Where Will Food Come From? A Look at the Potential of Vertical Farming in Norway

Aidan Sliwkowski[a*] and Jefferson K. Rajah[a]

[a] System Dynamics Group, Department of Geography, University of Bergen P. O. Box 7802, 5020 Bergen, Norway

[*] Correspondence: aidan.sliwkowski@student.uib.no

Abstract

The world's population continues to grow and its food demand along with it. Population growth is occurring particularly in urban areas where there is less available farm space. In response, governments and private leaders are looking for new agricultural advancements to feed this growing population, especially when it comes to providing fruit and vegetables. One such technology that is increasingly being highlighted is vertical farming. This paper looks to understand how vertical farming can be implemented in one country, Norway, and will try to answer the question: *As Norway's urban population grows, can vertical farming meet the growing demand for plant produce while reducing the need for imports?* The System Dynamics (SD) methodology was chosen as this problem is complex and occurring over time. It is used to help explain and explore the possibilities of a country's investment in vertical farming. Norway is a suitable candidate due to its willingness to become more self-sufficient and the capability of investing in this new technology. Based on the findings of this model, it is evident that vertical farming can make an immediate impact in increasing the amount of produce from domestic production. However, it is heavily reliant on government investments and will require more drastic measures to sustain a population whose consumption habits are continuously climbing.

Keywords: *agri-food system; vertical farming; system dynamics; simulation model*

Problem Identification

The world's population is estimated to surpass 10 billion people with 68 percent of the global population expected to live in urban areas by 2050 (United Nations, 2018; United Nations, 2022). These population changes indicate that there is a need for new sources of food production. One such technology is vertical farming.

Vertical farming is where food is grown vertically and nutrients are supplied through hydroponics, aeroponics or aquaponics (Cho, 2011; Zipkin, 2022). A basic requirement for vertical farms is that they are located near population centers with access to major transportation hubs (Zipkin, 2022). This makes them well-suited to provide fresh produce directly to growing urban populations. These types of farms are also resistant to changes in weather and environmental factors such as pests and disease that traditional farming is susceptible to.

This paper will focus on the growth in vertical farming in Norway. Norway is a country that has both the capital and willingness to invest more in vertical farming (Gustavsen et al., 2021). Norway is also a country that has both a growing demand for plant produce, which for this model includes both fruits and vegetables, and is experiencing a decrease in self-sufficiency from its own production (Ministry of Agriculture and Food, 2015; Opplysningskontoret, 2022; Statista, 2022). This is occurring as Norway's urban populations are on the rise (World Bank, 2018). As such, the dynamic problem arises:

> *As Norway's urban population grows, can vertical farming meet the growing demand for plant produce while reducing the need for imports?*

This is an important problem for the Norwegian government as the increase of locally grown produce improves the nation's food resilience and meets its population's food demands.

They key reference modes that will be used include total vertical farms, plant produce imported to Norway, and plant produce from Norway all within the years 2013 to 2032. As seen in Figure 1.1, it is desired and expected that vertical farms in Norway increase increasingly to meet the goal of increasing domestic production of plant produce. While there is no sufficient data indicating the number of vertical farms in Norway, the growth rate of the global vertical farm market is expected to be 24.7 percent per year between 2023 and 2028 (Research and Markets, 2023). The European market is also seeing rapid demand for vertical farms which is expected to be reflected in the Norwegian market (Butturini & Marcelis, 2021).

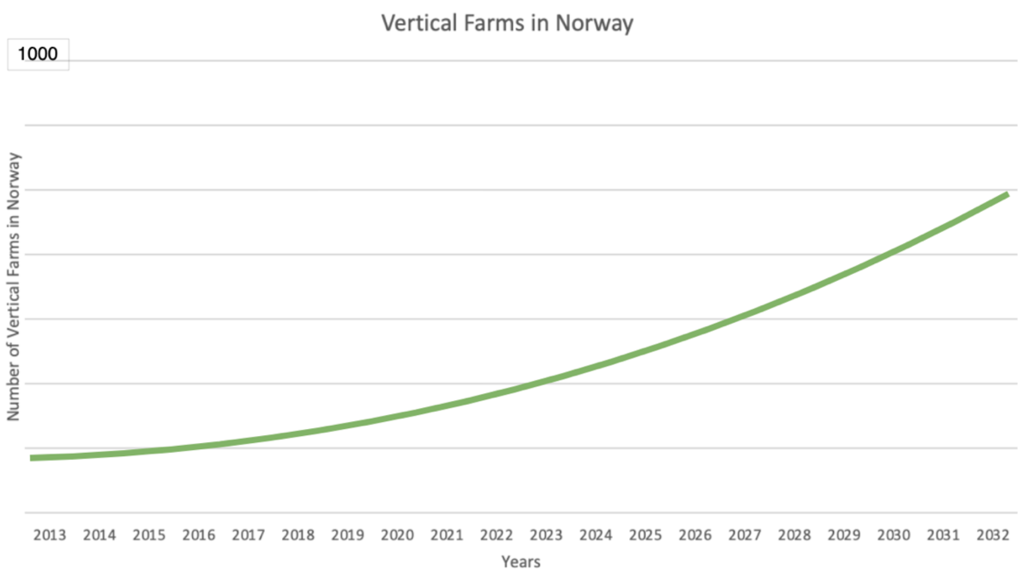

Figure 1.1: Reference Mode for Vertical Farms in Norway

Figure 1.2 shows that historically plant produce imports has been increasing increasingly and that domestic plant produce production has declined in a decreasingly decreasing manner since 1961 (FAO, 2023). The historic data in these figures has been provided by the Food and Agriculture Organization of the United Nations (FAO), but the trends are perceptions I made based on the data. The FAO made changes in their methodology to measure data in 2010, but the overall trends remain consistent. These trends are expected to continue as Norway has been less self-sufficient.

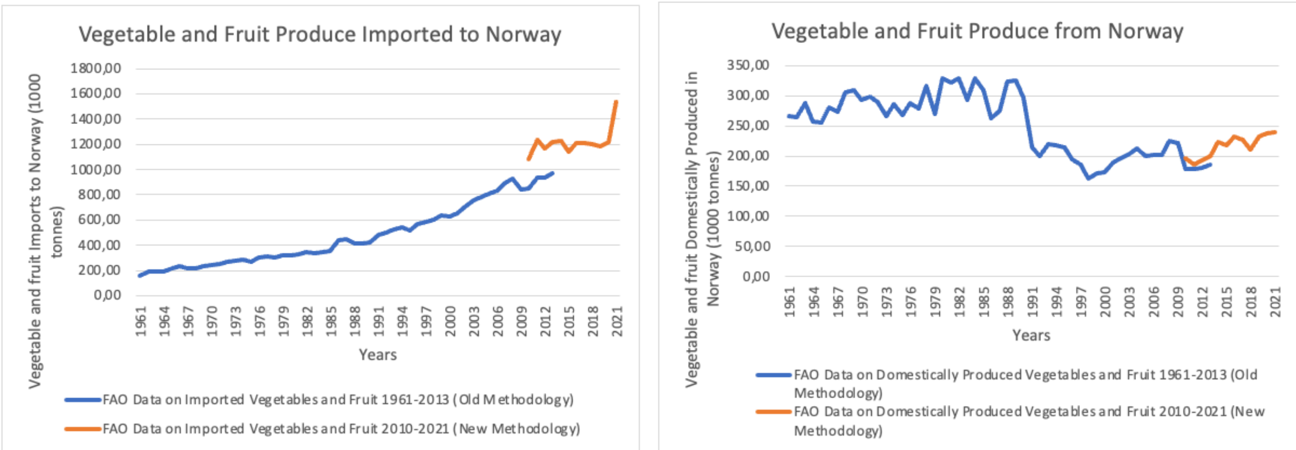

Figure 1.2: Vegetable and Fruit Production Imported vs Vegetable and Fruit Produce from Norway

In Figures 1.3, the red lines indicate the anticipated outlook of plant produce imports and domestic production respectively with the green lines are desired changes. It is desired that the total tons of imported plant produce will decrease increasingly, and the desired tons of plant produce will increase increasingly. This will showcase the desired effect of vertical farming as an effective means of reducing imported produce.

