders in the agriculture industry across different countries might be opposed to such a drastic shift in their industry. They may view vertical farming as a threat to their businesses.
- New technologies may arise in the coming years that render vertical farming irrelevant. As of yet, there is no indication of these technologies being developed.

NPV Analysis

In order to evaluate the economic feasibility of vertical farming we will conduct both an NPV and IRR analysis of the venture. This will allow us to assess the financial viability of vertical farming. In our detailed analysis, we will estimate both the capital cost required to build a vertical farm and the potential returns over a five-year period. This will allow us to evaluate whether or not vertical farming will benefit Israel's economy in addition to its sustainability benefits. A vertical farming venture that is financially viable and potentially profitable will attract investment from both the private and public sectors.

Our analysis will be divided into three sections: Capital Costs; Operational Costs; and Projected Revenues.

Capital Costs

We will begin by estimating the capital costs required to build a vertical farm in Israel. The capital costs required for building a vertical farm can be split up into the following categories:

- Property
- Construction
- Solar Panels
- Seeds

- LED Lighting
- Hydroponic Systems
- Labor*

(See Table 4 in Appendix)

Property

The vertical farm will be built upon a 140 square meter plot of land. The land will be purchased at $140 dollars per square meter. For the sake of our analysis we have used market prices from Be’er Sheva.

Construction

The vertical farm will consist of 12 floors, each floor containing 100 square meters. The cost of constructing each floor will be $8,500. Estimated time of construction will be one year. For the sake of our analysis we will assume no further external construction costs.

Solar Panels

Solar Panels will be fitted on the outside of the building on each floor. This will allow for maximum exposure to sunlight and enable the vertical farm to power itself and to become fully self-sustainable. The price per floor will be $16,800

Seeds

High quality, germinated seeds for planting produce will be purchased at the beginning of each year. This will constitute the only cost of goods sold. Seeds will be purchased for all varieties of fruits & vegetables produced. Estimated cost of purchasing seeds per year will be $20,000.

LED Lighting

Each floor in the vertical farm will contain "growing stacks" for produce that will have LED lights installed on top. The LED lights will be in use twenty-four hours a day, seven days a week. The lights will have to be replaced every three years. The cost of LED lights per floor will be $24,000.

Hydroponic Systems

As already mentioned, each floor in the vertical farm will be fitted with "growing stacks" that will grow the produce using advanced hydroponic systems. These systems will require piping, nutrients, flood trays and pumps. The total cost for installing all hydroponic systems throughout the building will be $173,500. Each year new nutrients will have to be bought and pipes will have to be replaced, at a cost of $150,000.

Labor

For the sake of our analysis we will assume all labor costs are paid upfront and all employees are paid minimum wage. The vertical farm will require three full-time employees. Employees will work eight hours a day.

Operational Costs

The vertical farm is a self-sustaining, self-powered building that requires minimum human input. The solar panels fitted across the length of the building provide the energy needed to power the farm; while the hydroponic systems recycle all water, and grows the produce 24/7. Indeed, one of the greatest benefits to a vertical farm is its self-sustaining nature, made possible by efficient technologies. However, these technologies do require maintenance. Below is a summary of the Operational Costs entailed in a vertical farm.

LED Lighting Maintenance

The LED Lighting systems have a lifespan of three years. Therefore, every three years the panels will have to be replaced. The cost of purchasing new panels has been included in the NPV analysis and has been deducted from the projected cash flows.

Hydroponic Systems Maintenance

Each year the hydroponic systems will have to be cleaned, repaired and sometimes replaced. The cost of maintenance and re-purchasing all hydroponic systems has been included in the NPV analysis and has been deducted from the projected cash flows

Seeds

The controlled environment farming method employed in the vertical farm generates far higher yields than traditional farming methods. Therefore, instead of harvesting produce once or twice a year, the vertical farm will harvest it's produce multiple times a year (depending on the crop). Therefore, seeds for replanting produce will have to be purchased regularly. For the sake of our analysis, the cost of seeds is calculated per year and is deducted from the projected cash flows.

