Micro-Feasibility Study

Vertical Farming

Commissioned by the Midlands Net Zero Hub
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Executive Summary

Introduction

Vertical farming involves growing crops in stacked trays or integrated into vertical walls, in indoor, highly controlled environments including the use of LED lighting systems. Vertical farming is a growing industry attracting attention from investors globally. Vertical farming offers the opportunity to grow hyper-local fresh food in urban environments. The most commonly grown crops in vertical farms are herbs, leafy greens, and microgreens. There are opportunities for vertical farming to be used to produce medical grade plants and in the propagation of seedlings and transplants.

Decarbonisation Opportunities

A key challenge in vertical farming is the high electricity demand and associated costs of LED lighting and cooling. Vertical farming can be co-located with renewable energy generation to create win-win scenarios where energy producers can export electricity at a higher price and growers can buy electricity at a lower price than through the grid.

Technology

There are various vertical farming technologies offered by companies in the UK and around the world. Large vertical farms entail substantial capital costs and are often designed and constructed in a bespoke manor by vertical farming companies. A smaller scale option is containerised vertical farms, which are small, scalable, and moveable turnkey solutions. These are suitable options for first time growers, and for testing systems and plant varieties.

Outline Business Case

The main operational costs of vertical farming are electricity for lighting and cooling, labour costs, and fertilisers. These can be estimated using figures from vertical farm suppliers and experts. Income is based on yield, which again can be estimated based on figures from experts, and growing trials.

This can be used to work out a cash flow. District Eating Ltd. (DEL) conducted an illustrative cash flow based on four freight Farms Greenery S containers, producing basil. Financial KPIs are reported in the table below. Internal Rate of Return (IRR) is a measure of return on investment, higher values are more attractive. Net present value (NPV) is the difference between incomings and outgoings, and indicates the profit.

Table 1: Financial KPIs of outline business case.

	Electricity price		
	£0.12	£0.16	£0.20
IRR	6%	2%	-4%
PayBack	11	16	0
NPV @ 20 years	£300,650	£84,873	-£130,905

This suggests that a vertical farm made up of four Freight Farms containers producing basil can be financially viable with an electricity price of £0.12/kWh. As mentioned, this is a simplistic business case. If a project is pursued a detailed business case should be carried out, including evaluation of different crop options.

Conclusions

- The supply of herbs, leafy greens microgreens could increase as more vertical farms are built at scale in the UK, which may result in crop price fluctuations. If supply increases, and demand stays the same, then prices could reduce. Therefore, it is advisable to consider other crop choices as well as those mentioned.
- Vertical farms have high energy demand for lighting and cooling. This leads to high operating costs and carbon emissions which can be prohibitive.
- Co-locating vertical farms with sources of renewable energy could provide a solution to this issue. The win-win point is the electricity price where producers are being paid more than they would to export to the grid, and growers are paying less than they would if buying from the grid.
- There are companies operating in the UK offering vertical farming equipment on a variety of scales. Small scale turn-key systems are available in the form of container farms.
- When obtaining quotes from vertical farming suppliers it is important to dissect capital and operational costs and yields.
- Capital costs for vertical farms are substantial and include many components.
- The main operating cost of vertical farms is electricity use. As such, the business case of a vertical farm is sensitive to electricity prices and may be vulnerable to the sharp increases we are seeing currently. Other operational costs include fertilisers, water, seeds and labour. Vertical farms have potentially low labour requirements as many processes can be automated.
- It is important to consider how pests and diseases will be managed in a vertical farm. This can be done through preventative and reactive measures, such as hygiene practices, the use of biological control strategies, and UV light.

Recommendations and Next Steps

- Consider whether a large-scale vertical farm or a small-scale container is required, based on market demand in farming, business ambition, and capital costs.
- Obtain quotes from vertical farming supplier companies.
- Consider potential crops and conduct detailed market research to confirm an outlet, or buyer.
- Contact existing vertical farms to learn and discuss methods, challenges, and successes.
- Find a suitable site with sufficient links to a source of renewable energy.
- Engage with key stakeholders at the chosen site and discuss options for connection to electricity source via a private wire.
- Conduct an outline business case as per the example provided in this report, and complete sensitivity analysis varying crop price and input costs to determine resilience of the business case.
- If the results of the outline business planning are positive, conduct an in-depth business case to evaluate economic viability.
- Build a supportive team. Vertical farms are expensive and crop production is a specialist endeavour. Get the support you need to maximise the chances of success.

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1.0 Introduction

Vertical farming involves growing crops in stacked trays or integrated into vertical walls, in indoor, highly controlled environments, including the use of LED lighting systems. Vertical farming uses hydroponic or aeroponic growing systems, both of which use significantly less water than conventional cropping, and eliminate the need for herbicides and pesticides. The efficient use of space and continuous cropping mean that high yields can be achieved on a small area of land. This makes vertical farming a suitable option for urban environments.

Vertical farming has the potential to provide nutritious, fresh food locally in urban environments. This reduces the need for long-distance transportation of food from overseas or rural areas into cities. There is also less energy use from farm machinery such as tractors, trucks, or harvesters. There are less seasonality issues because crop production occurs all-year round and can be programmed to match demand. Furthermore, because the crops are indoors, they are protected from the risk of contamination from external sources, including fluctuations in weather patterns.