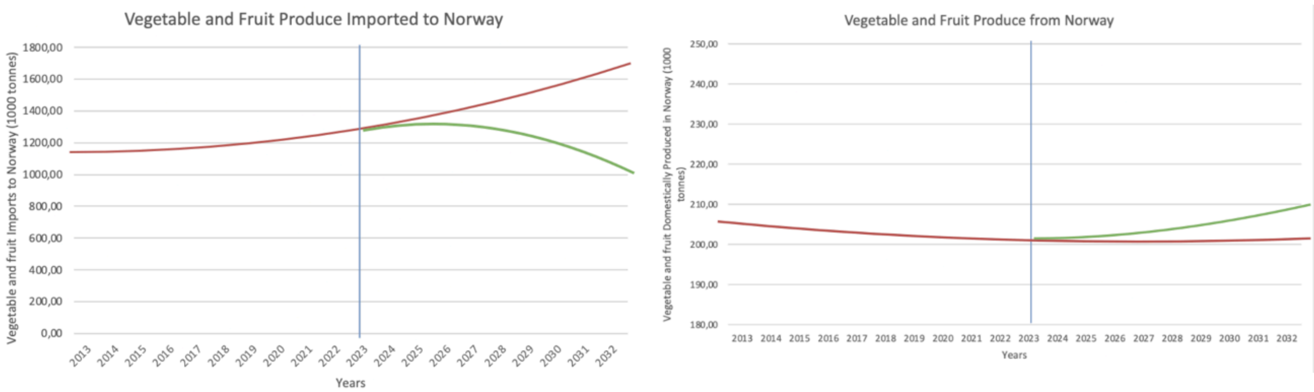

Figure 1.3: Model Reference Mode for Imports and Domestic Production

Dynamic Hypothesis

The following Hybrid Stock Flow Diagram (HSFD) is a simplified version of my model highlighting the **important** feedback loops that can be used to explain my model. It was built using information from academic literature with two sources proving especially beneficial. Song et al. (2021) use a System Dynamics approach when looking at vertical farming implementation in Singapore. Meanwhile, Rajah and Grimeland (2022) help to provide insight on the structure of agricultural models, particularly when it comes to measuring food demand.

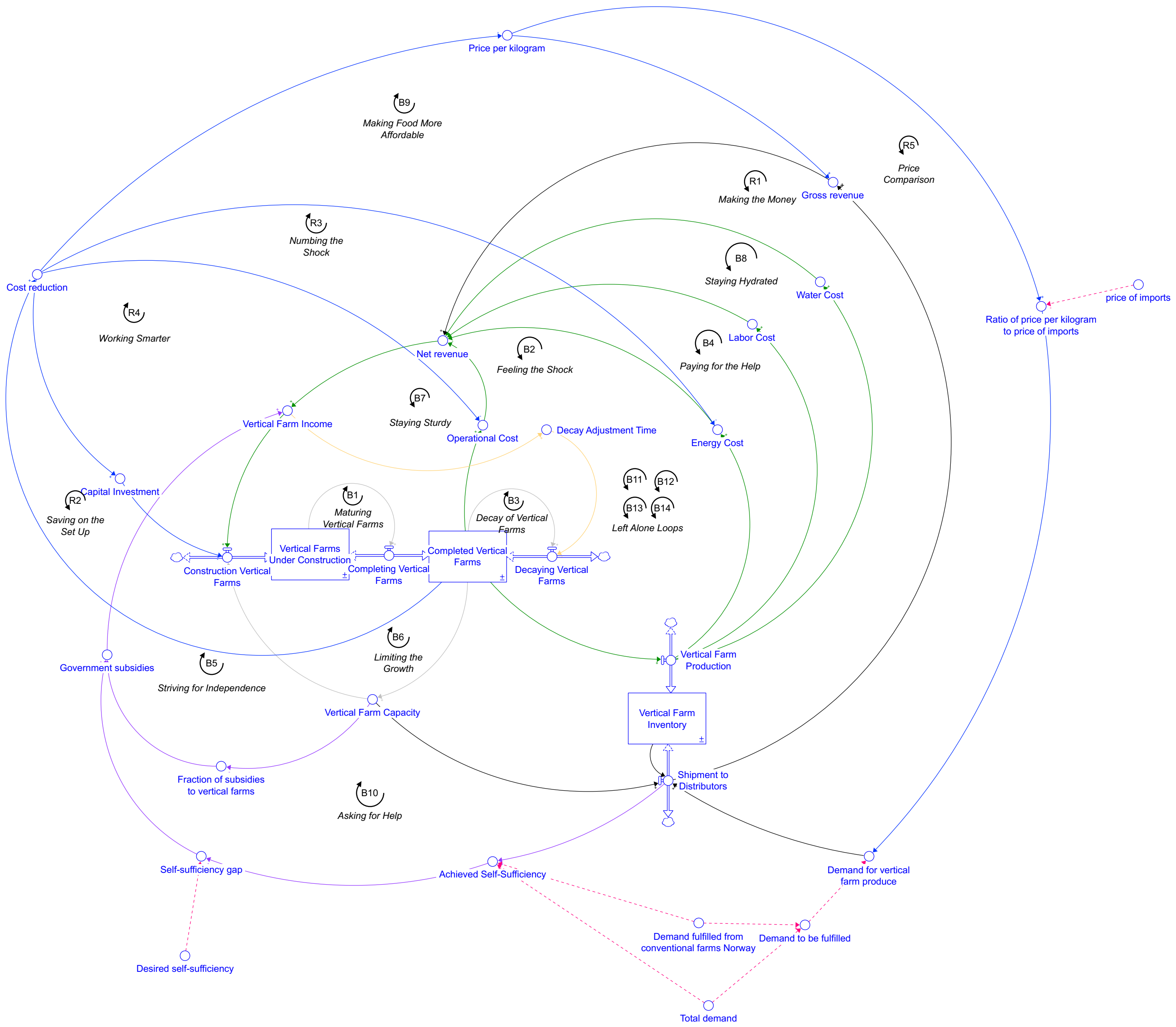

Figure 2.1: Hybrid Stock Flow Diagram of Vertical Farming in Norway

<u>The Cost Loops</u>

The first series of loops will be described together as they indicate similar impacts on the model. These are balancing loops which include the following: *Feeling the Shock (B2), Paying for the Help (B4), Staying Sturdy (B7), and Staying Hydrated (B8)*. *B7* showcases the operational cost loop so that as there are more vertical farms, the total costs of maintaining operating vertical farms increases, lowering the amount of vertical farm income. In *B8,* as the number of vertical farms increase, more water is required per kilogram of produce which lowers the vertical farm income. The same could be said with *B2* and *B4*. However, these loops indicate the costs of electricity and labor respectively.

These loops are the main costs of vertical farming as identified throughout the literature and business insights (Avgoustaki & Xydis, 2020a; Avgoustaki & Xydis, 2020b; Banerjee & Adenaeuer, 2014; iFarm, 2023; Kobayashi et al., 2022; Song et al., 2021; Pereira, 2023; Zipkin, 2022). A few sources have proven especially helpful in model construction. Avgoustaki & Xydis (2020a) provide the typical cost structure of a vertical farm in Denmark based on plant produce output. This provides helpful insight for the structure of the model considering that Denmark is a neighboring country that is experiencing a growing demand for plant produce and desire to limit vegetable and fruit imports. Kobayashi et al. (2022) have produced a similar study to portray the energy costs of vertical farming in Sweden.

Unlike other types of farming, it is believed that vertical farming will not be impacted by needs related to soil nutrients or expenses related to pests and pathogens (Avgoustaki & Xydis, 2020b; Roberts et al., 2020). Roberts et al. (2020) identify that vertical farms can still be impacted by pests and pathogens but acknowledge that there is not enough scientific investigation into this matter and that vertical farming already minimizes the impacts of these threats. As such, the model does not incorporate these costs.

Income Loop

Vertical farming generates gross revenue seen in the reinforcing loop *Making Money (R1). R1* showcases the revenue from sales of produce in Norway as determined by the amount of produce shipped to distributors and how close to capacity vertical farms are. Capacity in this instance is an indicator of how much of the unfulfilled demand can be met by vertical farming. With a higher capacity, distributors will look to meet more of the demand from vertical farms. This, in combination with the costs, feeds into net revenue which can then be used to reinvest into constructing more vertical farms. The amount a vertical farm will generate will vary depending on the actual product, but an average price is introduced in my model based on the average costs (Coyle & Ellison, 2017).