Labor

As mentioned above, three employees will be hired for the operation of the vertical farm and will be paid minimum wage.

Projected Revenues

The vertical farm will produce a variety of fruits & vegetables, each with varying yields and market values. The fruits & vegetables produced in the vertical farm are as follows. (See Appendix for full table).

- Carrots
- Radish
- Potatoes
- Tomatoes
- Peppers
- Strawberries
- Peas

- Cabbage
- Lettuce
- Spinach

The vertical farm will produce 930 tonnes of produce per year[3]. The total value of production each year will be approximately $4,085,000.[4]

Results and Conclusion of NPV Analysis

Our analysis shows that the vertical farm has an NPV of approximately $5,850,000 and an IRR of 15%. This proves that vertical farming is a financially profitable venture that would appeal to both the private and public sector. With enough capital investment, vertical farms can be built across Israel and can generate added value to the economy.

The main contributing factor to the profitability of the vertical farm is the amount of sunlight available in Israel. The ability of the solar panels to generate enough energy to power all the LED lighting in the Vertical Farm hugely decreases the operational costs. Other vertical farming ventures around the world have failed due to the huge electricity costs involved in LED lighting. Israel's geographic location and exposure to sunlight offers a unique advantage. Without enough solar power, the profitability of vertical farming would be significantly reduced. However, in Israel the venture becomes profitable and viable. (See appendix for full NPV analysis).

Status of Agriculture in Israel

Israel is a small country with extremely limited land resources and every increasing population. As of 2020, only 19% of total land in Israel is used for agriculture. Of that agricultural land, only 90% is actually utilized for production. One of the reasons postulated for this is that not all of the land is used in order to maintain profitability. If all agricultural land were to be used, profits for local farmers would begin to decrease.

[3] See Table 1 in Appendix
[4] See Table 2 in Appendix

Furthermore, there is an ongoing debate within Israel regarding the use of land. Many people believe that agricultural land should be maintained at all costs, while others contend that the expansion and establishment of cities is paramount. Regardless, it seems to be the policy of the Israeli government to gradually close agricultural land in the coming years.

In order to mitigate the closure of agricultural land, the government has begun to free up land in the desert regions in the south of the country. However, the cost of pumping water into these desert regions is incredibly high and poses a significant obstacle to any farming ventures in the reason. Vertical farming on the other hand eliminates this obstacle entirely. Vertical farms recycle up to 99% of water used. Therefore, no water would have to be pumped into the desert region from afar. The significant sunlight available in the desert region will allow the vertical farms to power themselves using solar panels, and the lack of water resources would prove to be a non-issue. In terms of finding an effective, viable and pragmatic solution to farming in the Negev, vertical farming offers the perfect solution.

Desert Region

Israel is located in a desert region which poses a series of challenges to agriculture. However, as discussed by Hornebck (2012), farmers should always look to leverage environmental factors to their advantage despite how discouraging these factors may seem. What a desert region lacks in water it makes up for in sunlight. Therefore, Israel should implement agricultural technologies that use very little water and are powered by solar energy.

Although Israel today is a water-safe country, it is still very costly to pump water into desert regions. Consequently, if Israel were to establish farms in the Negev area it would have to implement farming techniques that do not need water to be pumped from afar. Vertical farming is such a farming technique, as 99% of water is recycled. Thus, water would have to be pumped or transported only once to the farm. This would almost entirely eliminate the obstacle to farming in a desert region.

Furthermore, and perhaps most critically, Israel is able to utilize its abundance of sunlight to reduce electricity costs and power its farms. Notably, many of the failed vertical farming ventures around the globe in recent years have failed due to exorbitant operational costs. The amount of electricity needed to power LED lights on an industrial level is extremely high. If these costs can be reduced, there is seemingly nothing stopping the success of a vertical farming venture.