Vertical farming has the potential to provide skilled jobs in engineering, agronomy, biotechnology, construction, maintenance, as well as providing ongoing research and development opportunities to continually improve technology as the sector grows and matures. Automated vertical farming requires less labour in comparison with conventional agriculture, making it less vulnerable to labour shortages that have been affecting the food and farming sector[1].

2.0 Decarbonisation Opportunities

The main challenge facing vertical farming currently is the high energy use, which leads to high operational costs and, depending on the energy source, high carbon dioxide (CO_2) emissions. It is important to select LED luminaires with the highest efficiency ratings and to carefully manage the length of the photoperiod, in line with the requirements of the crop. For vertical farming to compete with conventional agriculture in terms of carbon footprint, it is essential that vertical farms use renewable energy. One business opportunity for vertical farming is to co-locate farms with renewable electricity generation to supply low cost, low carbon energy.

2.1 Displacing renewable energy grid exports - The Win-Win

Co-locating vertical farming with renewable energy production can create win-win scenarios. The energy producer can sell electricity for a higher price than if they were exporting to the grid, and the grower can buy electricity for a lower price than if they were buying from the grid. This is because renewably generated power is typically sold for a lower price than the cost of purchasing power from the grid. To put it another way, it will usually be cheaper to purchase power from a renewable electricity generator at a cheaper price than buying from the grid, because operating in this way cuts out the middleman.

Although electricity prices are continuously fluctuating, and in the first quarter of 2022 have risen at unprecedented rates, it is likely that the gap between export prices and purchase prices will continue to exist, creating the opportunity for win-win situations when electricity is sold

[1] https://committees.parliament.uk/work/1497/labour-shortages-in-the-food-and-farming-sector/

directly from a producer to a consumer. This 'win-win' point is demonstrated by the red star on the graph below.

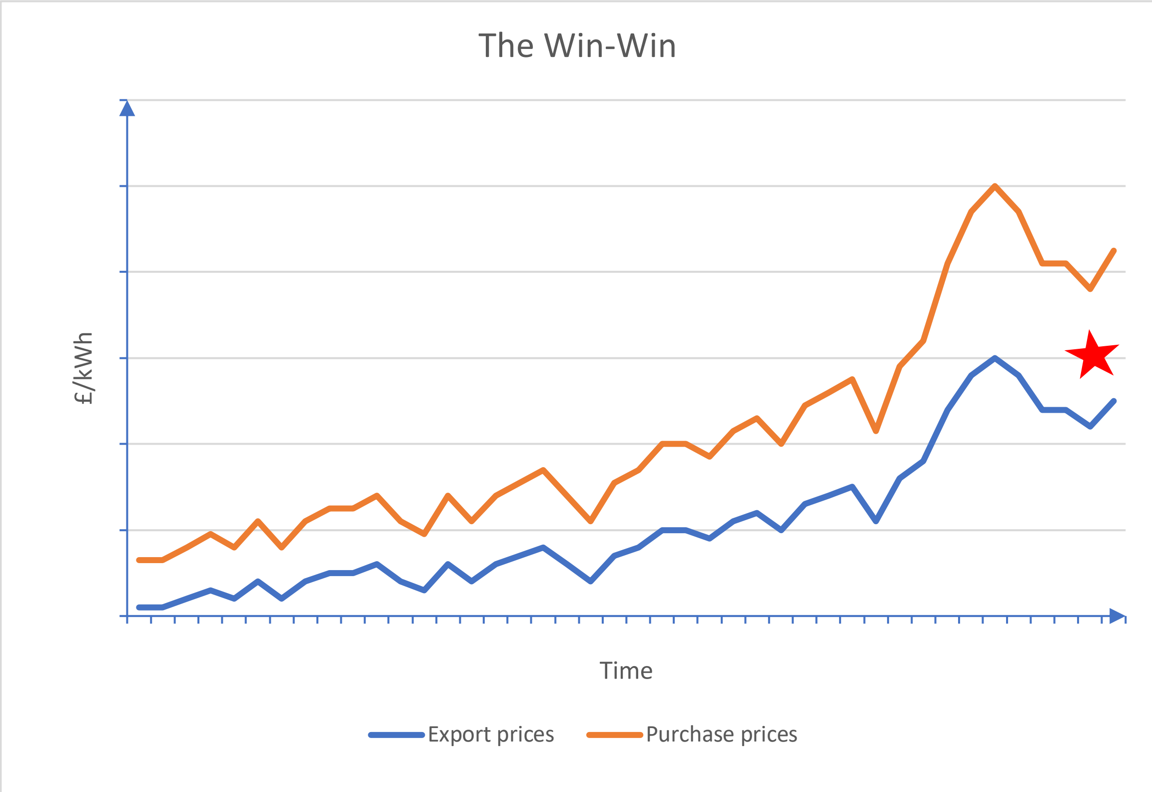


Figure 1: Graph demonstrating the win-win point in between renewable energy export and purchase prices.

Electricity can be sold directly from producers to growers via a private wire, or through an agreement known as a virtual private wire or sleeving arrangement. There are capital costs associated with construction of a physical private wire, which could be the responsibility of the grower, or the energy producer, or a third party. There are many sites across the UK producing renewable power that could potentially be used for vertical farming, including anaerobic digester sites, wind and solar farms. Matching growers with sites with renewable energy production is a specialist service offered by DEL.