Government Subsidies Loops

The next category of feedback loops in the model can be identified as the government subsidy loops. This includes the balancing loop *Striving for Independence (B5*) and *Asking for Help (B10)*. These loops showcase how the increase in vertical farms impact on Norway's plant produce self-sufficiency. In other words, Norway's ability to meet the plant produce demands of its citizens. B10 shows that as the number of new vertical farms increases, the vertical farm capacity increases driving shipments to distributors, and Norway's self-sufficiency increases as a result. As self-sufficiency increases, the need for government subsidies decreases, reducing the construction of new vertical farms. Meanwhile, B5 shows a similar story but from the perspective of vertical farm capacity directly. As vertical farm capacity is increased, there is decrease in the fraction of total agricultural subsidies put towards vertical farming as there is a shrinking need for government subsidies as the industry becomes established.

Plant produce self-sufficiency is a growing concern for Norway which has seen a decline in its self-sufficiency (Ministry of Agriculture and Food, 2015). Vertical farms have been a response for many countries looking to new technologies to supplement food demand (Benke & Tomkins, 2017; Song et al., 2021). In the context of Norway, it is unique in that there is already research looking into the willingness of its citizens to pay for new commercial vertical farms (Gustavsen et al., 2022). This indicates that there is public support for the government to help subsidize vertical farming to meet the food demands for fruits and vegetables in Norway.

Economies of Scale Loops

These loops have been identified through the theory of economies of scale. Silberston (1972) provides academic support for this theory in that as an industry increases in scale, it can reduce costs through specialization and the ability to better control input costs of production. This model reflects that in loops *Saving on the Set Up (R2), Numbing the Shock (R3),* and *Working Smarter (R4).* As the vertical farm industry increases in scale, they can bring costs down to operations, upfront capital costs, and energy costs. By lowering costs, price of food can be lowered, increasing revenue as seen in the loop *Making Food More Affordable (B9).* As prices are lowered, produce from vertical farms become more attractive as seen in the loop *Price Comparison (R5).* As price per kilogram becomes closer to the price of imports, or as the ratio of the two decreases, there is an increased demand for vertical farm produce. This drives revenue, more farms, and more cost reduction due to scaling. This increases the amount of net revenue available to reinvest in vertical farm construction.

Labor costs and water costs were determined to not decrease as these prices are set outside of the actual production process and these vertical farms are already running close to maximum efficacy. Vertical farms recycle close to 100 percent of the water it uses and the technology already makes harvesting very efficient (Avgoustakis & Xydis, 2020b).

Self-regulation Loops

Balancing loops *Maturing Vertical Farms (B1), Decay of Vertical Farms (B3),* and *Limiting the Growth (B6)* showcase how vertical farm production self regulates. *B1* shows more vertical farms under construction, more farms are being completed which decreases the number of vertical farms under construction. *B3* shows that as there are more completed vertical farms, there are more farms that will decay leaving fewer vertical farms. Both loops also indicate a time delay which limits the speed of these processes. Lastly, *B6* shows as the number of vertical farms reach capacity, there are fewer new farms beginning the construction process, leaving the number of completed vertical farms less than it would be otherwise and the capacity reduced. These loops provide important balancing functions in this model.

Scenario Loops

These loops are categorized as one, the balancing *Left Alone Loops (B11, B12, B13, B14).* These loops only occur when vertical farm income goes negative. A scenario in which this occurs will be further explained in the Policy Analysis section of this paper. In short, this scenario indicates that when vertical farm income goes negative because of an end to government subsidies, these loops will turn on. The regular costs generated from electricity, water, labor, and operations will drive vertical farm income negative. Once negative, vertical farm income will drive the decay adjustment time to shrink. This emphasizes that once the vertical farm industry is losing more money than it is making, the industry will shrink. The larger this negative value, the faster the industry will collapse. As the industry collapses, there are fewer costs being generated which leads to vertical farm income becoming less negative. As it becomes less negative, the decay adjustment time becomes larger again. These loops are corrective to prevent runaway negative vertical farm income.

Validation

Assumptions

Assumptions I made throughout this model were done based on a review of the literature and data sourced from a variety of data banks to provide insight on model structure.

The most prominent assumption is that of my economies of scale loops. I identified that as the vertical farm industry grows, they could bring down costs as is the case with many industries (Silberston, 1972). As such, I am assuming costs would decrease proportionally at the same rate as it would indicate how costs overall would decrease as the vertical farm industry scales. More research is needed. A fraction of this cost savings is shared with the consumer by lowering price.

I made assumptions on the average price per kilogram, but this made sense considering the model structure. This average price was determined to cover the costs plus a twenty percent profit margin. I also made assumptions on my initial stock values and some parameters, but these were supported by evidence from the literature review and hand calibration.

Finally, based on research, I assumed that vertical farms could grow any type of plant produce and that any unmet demand would be fulfilled by imports as Norway is a wealthy country with the means to import food that it cannot produce (Cho, 2011; FAO, 2023).f

More information on how this literature impacted specific variables can be found in my documentation in my supplementary materials.

<u>Model Validation Tests</u>

I performed a series of validation tests to build confidence in my model. I will discuss these tests, but further information can be found in Appendix B.

A *structure confirmation test* was conducted using the literature on vertical farming as well as a variety of data sources to structure the model. The structure was considered a realistic representation of the investment of vertical farming in Norway and the corresponding demand for food.

A *parameter confirmation test* was completed so that the parameters used were backed by the literature review and a variety of professional data sources. They all hold a real world meaning.

A series of *extreme conditions tests* were performed, and the model revealed no unexpected behavior.

The model was *tested for integration* errors by running initially with Euler and then with RK4 at differing DTs. Due to a lack of difference, the Euler simulation method was chosen with DT of 1/8.

This model holds *dimensional consistency* with the equations. This is confirmed by the Stella software used for this model.

The parameters were tested for inconsistencies through *behavior sensitivity tests*. More in depth review of the model behavior can be identified in the model analysis and supplementary materials.

The model underwent a *behavior pattern reproduction*. The reference modes of domestic plant produce, and vertical farms have been met, but the demand from imports is matching the feared reference mode. This is a result of demand increasingly increasing and the demand from vertical farm production not rising fast enough to make a significant impact on unfulfilled demand. As such, demand is met by imports. While not all reference modes were met, this model is still considered valid and useful based on the previous tests.

Model Analysis

<u>Base Run Simulation</u>

The graphs shown in Figure 4.1 show the following key performance indicators (KPIs) that I will use to analyze this model. These indicators include demand met from domestic production, demand for imports, completed vertical farms and vertical farm income. Using the Stella software, I use the Loops That Matter tool to help analyze the behavior.