As already mentioned, Israel is exposed to an abundance of sunlight, approximately 3,300 sunlight hours per year. For the purpose of comparison, Sweden is only exposed to approximately 1,800 sunlight hours per year. Despite this lack of sunlight, Sweden has still launched several vertical farming ventures. This wealth of sunlight enjoyed by Israel offers a huge comparative advantage for vertical farming. The operational costs for vertical farming in Israel will be drastically smaller than most countries in the world where vertical farming has already been implemented.

In summary, Israel's desert landscape offers a unique opportunity for vertical farming. The profusion of sunlight will allow Israel to power its vertical farms with solar panels, while most of the water used will be recycled and won't have to be pumped excessive distances at high cost. Israel should leverage its environment to its advantage and make the desert bloom once again.

Food Supply in Israel

Imports Dependency Ratio (IDR):

The IDR is a model which can be used to explain the level of dependency that a country has on imported foods.

The IDR is calculated as follows:

$$IDR = \{Imports/ [Exports- (Imports + Production)]\} *100$$

If the IDR is greater than 100% then the country is entirely dependent on imports, and produces zero products domestically. This would prove to be a very precarious position for a country's food supply. In order to achieve food security, a country should try to reduce its IDR.

In Israel, as of 2017, the IDR for fruits and vegetables stood at 45%. (Tal, et al., 2019). This figure is relatively high and shows Israel's dependency on foreign imports for fruits & vegetables. In order to increase Israel's food security and reduce its dependency on foreign imports, Israel needs to produce more fruits & vegetables domestically. Vertical farming will enable Israel to do so.

Current State of Affairs

Agricultural subsidies provided by the Israeli government today are provided solely to farms that have suffered extreme weather damage or natural disasters. Additionally, these subsidies are water based, meaning the farms are provided with discounts on water. The total subsidies provided per year amount to approximately NIS 1 billion. In contrast, the USA spends roughly $20 billion in direct subsidies to farmers each year. Similarly, EU farmers receive approximately €40 billion per year.

Furthermore, the policy of the Israeli government is not focused on turning Israel into a food secure nation. Israel is a small country that lacks land resources. Since no comparative advantage can be achieved in agriculture, the government has pivoted its focus towards other industries in which Israel can achieve superiority. The age of kibbutz agriculture building the Israeli economy is certainly over.

Policy Recommendations

1. The Israeli government should expand its agricultural subsidy policy with a focus on developing vertical farms in the south of Israel. Direct cash subsidies should be provided to private vertical farming ventures in order to reduce the capital costs involved in building vertical farms. A reduction in capital costs will incentivize the private sector to invest in vertical farming.
2. The Israeli government should further invest in vertical farming research and development. This research will go a long way to improving vertical farming technologies in two ways: firstly, by improving the efficiency of such technologies; secondly, by decreasing the cost of such technologies. Higher productivity and reduced costs will allow the private sector to engage in vertical farming at a competitive level.

3. The Israeli government should free up more land in the south for the use of vertical farming. As of today, swathes of desert land are left unutilized. If the government allows for the building of vertical farms in these areas, there will be a boost in agricultural production and value added into the economy.
4. The government should not abandon the agricultural industry, and should refocus on establishing Israel as an agricultural powerhouse. Israel's lack of land does not mean it cannot achieve a comparative advantage in agriculture. With vertical farming technology, anything is possible. Furthermore, a boost in locally produced agriculture will greatly reduce food costs for everyday Israelis.
5. The Ministry of Agricultural and Ministry of Economy and Industry should jointly fund the building of a pilot vertical farming project in the Negev. This pilot project will allow the government to determine whether or not vertical farming is a viable, self-sustaining, energy-efficient solution. If the pilot project is a success, both the public and private sectors can begin investing heavily in building vertical farms throughout Israel.
6. The Israeli government should auction off abandoned buildings in the center of Israel. These abandoned buildings can be easily transformed into vertical farms. The fruits & vegetables produced in these farms can be sold directly to nearby grocers, thus significantly reducing transportation costs. This process will greatly contribute to the development of food security in Israel; and will also increase property value in rundown urban areas.