2.2 Cooling Demand

Unlike glasshouses, vertical farms require more cooling than heating. They are usually built inside insulated buildings that can be purpose built, or in some cases existing insulated buildings such as cold stores. Vertical farms contain LED lights which are typically around 50% efficient and produce heat as well as light. As such, vertical farm environments require cooling whenever the light systems are in use. If the vertical farm is located on a site with waste heat, absorption chillers can use this heat for cooling. Absorption chillers work on the same principles as traditional electric chillers, but they use heat to create pressure to drive the cycle. It can be possible to reduce the overall emissions associated with summer cooling through use of absorption chillers when compared with traditional electrically powered cooling units. However, because absorption chillers are typically less efficient, viability will be dependent on the cost and carbon factors of input heat and input electricity. Therefore, viability of absorption chillers will be site dependent.

If the vertical farm is connected to a heat network, absorption chillers can provide the additional opportunity of balancing the heat network load, because demand for cooling will be higher in summer when demand for heat from the network is lower. This can help to improve the efficiency and business case of a heat network, making vertical farms an attractive heat network customer.

3.0 Crop Options

Currently, the most common crops grown in vertical farms are herbs, leafy greens, and microgreens.

3.1 Herbs

The European market for fresh herbs is increasing, as consumers are becoming more interested in healthier products and a broader range of culinary experiences. Common herbs in European cooking include Basil, Parsley, Coriander, Chives, Rosemary, Thyme, Oregano, Dill, Mint, Sage, Tarragon, Chervil, Marjoram and Lemongrass[2]. The UK imports herbs out of season – largely from Spain, but also from Kenya, Jordan and Mexico. Tesco have reported that basil makes up around 40% of potted herb sales. There is also increasing interest in oriental herbs such as Thai basil, and lemongrass, due to the UK's cultural diversity and expanding preferences for globally influenced flavours.

3.2 Leafy Greens

Leafy greens include lettuce leaves such as Batavia, Butterhead, Little Gem and Romaine, Kale, Spinach and oriental greens such as Pak Choi. Leafy greens typically grow from seed to seedling in around 14-20 days, and from seedling to harvest in 13-30 days. Production of leafy greens in the UK is seasonal, with heavy reliance on imports in winter. For example, in June, Britain produces 95% of its own salad leaves, whereas in January 90% are imported from EU countries like Spain[3]. Use of vertical farming can extend domestic production to grow all year-round. Although demand for leafy greens is high, they aren't worth as much per kg in comparison with herbs and microgreens. This can present a financial challenge, which in some cases has been overcome through applying economies of scale and building bigger farms.

3.3 Microgreens

Microgreens are on a continuously upward market trend in Europe due to their associated health benefits and fast adoption of indoor and vertical farming, especially in cities. Microgreens can have 40X more nutritional value than mature vegetables. They are rich in vitamins, minerals (Ca, Mg, Fe, Mn, Zn, Se and Mo) phytonutrients (ascorbic acid, β-carotene, α- tocopherol and phylloquinone) and antioxidants[4]. The most common varieties of microgreens include Amaranth, Mustard, Parsley, Radish, Cabbage, Celery, Chard, Chervil, Coriander, Cress, Fennel, Kale, Rocket, Beets, Basil, and Sorrel. Cereals such as rice, oats, wheat, corn and barley, as well as legumes like chickpeas, beans and lentils are also sometimes grown as microgreens[4]. The global microgreens market is expected to grow annually with 7.6%, reaching US$ 17,039.744 million in 2025[4]. Microgreens can be profitable in vertical farming

[2] https://www.cbi.eu/market-information/fresh-fruit-vegetables/fresh-herbs/market-potential
[3] https://www.bbc.co.uk/news/business-55408788
[4] http://managementjournal.usamv.ro/pdf/vol.21_3/Art72.pdf

because they are high value, gourmet crops. With a growing cycle of 7-21 days, many cropping cycles can be completed throughout the year leading to high yields.

3.4 Other Potential Crops

Hyper-control of growing conditions and nutrient levels and minimal human interaction mean that vertical farming has potential for production of medical grade plants and extracts. For example, prominent UK vertical farming company, Vertical Futures, is partnered with phytopharmaceutical company DePlantis Ltd. to grow an ingredient for a licensed medicine[5]. Pharmaceutical crops could be a profitable option for vertical farms, although production must be carefully controlled to ensure the required quality of plant and concentrations of active ingredient can be produced, and operations are in line with pharmaceutical industry regulations.

Another potential crop option for vertical farms is propagation of crops such as tomatoes, cucumbers, and flowers. These starter plants are high value and in high demand. Currently, many farmers rely on seedlings which have been imported from the Netherlands. Transplants can be sold on to greenhouse and field growers who produce the end products. Vertical farming ensures high germination rates due to the controlled environment. It should also be possible to reduce early pest and disease problems, due to the clean production environment.

4.0 Technology

4.1 Large Scale Vertical Farming Companies

There are several companies operating in the UK that develop, build and operate large scale vertical farms.