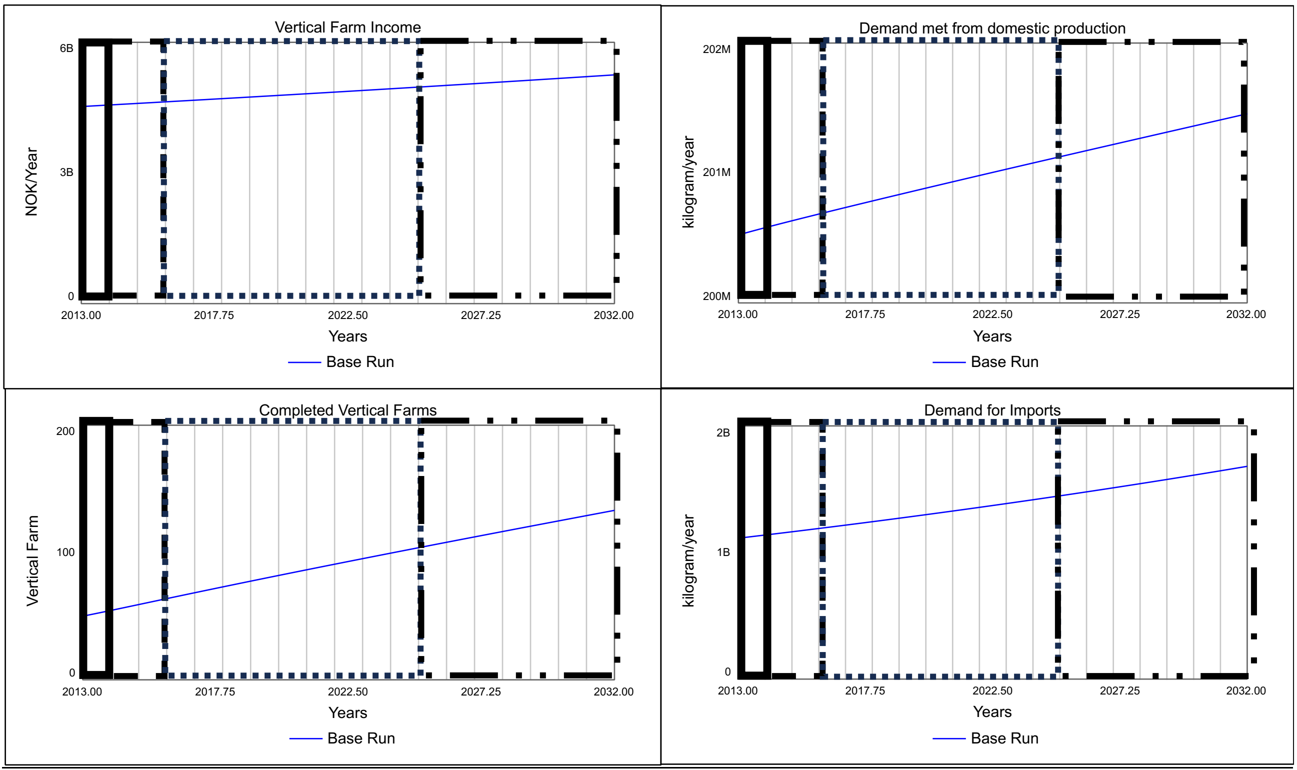

Figure 4.1: Base Run Simulation Results

As seen in the KPIs, the overall behavior of this model presents increasingly increasing behavior for demand for imports, completed vertical farms, demand met from domestic production and vertical farm income. For more insight on these variables, vertical farm income indicates net revenue plus government subsidies. Demand met from domestic production is a measure of the total shipment to distributors, which represents the amount of vertical farm produce meeting food demand, plus the constant demand fulfilled by conventional farms. Demand for imports is a measure of the remaining demand to be fulfilled minus the demand for vertical farm produce. As noted in my assumptions, it is assumed that any unmet demand will be met by imports. Lastly, completed vertical farms measures the number of vertical farms in operation.

From year 2013 to 2014, as seen in the first sector, loop *Maturing Vertical Farms (B1)* is dominant. In the initial year, the number of vertical farms under construction is low. Over the course of this year, the number of vertical farms under construction are pushed to increase by government subsidies loops. Both *Striving for Independence (B5)* and *Asking for Help (B10)* indicate that since the total number of vertical farms are low, capacity is far from full, and since there is a low self-sufficiency, close to a full amount of the allocated subsidies to vertical farms will be given. This then drives construction of vertical farms. B1 is dominant in this first year as it prevents an immediate implementation of vertical farms. There is a time delay to construct the farms. Yet, the number of completed vertical farms begin to increase as some of the initial number of vertical farms under construction are completed.

There is still exponential behavior in the other KPIs as the existing number of completed vertical farms are already producing. They increase the amount of domestic produce. Vertical farms and vertical farm income continue to increase as the amount of government subsidies increases, which provides more funding to boost vertical farm construction. Total demand for imports continues to increase similarly as the demand continues to increase faster than vertical farm production can decrease the total demand for imports.

From 2014 to 2016, loop *Decay of Vertical Farms (B3)* comes into dominance which can be seen in the second sector on the graphs. B3 grows in strength in the first year as the number of completed vertical farms increase. It then takes over, limiting an immediate decay of vertical farms. Due to a time delay, completed vertical farms are expected to last 30 years. Some will begin the decay process, but they will be prevented from decaying immediately. This leads to the number of vertical farms increasing further during this period.

As the number of verticals farm increases, the vertical farm capacity increases as well. This drives demand met from domestic production as seen in *Making the Money (R1)* loop in which increased vertical farms increases capacity which increases shipments to distributors, increasing demand met from domestic production, increasing net revenue and further driving completed vertical farms. It should be noted that the cost loops remain stronger than R1 as there is not enough demand to increase gross revenue enough to completely cover the costs. Yet, vertical farm income is being boosted by government subsidies which is reflected in the increasingly increasing behavior. Subsides can cover the costs and provide funds for new construction.

Additionally, the price per kilogram is still higher proportionally to price of imports. The economies of scale loops are coming into action, but they are not able to reduce costs or the price per kilogram enough to further drive demand for vertical farm produce. Since the ratio of price per kilogram to price of imports remains above one, loop *Price Comparison (R5)* indicates a limit in how much demand will increase. People are still less willing to purchase vertical farm produce if the price remains higher than imported goods. Concurrently, capacity remains relatively low despite increasing which drives B5 and B10. This explains why government subsidies continue to be given to vertical farm construction so that the vertical farm income and the number of vertical farms continue to increase.

It should be noted that the number of vertical farms, and as a result the amount they are able to meet demand, is not increasing quick enough to make an impact on demand for imports. The total demand is continuously increasing due to growing population and consumption per capita, which means the demand for imports continues to increase.

From 2016 to 2025, B1 is dominant again which can be seen in the third section of the graphs. Government subsidies continue to drive new vertical farms and vertical farm income. This coincides with *Saving on the Set Up (R2)* where with more vertical farms, the economies of scale will lower the needed upfront capital investment, further driving new vertical farms under construction. As such, B1 plays a large role in preventing these farms from being completed immediately. Regardless, more vertical farms are still completed.

Meanwhile, vertical farm capacity increases, leading to increasingly increasing behavior for the demand met from domestic production. Since carrying capacity is still relatively low, government subsidies to continue to grow the vertical farm industry. This ensures loop B1 remains dominant.

Again, it should be noted that demand for imports is continuing to increase increasingly. The total demand is ever rising, and the amount of demand met by vertical farms is not increasing by enough.

2025 to 2032, B1 and *Feeling the Shock (B2)* are dominant, but R1 and R2 are growing in strength. The corresponding behavior can be seen in the final section. B2 represents how energy costs become more influential in this model. As the number of vertical farms continue to increase, they produce more fruits and vegetables so further costs are incurred as there are more farms. These costs are mitigated by government subsidies which continue to increase vertical farm income.

However, loops R1 and R2 increase in strength. R1 shows how the revenue loop becomes stronger as the increased number of vertical farms increases capacity and, thus, drives demand for vertical farm produce. Meanwhile, R2 shows how the economies of scale are becoming increasingly impactful as well. R2 specifically shows that the upfront costs from capital investment are decreasing enough to further increase the number of vertical farms under construction. Less upfront capital is needed to build each additional vertical farm.

This loop also shows how the economies of scale are influencing the model. The reduction in price per kilogram in relation to price of imports helps to further drive revenue and ensure vertical farm income is higher. This decrease in ratio of price per kilogram to price of imports helps to drive demand for vertical farm produce which further increase increasingly demand met from domestic production. Yet, total demand is still increasing. Vertical farms are not meeting enough of the unfulfilled demand. Thus, demand for imports continues to grow exponentially.

Sensitivity Analysis

An extensive sensitivity analysis for all exogenous parameters and table functions was conducted on the model. Figure 4.2 outlines the results of the analysis. Overall, the behavior modes of the KPIs remained largely the same and complied with the expectations of the model. Only "desired self-sufficiency" indicated behavioral sensitivity. More information can be found in supplementary materials.

Model Sector	Parameter	Range	Sensitivity
Vertical Farming Finances	Sensitivity of ratio of relative vertical farms on cost reduction change rate	0.15-0.45	Not Sensitive
	Indicated cost reduction change rate	(-0.0045)-(-0.0015)	Not Sensitive
	Profit Margin	1-1.8	Numerical
	Fraction of cost reduction to consumers	0.15-0.45	Not Sensitive
	Max cost reduction	0.35-1	Not Sensitive
	Average price of imports	12-90	Numerical
	Sensitivity of effect of ratio of price per kilogram to price of imports on fraction of demand for vertical farm produce	(-1.5)-(-.5)	Numerical
	Average energy need	136-408	Numerical
	Labor need per kilogram of produce per year	0.00009-0.000027	Not Sensitive
	Water need per kg of produce per year	8.5-25.5	Not Sensitive
	Average operational cost per farm per year	54500-163500	Not Sensitive
	Average cost per L per year	0.005-0.015	Not Sensitive
	Average annual salary Norway	190000-570000	Not Sensitive
	Average cost per kw per year	0.15-0.45	Numerical
	Average capital investment	287500000-862500000	Numerical
	Average cost of commercial space	13664-40992	Not Sensitive
	Indicated size of vertical farm	100-300	Not Sensitive
	Fraction of net revenue reinvested	0.4-1	Not Sensitive
	Average completion adjustment time	0.5-5	Numerical
	Income Loss Threshold	(-1000000)-(-6000000)	Not Sensitive
	Sensitivity of effect of relative vertical farm income on decay adjustment time	0.5-1.5	Not Sensitive
	Minimum decay AT	0.5-5	Not Sensitive
	Initial vertical farms under construction	0-12	Numerical
	Initial completed vertical farms	25-75	Numerical
	Initial vertical farm inventory	96000-288000	Not Sensitive
	Indicated decay adjustment time	15-45	Numerical
Government Subsidies Sector	Desired self-sufficiency	0.5-1.2	Behavioral
	Inflection Point	0.25-0.75	Numerical
	Steepness	2.5-7.5	Numerical
	Government subsidies to agriculture change rate	0.0035-0.0105	Not Sensitive
	Indicated fraction of subsidies to vertical farms per year	0.15-0.45	Numerical
Food Supply	Average output per vertical farm	15500-46500	Numerical
	Food waste rate	0.0025-0.0075	Not Sensitive
	Demand fulfilled from conventional farms Norway	100000000-300000000	Numerical
	Supply coverage	1.0-2.0	Numerical
Food Demand	Birth fraction	0.006-0.018	Not Sensitive
	Death fraction	0.004-0.012	Not Sensitive
	Reference net migration fraction	0.004-0.012	Not Sensitive
	Per capita consumption change rate	0.0035-0.0105	Not Sensitive
	Reference per capita consumption	130-390	Numerical