Conclusion

This paper has shown that vertical farming is an effective solution to food sustainability in the face of increased population growth in Israel. Moreover, this paper has illustrated how vertical farming can be implemented successfully. Technological innovation has always proven to be the way forward for civilization, and vertical farming is the next technological step in world agriculture. Vertical farming is both sustainable and effective, and can be successfully applied in the years to come. Israel should implement vertical farming as soon as possible in order to achieve food sustainability and revitalize its agricultural industry.

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Appendix

Table 1

Product	Production in Tonnes
Carrots	**74.57**
Radish	**29.57**
Potatoes	**192.84**
Tomatoes	**199.27**
Pepper	**170.99**
Strawberries	**88.71**
Peas	**11.57**
Cabbage	**86.14**
Lettuce	**47.57**
Spinach	**28.28**
Total	**929.5**

Table - Crops produced, type and quantity

Table 2

NPV/IRR Analysis						
Years	0	1	2	3	4	5
Cash Flows	$ (13,000,000.00)	$ 3,914,657.54	$ 3,914,657.54	$ 3,456,657.54	$ 3,914,657.54	$ 3,914,657.54
					NPV	$5,849,805.73
					IRR	15%

Table 2 – NPV and IRR Analysis

Table 3

```
. corr cropland irrigation fertilizer machinery labor gmo
(obs=187)

             | cropland irriga~n fertil~r machin~y    labor      gmo
-------------+------------------------------------------------------
    cropland |   1.0000
  irrigation |   0.7461   1.0000
  fertilizer |   0.7463   0.9157   1.0000
   machinery |   0.6710   0.9364   0.9512   1.0000
       labor |   0.5985   0.9234   0.8438   0.8866   1.0000
         gmo |  -0.0321  -0.0598  -0.0514  -0.0088  -0.0828   1.0000
```

```
. corr ln_cropland ln_irrigation ln_fertilizer ln_machinery ln_labor gmo
(obs=179)

             | ln_cro~d ln_irr~n ln_fer~r ln_mac~y ln_labor      gmo
-------------+------------------------------------------------------
 ln_cropland |   1.0000
ln_irrigat~n |   0.7582   1.0000
ln_fertili~r |   0.8665   0.7878   1.0000
ln_machinery |   0.6926   0.7231   0.8238   1.0000
    ln_labor |   0.8048   0.6500   0.6229   0.3820   1.0000
         gmo |   0.0729   0.0736   0.1755   0.2627  -0.0832   1.0000
```

Table 3 – Correlation Table

Table 4

Expenses	Cost in Dollars		
Property			
Purchasing Land	$ 10,200,000.00		
Construction	$ 1,680,000.00		
	Total Cost		$ 11,880,000.00
Solar Panels			
Purchase & Installation	$ 201,600.00		
	Total Cost		$ 201,600.00
Seeds			
Purchasing Seeds	$ 20,000.00		
	Total Costs		$ 20,000.00
LED Lighting			
Purchase & Installation	$ 288,000.00		
	Total Costs		$ 288,000.00
Hydroponic Systems			
Nutrients	$ 150,000.00		
Flood Trays	$ 4,300.00		
Pumps	$ 19,200.00		
	Total Costs		$ 173,500.00
Labor			
Wages	$ 266,500.00		
	Total Cost		$ 266,500.00
Total Capital Cost	**$ 12,829,600.00**		