- **Jones Food Company (JFC):** A company specialising in designing, building and operating vertical farms. JFC's vertical farm in Scunthorpe, North Lincolnshire, was the largest vertical farm in Europe when it was launched in 2018. Measuring 5000m^2 and with 17 layers of stacked crops, the farm supplies 1/3 of the UK's basil demand. JFC is in the process of developing a 13,700m^2 vertical farm in Gloucestershire with backing from The Ocado Group[6]. When the vertical farm opens in late 2022 it will be the largest vertical farm in the world.

- **CambridgeHOK**: A company that works in glasshouses, construction, energy, supplementary lighting, and vertical farming. CambridgeHOK offer a design and build package to clients, which involves designing a bespoke vertical farm based on the client's needs.

The upfront costs of establishing a vertical farm are substantial. This is especially the case with large scale vertical farms, which can be expected to cost £1,000-£2000 per m^2 depending on level of technology[7]. Based on this benchmark, a 5000m^2 vertical farm could have a capital cost

[5] https://www.scientistlive.com/content/vertical-growing-technology-medicinal-herbs
[6] https://www.jonesfoodcompany.co.uk/our-latest-news/the-worlds-largest-vertical-farm
[7] https://cambridgehok.co.uk/news/how-much-does-vertical-farming-cost

of £7,500,000-£10,000,000, dependant on the level of complexity involved in construction, automation, and provision of attendant equipment.

4.2 Containerised Vertical Farms

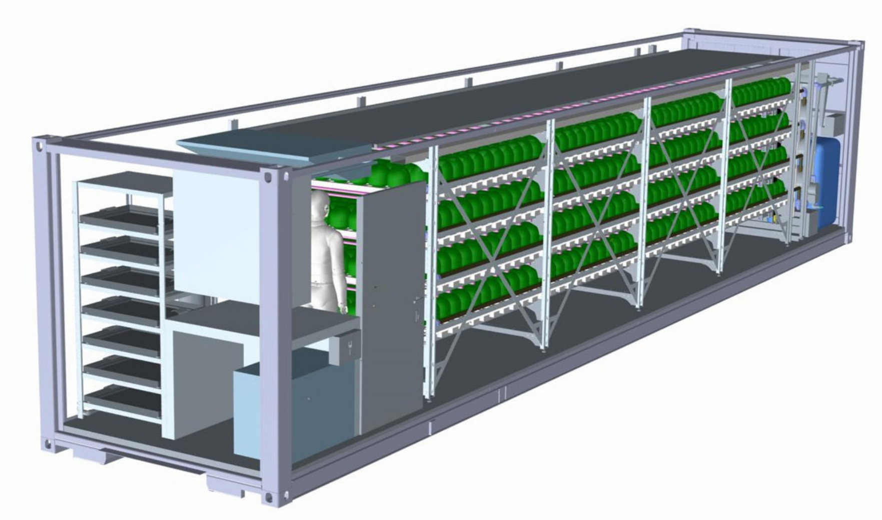
Modular vertical farms are turnkey vertical farm systems built within purpose-built shipping containers. Containerised vertical farms offer a scalable, mobile option which can be well suited to urban areas with little land availability, or where long-term tenure cannot be confirmed. They are convenient for first time growers, as producers can start with one module and add more as they gain experience and grow their business. There is likely to be a maximum number of containers after which it is more efficient to build a farm in a building for large-scale production.

DEL compiled a list of companies offering containerised vertical farming solutions. We narrowed the list down to four companies who have operational containerised vertical farms around the world. Of these, meetings were held with representatives from three companies.

- **LettUs Grow**: A containerised vertical farming company based in Bristol, UK. Offering the 'Drop & Grow' vertical farming system which comes in 24ft or 48ft container[8]. The system uses aeroponics, where plants are grown in a nutrient rich mist, which boasts 20% higher yields than hydroponics and uses a nozzleless system designed to avoid blockages. The system uses Ostara technology and software platform.

- **Bridge Greenhouses Ltd, in partnership with Urban Crop Solutions**: Offering vertical farming Grow Modules built in 40ft containers[9]. The four-layer hydroponic design offers 80m^2 of growing space per module. Bridge recommends combining modules, for example to create the Module X-8 Plant factory which is made up of 8 modules.

[8] https://www.lettusgrow.com/container-farm
[9] https://www.bridgeverticalfarming.co.uk/farmpro-container/



- **Freight Farms**: A vertical farming company based in Boston, US, with operational containerised vertical farms all over the world[10]. They offer the Greenery S, a vertical farming system in a custom built 40ft container.

[10] https://www.freightfarms.com/greenery-s

Table 2: Comparison of containerised vertical farming companies, using data provided by companies.

Containerised VF company	Footprint	Growing Space	Cost per Unit	Cost per m^2 of growing space	Expected yield	Power demand
	m^2/unit	m^2/unit	£/unit	£/m^2	kg/m^2/year	kWh/m^2/year
LettUs Grow	48	55	£135,000*	£2,455	Pea Shoots: 120 Basil: 38 Microradish: 228	Pea Shoots: 1,327 Basil: 2,177 Microradish: 2,045
Bridge Urban Crop Solutions	30	86	£ 157,622**	£1,838	Basil: 64 Microradish: 222	742
Freight Farms Greenery S	30	21	£104,249***	£4,871	129	3,155

*Price includes UK delivery, installation, and commissioning. Does not include operations area, VAT, or site evaluation.
**Converted from Euros. Price includes delivery, turnkey system, training, guided support for first harvest. Does not include post-harvest automation e.g. packing.
***Converted from US Dollars. Quote received of $139,000, plus $200 per month for control system software. Quote did not include shipping from Boston, we estimated $500 for this. Does not include Import Duty.