Figure 4.2: Sensivity Analysis Overview

Policy Analysis

For this model, I will be testing two policies against the base run and an additional scenario that I deem possible, if not likely, to occur. Both scenarios will present challenges to establishing vertical farming in Norway. By running these policies in the base run and the additional scenario, I hope to provide insight into how vertical farms can be implemented more effectively in Norway. The base run shows that while vertical farms are increasing, the demand met from domestic production is increasing, and vertical farm income is increasing, so too is the demand for imports. This indicates that vertical farm industry relies too much on government subsidies to build more farms and that demand for imports are not impacted enough for Norway to be more self-sufficient.

No Subsidies Scenario

Describing the scenario first, it is a scenario in which there are no more subsidies from the government. It assumes that there is a new government administration that has come into leadership and has made a political decision to change its stance towards vertical farming and remove all subsidies. The scenario is implemented in 2023. The comparison between the base run and the scenario run is shown in Figure 4.3.

As seen, this scenario showcases how there is an immediate decline in the KPIs vertical farm income, demand met from domestic production and completed vertical farms. Demand for imports is not impacted as it is being driven by the exogenous driver of plant produce demand as determined by a growing population. The other KPIs decline due to the balancing *Left Alone Loops (B11, B12, B13, B14).* These loops indicate that as soon as government subsidies are removed, the costs drive vertical farm income negative. Once negative, the decay adjustment time is rapidly reduced which leads to an immediate decline in the number of vertical farms. As there are fewer vertical farms, fewer costs are generated which brings vertical farm income back towards zero.

Demand met from domestic production is reduced to approximately 200 million kilograms per year as the collapse of the industry would lead to no increase in demand being met from domestic production. Demand would only be met from existing conventional farms.

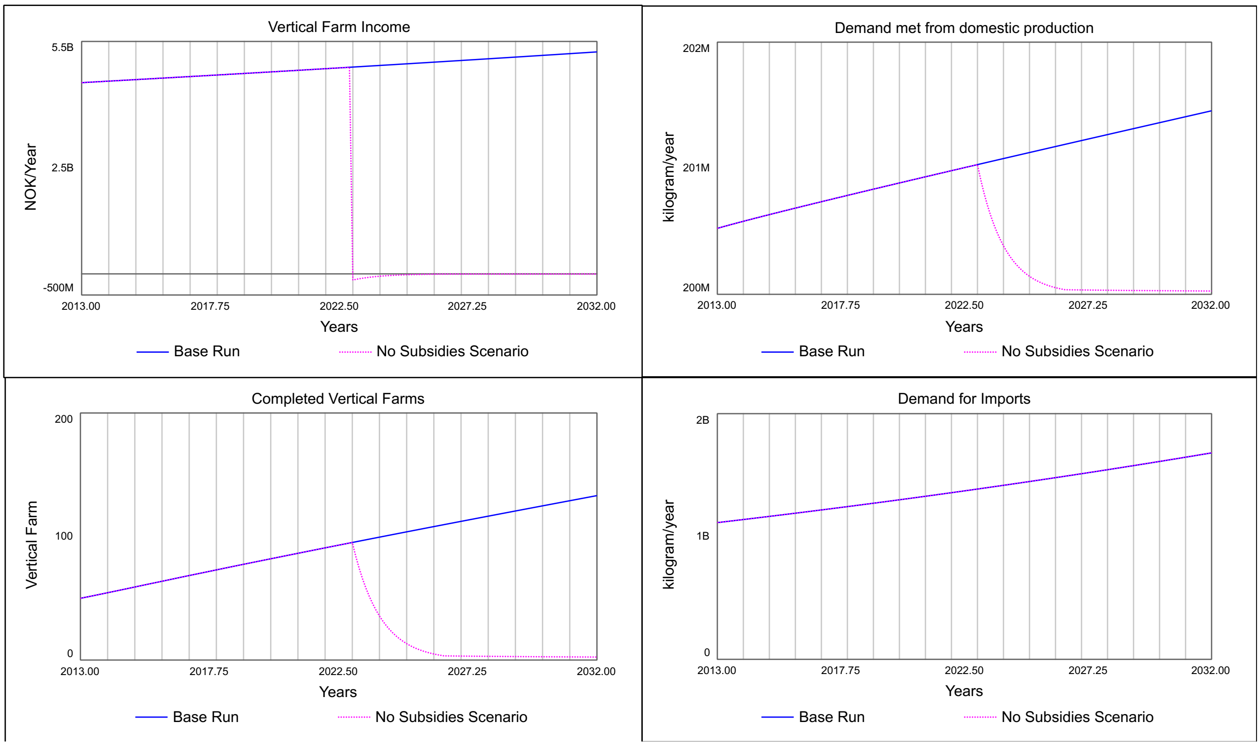

Figure 4.3: Base Run versus No Subsidies Scenario Run

Import Tax Policy

This is a policy that is meant to showcase a price increase on imports so that import prices, a leverage point, become greater than price per kilogram. The average price of imports is increased by 150 percent in year 2023. Seen in Figure 4.4, a comparison with the base run shows that vertical farm income increases. Demand met from domestic production spikes and then increases more quickly. Meanwhile, there is a slight increase in completed vertical farms.

This policy was introduced as it was identified using the Loops that Matters tool that *Making the Money (R1)* is not dominant but grows in dominance during the base simulation. Meanwhile, *Maturing Vertical Farms (B1)* is dominant for almost the entire run. By increasing the price of imports, this leads to a stronger demand for vertical farm produce. This drives shipments to distributors which increases revenues. This further increases vertical farm construction which increases vertical farm capacity and further increases demand for vertical farm produce. This describes R1 becoming stronger and more influential on the model.