Table 4 – Capital Costs

Table 5

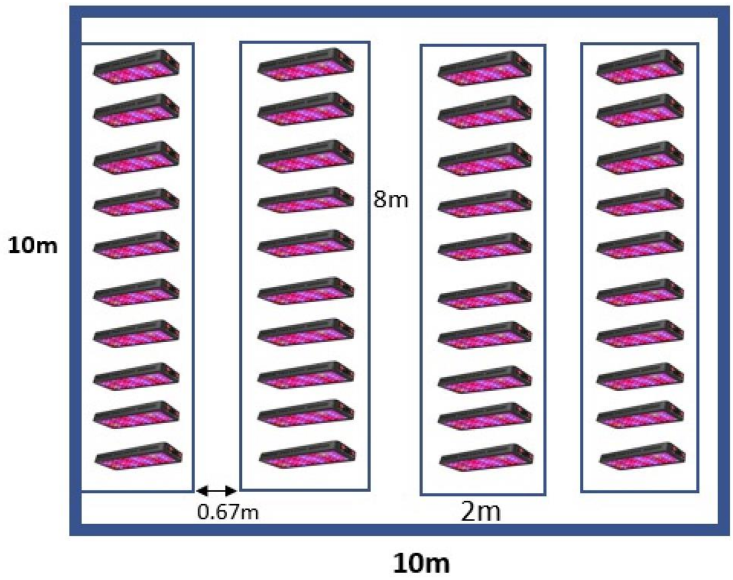

Table 5 – Illustration of grow system, per floor

Table 6

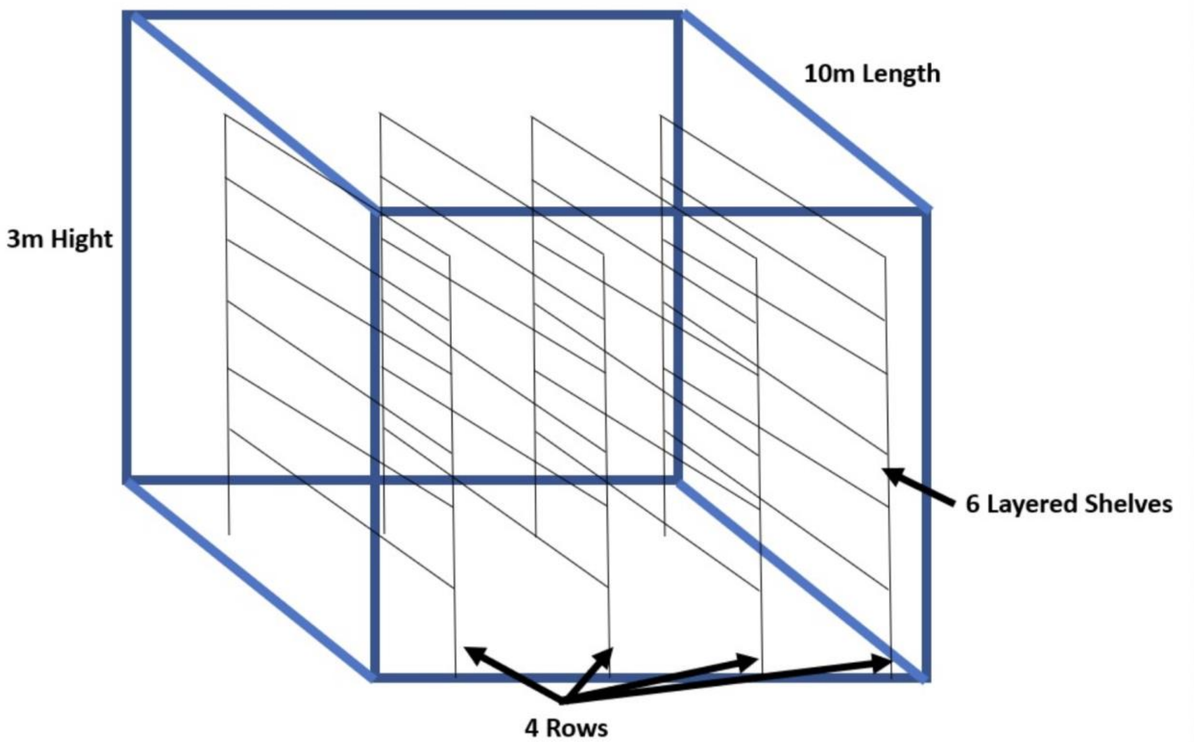

Table 6 – Illustration of each floor in vertical farm