4.3 Conclusions

According to the information supplied by the companies, Bridge Urban Crop Solutions has the lowest capital cost per m^2, though this metric shouldn't be considered in isolation.

It is difficult to compare each company in a like for like manner, because the cost and specification information provided by each company differs slightly in comparison to the other. Similarly, yield and power demand are difficult to compare as they vary based on the crop grown, and some companies differentiate between crops whilst others do not. For example, Lettus Grow provided expected yield and power demand for three different crops, showing that basil has a higher power demand than other crops. Bridge Urban Crop Solutions provided a breakdown of yields for different crops, reporting a higher yield for basil than Lettus Grow and a similar yield for microradish. Bridge Urban Crop Solutions reported by far the lowest power demand but did not provide differentiation of which crop this power demand was based on. Freight Farms reported much higher power demand than the other two companies in the comparison. Freight Farms did not provide specific yield predictions for different crops, simply estimating "2-4 tons per year".

It is important to note that yield predictions from vertical farming companies are likely to be based on trials in small scale research units that are running at maximum efficiency 100% of the time. Therefore, companies' estimated yields may be best case scenarios. It is therefore important for growers interested in vertical farming to seek out and review case studies of other farmer using the same or similar equipment, and to conduct their own trials to get realistic yield estimations for their business plans rather than relying on companies' estimated yields. Use of newer varieties, which have been produced specifically for use in controlled environment agriculture, will be important to maximise yield and quality.

5.0 Capital Costs

Capital costs for vertical farms are significant. Potential farmers must scrutinise quotations provided by suppliers to ensure they account for all components required in a vertical farm. Prices provided by suppliers can be simplistic and it is therefore important that the customer breaks this down and factors in any additional costs. The elements included in capital cost depend on whether the vertical farm is in a container, an existing building, or a new-build. They also vary depending on whether the supplier offers a turnkey solution or not. The customer should check if their quote includes the following at a minimum:

- If applicable, building fabric such as foundations, metal frame, sides/cladding, roof
- Racking
- Connection to utilities (water, power, gas if required), plus any grid upgrades that may be required, and / or cost of integrating with onsite renewable energy supply
- Plant trays with pre-formed plastic insert in the bottom for channelling nutrient solution
- Equipment for cleaning trays and other components
- Transport system for plant trains, e.g. conveyor build, vehicle to move trays around
- Lighting system (some vertical farming companies include this, others will direct customers to a lighting supplier)
- Support for lights
- Air treatment system (filtering and cooling)
- Fan ventilation
- Drains and water treatment system
- Monitoring system for temperature, humidity, and CO_2 ppm
- CO_2 storage tank and pressure apparatus, piping into the building, and regulation system
- Nutrient mixing area
- Staff hygiene systems and equipment.

Anything not included in quotes from suppliers should be factored in. Additional costs to the quote are likely to include:

- Germination area
- Harvesting/packing area
- Site processing: Assessment, levelling, removal of soil
- Hard landscaping
- Access roads
- Security fencing
- External lighting
- Delivery costs and import taxes.

6.0 Operational Costs

Operational costs of running a vertical farm are complex, and estimations from suppliers may be simplistic. It is therefore important for growers to spend time on detailed calculations to predict operational costs and ensure that everything is factored into the business case, so as to be sure of the required yield and income required to generate a positive cash flow.

This section outlines some of the key important operational costs of a vertical farm to provide a high-level indication of viability, the first steps as part of an 'outline feasibility' study.

A detailed business case would consider additional operational costs such as seeds, packaging, cleaning equipment, software, insurance and maintenance costs.

6.1 Lighting

Energy use for lighting is one of the major operational costs of running a vertical farm. Cost can be estimated by a simple calculation using the specification of the lights used, hours of usage, the electricity price per kWh, plus the electricity standing charge. The hours of lighting will vary for different crops, which will affect the power demand and cost.

$$(Wattage\ of\ lights \times hours\ of\ use \times electricity\ price) + Standing\ charge$$
$$= Annual\ Cost\ of\ electricity\ per\ light$$

For example, if using the Philips GreenPower LED 120 to grow basil in a vertical farm with 100 LEDs, the power cost per light could be estimated as follows:

Wattage of lights	71W = 0.071kW
Hours of use	17 hours per day = 6,205 hours per year
No. of lights required	100
Electricity price	£0.20/kWh
Standing charge	£0.23/day

$$(0.071 \times 6{,}205 \times £0.20) + (£0.23 \times 365)\ x\ 100\ = £17{,}206\ per\ year$$

6.2 Cooling

Along with lighting, cooling is another major contributor to the operational costs of a vertical farm. LED lights are not 100% efficient so a proportion of input energy is released as heat. Because vertical farms are inside sealed buildings, they must be cooled, especially in the summer months to maintain optimum temperatures and avoid overheating. Cooling demand can be estimated by using external temperatures and desired temperatures to create a heat demand profile. This is a complicated process that can be done by specialist consultants such as District Eating Ltd. The output of the modelling will show the kWh cooling demand and in which months it is required. An environmental computer inside the vertical farm measures and maintains a set temperature and humidity profile for each crop.