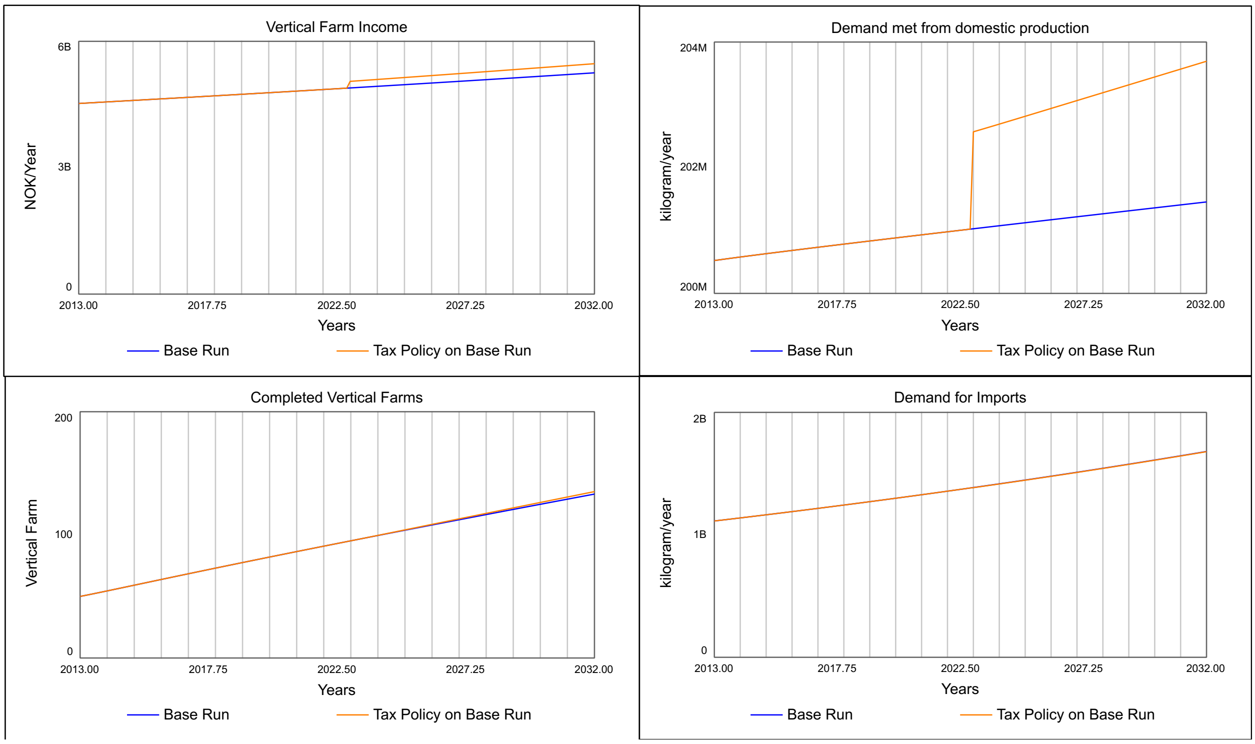

Figure 4.4: Base Run Camparison with Import Tax Policy Implementation

Energy Efficiency Policy

The second policy showcases how the implementation of more efficient LEDs could lower costs. Stella's Loops that Matter identify that *Feeling the Shock (B2)* has a large influence on the model as energy takes up most of the expenses. As such, this loop was targeted with a plausible policy where there is an improvement in energy efficient LEDs (Kobayashi et al., 2022). In 2023, energy efficiency will increase by 25 percent. This improved efficacy will mean energy need for both lighting and the temperature control requirements to counteract the heat generated from the lighting will be reduced.

By lowering energy need, B2 is weakened. The impacts can be seen in Figure 4.5. Vertical farm income increases because of a weaker B2. There are fewer electricity costs. Meanwhile, demand met from domestic production increases as the lower energy need reduces price per kilogram. Price per kilogram is determined to cover costs plus a profit margin. With a lower price per kilogram relative to imports, this drives more demand for vertical farm production.

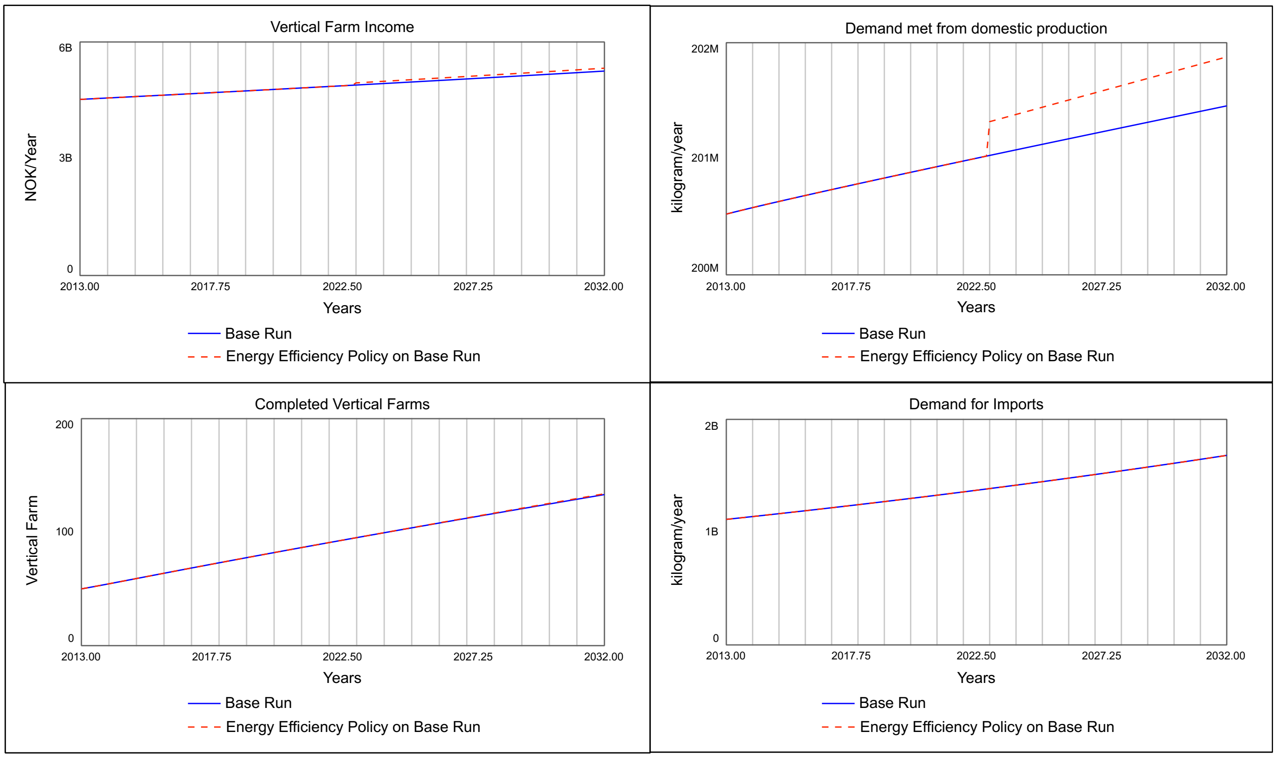

Figure 4.5: Base Run Camparison with Energy Efficiency Policy Implementation

Import Tax Policy plus Energy Efficiency Policy

Both policies were implemented together on the base run to test the effect. The results can be seen in Figure 4.6. There is a significant increase in vertical farm income which is caused by strengthening *R1* in Import Tax Policy and weakening *B2* in Energy Efficiency Policy. *R1* is also strengthened by the reduction of energy need from Energy Efficiency which increases demand met from domestic production. However, there is still only a slight change in completed vertical farms which is coming primarily from the Tax Policy. Demand for imports remains unchanged. These policy implementations are not enough to impact demand for imports.

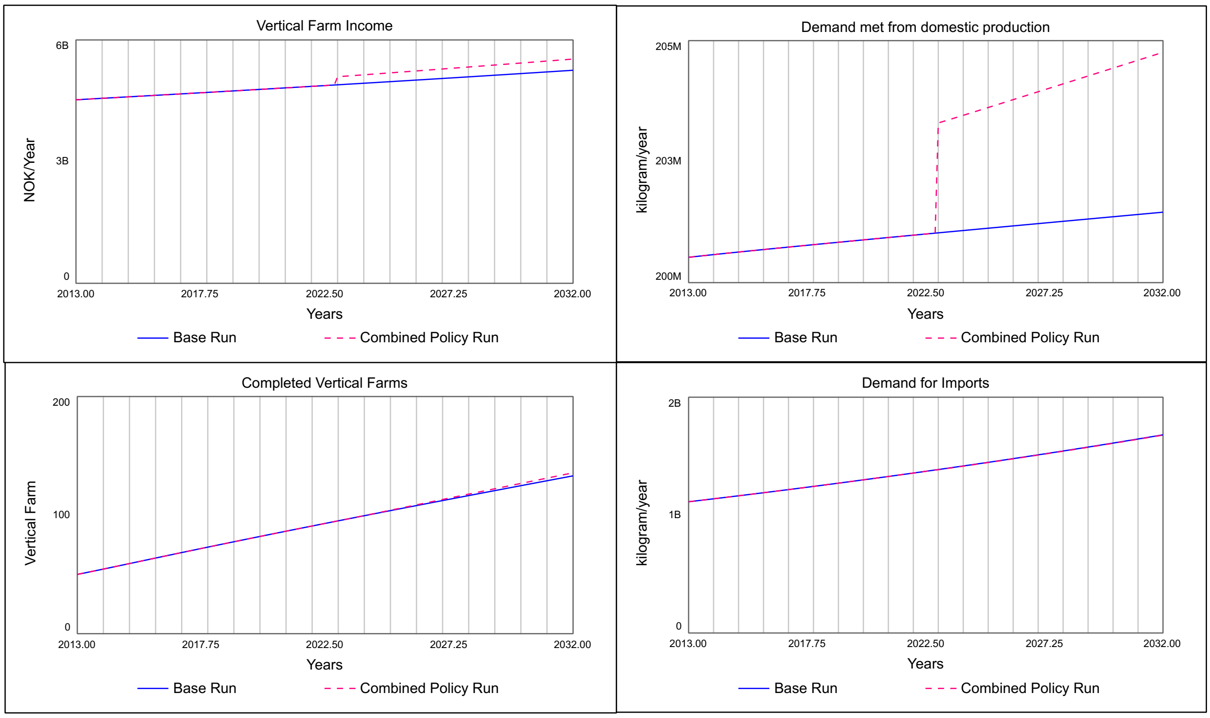

Figure 4.6: Base Run Camparison with Combined Policy Implementation

Policy Implementation on No Subsidies Scenario

Shifting towards policy implementation on No Subsidies Scenario in which government subsidies towards vertical farming are reduced, Figure 4.7 shows four runs which include the scenario with no policies implemented, the scenario with Import Tax Policy implemented, the scenario with the Energy Efficiency Policy implemented, and the scenario with both polices implemented. The largest changes can be seen in the number of vertical farms and demand met from domestic production.