Cooling can be provided by absorption chillers or electric chillers. Electric chillers have higher electrical demand but are more efficient, whereas absorption chillers use hot water as an input and require a smaller amount of electricity to run, but are less efficient. Support can be obtained from consultants to evaluate which is the best option. This decision will be dependent on the specific cost and carbon factors of heat and electricity for the project.

6.3 Staff

There is no prescribed number of staff required in a vertical farm. Depending on the level of automation, there is often little need for more than one or two members of staff in the growing area. Staff are needed to monitor plant growth and oversee automated processes. Because people increase the risk of contamination substantially, it is advisable to minimise the number of people required in the growing area.

More staff are often required for the sowing and harvesting phases, and for cleaning and quality control. There is no prescribed formula to estimate the number of staff required for a vertical farm, and requirements vary based on crop choice and equipment. However, a rough estimation would be that for a 5000m^2 farm you could expect to see 1-2 staff in the growing area, and a team of 10 overseeing planting, harvesting, quality control and cleaning, though again, this number can be reduced if levels of automation are increased.

A small container farm such as the Freight Farms Greenery S or LettUs Grow's Drop & Grow container only requires 15-25 hours work per week for growing, maintenance, processing, and cleaning. Therefore, operational costs for labour can remain relatively low.

6.4 Water and Nutrients

Water demand for vertical farming is relatively low compared to conventional agriculture and horticulture. A 30m^2 hydroponic container farm may use as little as 19 litres per day[11]. For larger scale farms, the amount of water required varies based on methods. To achieve the water savings advertised by vertical farming, it is essential that water is recirculated in a closed-loop system. Use will vary depending on equipment use. Suppliers will provide figures for water use in specifications. Customers should remember to factor in costs of water treatment, disposal of foul and wastewater disposal from the site, and standing charges.

Nutrients are supplied via hydroponic solutions in vertical farming. They can be purchased as individual fertiliser compounds or pre-made nutrient mixes. Fertilisers are diluted with water and mixed with calcium nitrate in nutrient mixing tanks in the vertical farm. The mixing, dilution and delivery of the required nutrient solution may be managed by an irrigation computer system. Collection, treatment, and recirculation of nutrient solutions may also be achieved using the same irrigation monitoring and dosing equipment. The cost of fertilisers has risen dramatically in the last year and is subject to market price fluctuations. The cheapest way to supply nutrients is to buy them separately and create mixes manually in the vertical farm. Advice on nutrient recipes for different crops can be sought from specialist advisors.

7.0 Yield

It is important to differentiate between gross and net yield. Gross yield is the total volume of plant harvested. Net yield is the weight of the marketable plant. The ratio of net yield to gross

[11] Based on Freight Farms container unit.

yield will depend on the produce specification agreed with the market outlet, but 10% can be used as an initial approximation.

DEL recommends that potential growers conduct their own trials and calculations to work out an estimated yield rather than relying entirely on suppliers estimated yields, which are often a best-case scenario. The following formula can be used to estimate yield:

$$No.\, vegetative\ plant\ sites\ \times\ no.\, growth\ cycles\ per\ year \times\ saleable\ weight\ of\ each\ plant\ (kg)\ \times\ [1 - assumed\ harvest\ failure\ rate\ \%]$$

For example, the yield of basil in a 30m^2 Freight Farms Greenery S container farm could be estimated as follows:

No. vegetative plant sites	13,000[12]
No. growth cycles per year	10[13]
Saleable weight of each plant	5g = 0.005kg
Assumed harvest failure rate	20%[14]

$$13{,}000 \times 10 \times 0.005kg \times (1 - 0.2) = 520kg\ basil\ per\ container\ per\ year$$

Yields will vary based on growing system, varieties in use, actual spacings, light quality and photoperiod irrigation and nutrient regime, temperature and humidity, air flow, CO_2 concentration, control of pests and diseases, and efficiency of operations. The numbers here should be used only as a demonstration of methodology, and trials should be completed for the actual growing system selected. Growers can expect higher failure rates in the first year of growing, whilst skills are learnt and developed.

8.0 Outline business case

An example outline business case was conducted for a vertical farm made up of 4 Freight Farms containers, producing basil. This was a simplified business case, to demonstrate the first steps required to get a feel for a project, and its likely viability. The outline business case considered the capital cost of the four containers, the operating costs of electricity, staff, nutrients and water, and the income from selling basil at current retail prices. A 20-year cash flow was completed, and financial KPIs were calculated to estimate likely viability of the project. This is a simplistic model that does not account for many costs including capital costs that are not part of the Freight Farms container farm, and additional operational costs such as seeds, hygiene equipment, packaging, maintenance, and insurance.

Financial KPIs are outlined in the table below, across several electricity prices to reflect the current volatility in the energy market. Internal Rate of Return (IRR) is a measure of return on investment, higher values are more attractive. Net present value (NPV) is the difference between incomings and outgoings, and indicates the profit.