When looking only at Energy Efficiency Policy implementation, it has the smallest impact on the model. The policy weakens loop B2 by lowering the energy need and expense in the model. It also increases revenue by strengthening indirectly loop R1 by decreasing the price per kilogram in relation to price of imports which drives demand for vertical farm production. However, it is not enough to limit the loss of subsidies. Completed vertical farms decline rapidly as there are no more subsidies to keep vertical farm income positive. As such, the balancing loops B11, B12, B13, and B14 lead to a rapid decline in completed vertical farms. It should be noted that demand met from domestic production declines in the same way as the No Subsides Scenario with no policy implementation, but it is numerically different as the reduced strength of B2 showcases lower electricity costs to operate vertical farms. The lower costs also result in slightly higher vertical farm income and slightly higher completed vertical farms in comparison to the no policy scenario run.

The Import Tax Policy has a more significant impact in that it drives demand for vertical farm production by lowering the price per kilogram to price of imports ratio to below one. This then increases revenue enough so that vertical farm income remains positive albeit decreasing gradually. This is due to a strengthening of R1. However, it is not enough to weaken the effect of B1 as vertical farms are still limited from being constructed. This loop remains dominant as construction of vertical farms are largely driven by government subsidies. As such, completed vertical farms still decline, albeit more gradually, and demand met from domestic production stagnates and declines slightly because of a lower vertical farm capacity lowering demand. This counteracts the strengthening of R1.

Meanwhile, the policies enacted together show a stronger R1 that is strengthened by both policies. Vertical farm income remains slightly positive. Demand met from domestic production is increased significantly but declines as B1 remains the dominant loop limiting new vertical farms from being built as there are no more funds coming from the government. Without new farms, capacity is lowered, lowering demand for vertical farm produce. This fully emphasizes that government subsidies play a critical role in the initial phases of vertical farm industry in Norway.

Finally, it should be noted that the demand for imports is again not impacted as they are being driven exogenously by population. Realistic policies to increase demand met from domestic production to then lower demand for imports is difficult to identify in the current version of this model.

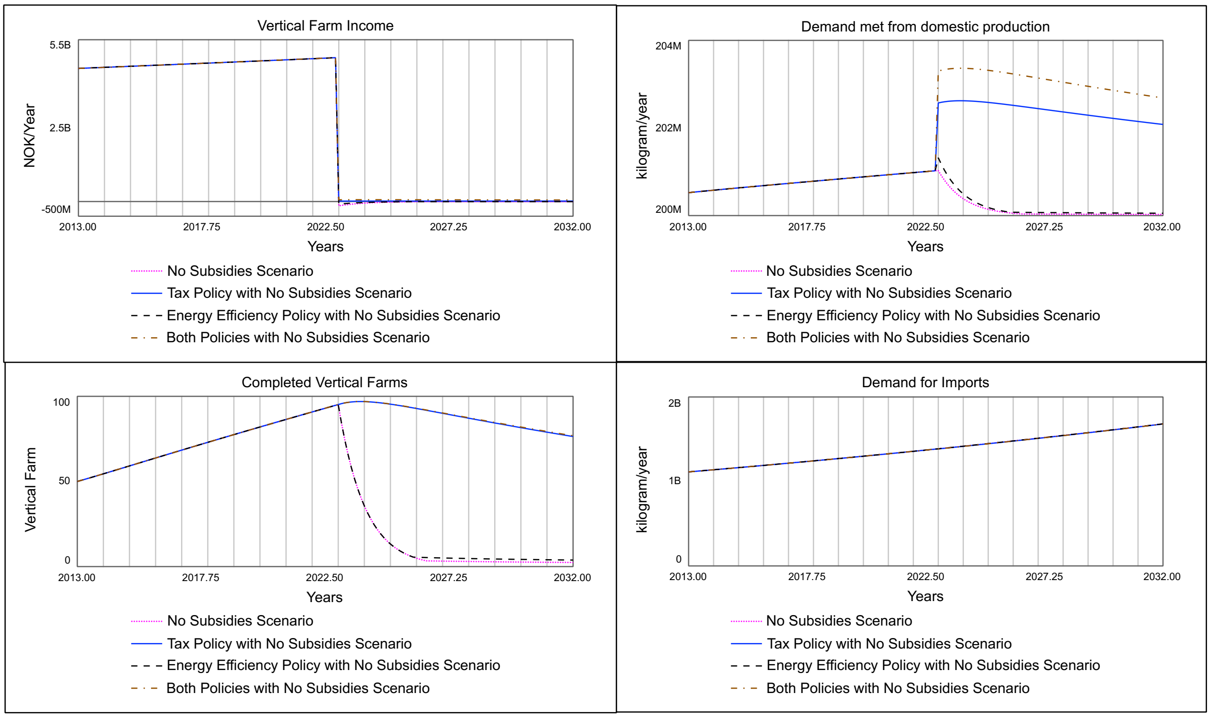

Figure 4.7: No Subsidies Scenario with Policy Runs

Conclusion

The run of the polices on the base simulation and scenario indicate limitations of the model. Since population is exogenous and driving total demand, it will take extreme measures to increase domestic production within a limited time frame to begin lowering demand for imports. As such, the model as it is currently constructed indicates that Norway will continuously need to rely on imports to meet their population's plant produce demands. Given the current structure of the model, Import Tax Policy would prove to be the most effective for both the base run and No Subsidies Scenario. It would ensure demand shifts towards vertical farm produce and ensure the industry is self-sustaining financially. This is significant as vertical farming will need to rely substantially on government subsidies to survive otherwise. Yet, this policy would prove the most difficult to implement as import taxes are often dictated by treaties and other government policies. The feasibility of this policy will need to be further researched.

There are other limitations that should be noted. Aspects of this model that I would like to further research include the implementation of soft modelling. These features would showcase the influence of marketing, word-of-mouth, and general perception of vertical farm produce. Vertical farm produce is often seen as higher quality albeit less natural than conventional or greenhouse production (Coyle & Ellsion, 2017). These impacts that flush out a more complicated decision-making process for consumers can showcase how the vertical farm industry can more impactfully supply Norway with plant produce. This can prove essential as the existing model does not show many leverage points and that this model is not able to feasibly impact demand for imports. I notice in my sensitivity analysis it could only do so by impacting reference per capita consumption and demand fulfilled from conventional farming. Increasing consumption for fruits and vegetables is desired by the Norwegian government and the output from conventional farming is unlikely to increase (Opplysningskontoret, 2022; FAO, 2023). By including these aspects, I can further introduce clarity into how vertical farming in Norway can meet the demand for plant produce while reducing the reliance on imports.

References

Apelthun, T. (2022, January 19). Norway: New 15.000m2 farm to supply the country's 5 biggest cities. Vertical Farm Daily. https://www.verticalfarmdaily.com/article/9391527/norway-new-15-000m2-farm-to-supply-the-country-s-5-biggest-cities/

Avgoustaki, D. D., & Xydis, G. (2020a). Indoor Vertical Farming in the Urban Nexus Context: Business Growth and Resource Savings. Sustainability, 12(5), 1965. https://doi.org/10.3390/su12051965

Avgoustaki, D. D., & Xydis, G. (2020b). How energy innovation in indoor vertical farming can improve food security, sustainability, and food safety? Www.sciencedirect.com, 5. https://doi.org/10.1016/bs.af2s.2020.08.002

Banerjee, C., & Adenaeuer, L. (2014). Up, Up and Away! The Economics of Vertical Farming. Journal of Agricultural Studies, 2(1), 40. https://doi.org/10.5296/jas.v2i1.4526

Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy, 13(1), 13–26. https://doi.org/10.1080/15487733.2017.1394054

Berglund, N. (2022, May 5). State offers billions to farmers. Norway's News in English — Www.newsinenglish.no. https://www.newsinenglish.no/2022/05/05/state-offers-billions-to-farmers/

Butturini, M., & Marcelis, L. F. M. (2019). Vertical farming in Europe. Plant Factory, 77–91. https://doi.org/10.1016/b978-0-12-816691-8.00004-2

Cho, R. (2011, October 13). Vertical Farms: From Vision to Reality. Columbia Climate School; Columbia University. https://news.climate.columbia.edu/2011/10/13/vertical-farms-from-vision-to-reality/

Coyle, B. D., & Ellison, B. (2017). Will Consumers Find Vertically Farmed Produce "Out of Reach"? Choices, 32(1), 1–8. http://www.jstor.org/stable/90014636

Exchange Rates UK. (2023, December 6). Norwegian Krone to US Dollar Spot Exchange Rates for 2013. Exchange Rates UK. https://www.exchangerates.org.uk/NOK-USD-spot-exchange-rates-history-2013.html

Finn. (2023, December 8). Næringseiendommer til salgs. Finn. https://www.finn.no/realestate/businesssale/search.html?area_from=200&area_to=300&location=0.20061&location=1.22046.20220&location=1.22046.20243&location=1.22046.20248&location=1.20012.20196&location=1.22042.20179&location=1.20012.20195

FAS. (2020). *Norway Extends Support to Businesses During the COVID-19 Crises*. United States Department of Agriculture Foreign Agricultural Service. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Norway%20Extends%20Support%20to%20Businesses%20During%20the%20COVID-19%20Crises_The%20Hague_Norway_04-20-2020

Food and Agriculture Organization of the United Nations (FAO). (2023). FAOSTAT. https://www.fao.org/faostat/en/#data/FBS%20

Freeing Energy. (n.d.). Energy Fact – Cost of LED lighting dropped 15-times as volumes increased. Retrieved December 11, 2023, from https://www.freeingenergy.com/facts/led-bulb-light-cost-price-historical-decline-g213/

iFarm. (2023, February 15). Vertical farming costs (2023 setup and operating costs). Ifarm.fi. https://ifarm.fi/blog/vertical-farming-costs

Index Box. (2023, December 12). Norway - Vegetables and Melons - Market Analysis, Forecast, Size, Trends and Insights. https://www.indexbox.io/search/vegetable-price-norway/

Gustavsen, G. W., Berglann, H., Jenssen, E., Kårstad, S., & Rodriguez, D. G. (2021). Willingness to pay for urban agriculture in Oslo. International Journal on Food System Dynamics, 64–73. http://dx.doi.org/10.18461/pfsd.2021.2008

Kobayashi, Y., Kotilainen, T., Carmona-García, G., Leip, A., & Tuomisto, H. L. (2022). Vertical farming: A trade-off between land area need for crops and for renewable energy production. Journal of Cleaner Production, 134507. https://doi.org/10.1016/j.jclepro.2022.134507

Ministry of Agriculture and Food. (2015, August 20). Food security. Regjeringen.no. https://www.regjeringen.no/en/topics/food-fisheries-and-agriculture/mat/innsikt/matsikkerhet/id2357158/

The Norwegian Tax Administration. (n.d.). *About government aid (state aid)*. Retrieved January 24, 2024, from https://www.skatteetaten.no/en/business-and-organisation/reporting-and-industries/industries-special-regulations/state-aid/about-state-aid/

Research and Markets. (2023). Global Vertical Farming Market by Growth Mechanism (Hydroponics, Aeroponics, Aquaponics), Structure (Building-based, Shipping container-based), Crop Type, Offering (Lighting, Sensors, Climate Control, Software, Services) & Region - Forecast to 2028. In Research and Markets: The World's Largest Market Research Store. https://www.researchandmarkets.com/reports/5136175/global-vertical-farming-market-by-growth?utm_code=7xngr6&utm_exec=cari18prd

Roberts, J. M., Bruce, T. J. A., Monaghan, J. M., Pope, T. W., Leather, S. R., & Beacham, A. M. (2020). Vertical farming systems bring new considerations for pest and disease management. Annals of Applied Biology, 176(3), 226–232. https://doi.org/10.1111/aab.12587

Opplysningskontoret for frukt og grønt. (2014). Totaloversikten 2010-2014. In Spise Deg God. https://www.frukt.no/globalassets/materiell/frukt--og-grontstatistikken/totaloversikten-for-2010-2014.pdf

Opplysningskontoret for frukt og grønt. (2017). Totaloversikten 2017. In Spise Deg God.

https://www.frukt.no/globalassets/materiell/frukt--og-grontstatistikken/totaloversikten2017-hyperlenker-korr2.pdf

Opplysningskontoret for frukt og grønt. (2022). Frukt- og Grønstatistikk 2022. In Spise Deg God. https://www.frukt.no/globalassets/materiell/frukt--og-grontstatistikken/frukt--og-grontstatistikk-2022-3.pdf

Pereira, M. C. R. (2023). Opportunities and challenges of vertical farming to contribute to the sustainability of food systems in Canada.The Canadian Agri-Food Policy Institute. https://capi-icpa.ca/wp-content/uploads/2023/06/2023-06-19-Maria-Carolina-Pereria-Individual-Report-CAPI-EN.pdf

Rajah, J. K. & Grimeland, M. (2022, July 19-22). Enabling Resilient Food Systems: Simulating the Impact on Local Farmers' Livelihoods in Greater Adelaide, Australia [Paper Presentation]. 40th International Conference of the System Dynamics Society, Frankfurt, Germany.

Silberston, A. (1972). Economies of Scale in Theory and Practice. The Economic Journal, 82(325), 369–391. https://doi.org/10.2307/2229943

Song, S., Hou, Y., Lim, R. B. H., Gaw, L. Y. F., Richards, D. R., & Tan, H. T. W. (2021). Comparison of vegetable production, resource-use efficiency and environmental performance of high-technology and conventional farming systems for urban agriculture in the tropical city of Singapore. Science of the Total Environment, 807. ScienceDirect. https://doi.org/10.1016/j.scitotenv.2021.150621

Statista. (2022, September 9). Value of fresh, chilled, frozen or simply preserved vegetables imported into Norway from 2009 to 2021 (M. Ridder, Ed.) Statista. https://www.statista.com/statistics/568691/import-value-of-vegetables-into-norway/

Statistics Norway. (2013). 06813: Holdings with greenhouses and area of greenhouses, by size of greenhouse area (C) (closed series) 1979 - 2010. Statistikk Sentralbyrå. https://www.ssb.no/en/statbank/table/06813/

Statistics Norway. (2022). National population projections. https://www.ssb.no/en/befolkning/befolkningsframskrivinger/statistikk/nasjonale-befolkningsframskrivinger

Statistics Norway. (2023a). Population and population changes, by year and contents. https://www.ssb.no/en/statbank/table/06913/tableViewLayout1/

Statistics Norway. (2023b). 10507: Yield and area of various horticultural crops 2010 - 2022. https://www.ssb.no/en/statbank/table/10507/

Statistics Norway. (2023c). General government revenue and expenditure. https://www.ssb.no/en/statbank/table/10725/tableViewLayout1/

Statistics Norway. (2023d). 11419: Monthly earnings, by measuring method, occupation, industry (SIC2007), contents and year. https://www.ssb.no/en/statbank/table/11419/tableViewLayout1/

Statistics Norway. (2023e). 12218: Self cost and fees in municipal water supply (M)

2015 - 2022. https://www.ssb.no/en/statbank/table/12218/

Statistics Norway. (2023f). 09366: Electricity prices in the end-user market (øre/kWh), by type of contract, contents and year. https://www.ssb.no/en/statbank/table/09366/tableViewLayout1/

United Nations. (2018). World Urbanization Prospects: The 2018 Revision. United Nations Department of Economic and Social Affairs. Downloaded from https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf

United Nations. (2022). World Population Prospects. United Nations: Department of Economic and Social Affairs Population Division. https://population.un.org/wpp/Graphs/DemographicProfiles/Line/900

World Bank, The. (2018). Urban population (% of total population) - Norway. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=NO

Zipkin, A. (2022, April 6). Vertical Farms Expand as Demand for Year-Round Produce Grows. The New York Times. https://www.nytimes.com/2022/04/06/business/vertical-farms-food.html