[12] From Freight Farms specification booklet.
[13] Based on a 31 day growing cycle, as estimated by Bridge Urban Crop Solutions, allowing for time in between to sanitise and replant.

Table 3: Financial KPIs of the outline business case.

	Electricity price		
	£0.12	£0.16	£0.20
IRR	6%	2%	-4%
PayBack	11	16	0
NPV @ 20 years	£300,650	£84,873	-£130,905

This suggests that a vertical farm made up of four Freight Farms containers producing basil can be financially viable with an electricity price of £0.12/kWh. As mentioned, this is a simplistic business case. If a project is pursued a detailed business case should be carried out, including evaluation of different crop options.

8.1 Sensitivity Analysis

A sensitivity analysis was conducted to see how this outline business case varies with electricity price. The graph below shows that a positive IRR can be achieved if electricity costs £0.17/kWh or less. If electricity costs more than £0.17/kWh, the vertical farm is not profitable. This suggests that vertical farming could be vulnerable to increases in electricity price and volatile energy markets. Having a private wire agreement with a renewable energy producer could help mitigate this.

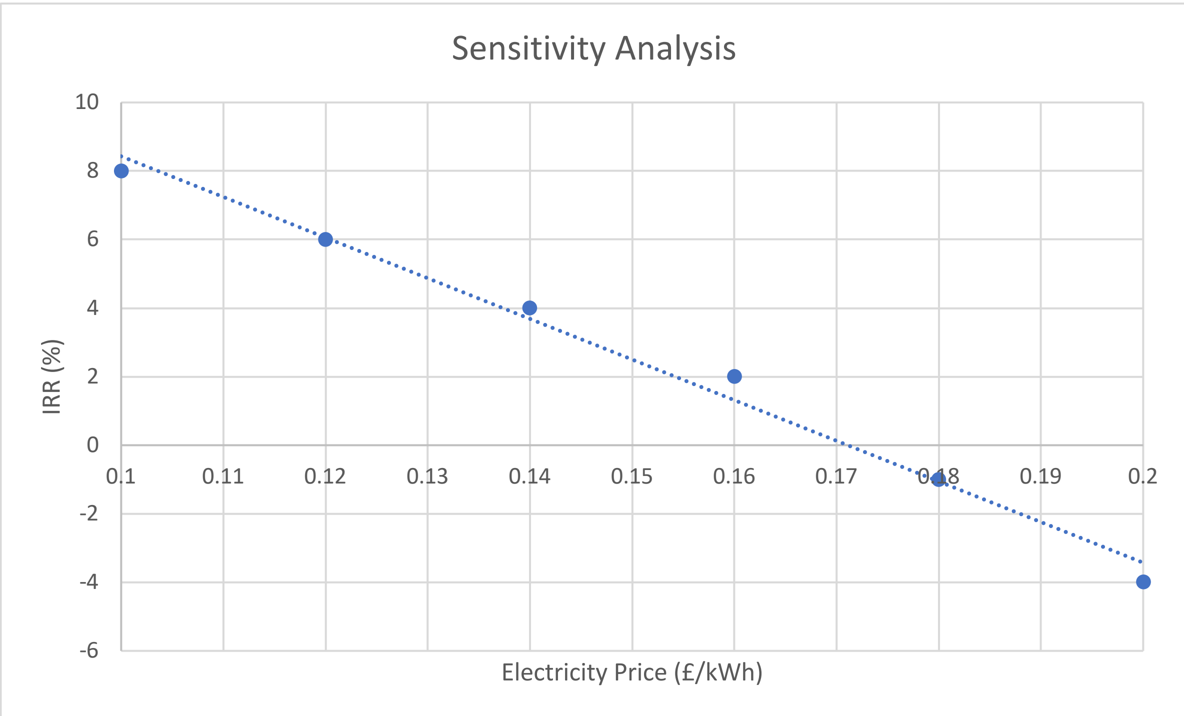


Figure 2: Sensitivity analysis of outline business case at various electricity prices.

It is important to note that this analysis is based on Basil price as of February 2022, which will likely increase as food market pricing is adjusted to reflect rising input costs. There is a lag time between energy and food prices, and at the time of writing, food prices have not yet caught up with rising energy prices. Detailed market research is required prior to setting up a vertical farm to understand the input and crop prices required for viability of the business case.

9.0 Practical Operational Requirements

9.1 Control systems

Vertical farms are monitored by control systems which maintain optimum conditions for growing and draw attention to any inefficiencies. Sensors located around the vertical farm monitor parameters such as water flow rate, nutrient levels, pH levels, electrical conductivity (EC) concentrations, humidity, temperature, and CO_2 concentration. These measurements are fed back to the control system, and inputs can be altered accordingly.

9.1.1 Lighting

The grow light spectrum is the electromagnetic wavelengths of light produced by a light source. Light spectrum wavelengths are universally measured in nanometres (nm). Plants use light in the photosynthetic active radiation region of wavelengths, which is from 400nm to 700nm. LED lights are used in vertical farming to maximise exposure to these wavelengths, thus maximising photosynthesis and plant growth.

Most vertical farms use a combination of red, blue, and white LED lights. Red light helps stem and leaf growth, encouraging the release of a hormone that prevents chlorophyll from breaking down. This helps produce large, healthy plants. Blue light helps create bushy plants with thick stems and lots of foliage and is particularly important for seedlings to develop strong stems. White LEDs give exposure to the full light spectrum, which has incremental benefits for plants as well as red and blue light.

Control systems can create lighting regimes that maximise the plants' exposure to wavelengths at the optimum time in the growing cycle.

9.1.2 Air Flow and CO_2 Concentration

Airflow must be controlled within vertical farms to ensure that plants have a consistent supply of oxygen and CO_2. If airflow is not properly maintained, it can create stagnant zones. As plants mature and become bushier, air flow rate around the base of plants can be reduced, which without care and adjustment can result in stagnant zones increasing the risk of mould and disease development. Monitoring and maintaining air flow is especially important as plants mature. Sensors monitor humidity, temperature, and CO_2 concentration, and adjust controls to increase airflow and prevent dead zones.

9.1.3 Water Flowrate and Nutrient Concentration

As with other parameters, sensors continuously measure flow rates, pH levels and EC concentrations. If sub-optimal conditions are detected, the irrigation control system will adjust pH and EC levels as required to maintain optimal flow rates and nutrient concentrations.

9.2 Managing Pests and Diseases

Whilst vertical farms aim to restrict the entry of pests and diseases, it is impossible to exclude them all together. Pests and diseases can be introduced via accidental contamination by employees, ventilation systems and uncontrolled use of doorways[15]. With such a high density of plants, it vital to prevent pests and diseases from entering the growing system and causing economic losses. Vertical farm operators should be prepared for the occurrence of pests and diseases and have measures in place for their control. There are various preventative and reactive methods of managing pests and diseases within vertical farms.

9.2.1 Minimizing Risk of Contamination

Hygiene measures are extremely important in vertical farms to prevent the introduction of pests and diseases. Preventative measures can include minimising the number of people that enter the growing area, filtering air that comes into the growing area, and requiring people who enter the growing area to wear protective clothing. It is common practice to wear a sterile suit, hair net and wellingtons when entering a vertical farm. At some vertical farms, employees go through an air shower which blows off dust and hair containing any mites, spores, or pathogens from the outside world.

9.2.2 Biological Control

Biological pest control is the removal of pests by their natural enemies into the farming system. For example, predators such as ladybirds, lacewings, ground beetles and mites consume the pests. If a particular pest problem is identified, predatory insects and parasites may be introduced directly on to trays with the growing crops, in order to establish a population of natural enemies. If a pest problem is anticipated, the introduction of the biological controls may be completed in advance of the pest development. The use of sticky traps may also help in the detection process and regular crop monitoring is also vital to success of these natural pest control systems. Pathogens

[15] https://www.researchgate.net/publication/339493920

that target specific host species can also be introduced. It is important to carefully monitor and record all developments when using biological control.

9.2.3 Use of Ultra-Violet light

UV light can be used as an alternative to chemicals to significantly reduce mildew and mould. UV light has also been found to reduce survivorship of mites. Using UV light requires additional capital cost and health and safety considerations. Therefore, need for UV light may be something to consider at the design and construction stages. This will also increase the cooling demand as UV LEDs only transfer about 15-25% of received power input into light, with the rest released as heat.

9.3 Staff, Machines and Robots

The following processes are required to be completed either by staff, machines or robots:

- Seeding
- Transplanting
- Harvesting
- Packaging
- Tray washing

The choice of whether these tasks are carried out by humans or robots depends on the scale, access to finance and the individual business case of the vertical farm in question. In small scale container farms, operations are done manually by humans. In large scale farms, robots are introduced to minimise contamination and increase efficiency. Tasks that still require humans include delicate operations such as seeding, plant trimming and removal of waste plants, cleaning, and quality control. Jobs such as moving plant trays can be done by robots.

10.0 Conclusions

- Vertical farming is a growing industry attracting attention from investors globally. Vertical farming offers the opportunity to grow hyper-local fresh food in urban environments.
- The most commonly grown crops in vertical farms are herbs, leafy greens, and microgreens. There are opportunities for vertical farming to be used to produce medical grade plants and seedlings in plant propagation.
- The supply of herbs, leafy greens microgreens could increase as more vertical farms are built at scale in the UK, which may result in crop price fluctuations. If supply increases, and demand stays the same, then prices could reduce. Therefore, it is advisable to consider other crop choices as well as those mentioned.
- Vertical farms have high energy demand for lighting and cooling. This leads to high operating costs and carbon emissions which can be prohibitive.
- Co-locating vertical farms with sources of renewable energy could provide a solution to this issue. The win-win point is the electricity price where producers are being paid more than they would to export to the grid, and growers are paying less than they would if buying from the grid.
- There are companies operating in the UK offering vertical farming equipment on a variety of scales. Small scale turn-key systems are available in the form of container farms.
- When obtaining quotes from vertical farming suppliers it is important to dissect capital and operational costs and yields.
- Capital costs for vertical farms are substantial and include many components.
- The main operating cost of vertical farms is electricity use. As such, the business case of a vertical farm is sensitive to electricity prices and may be vulnerable to the sharp increases we are seeing currently. Other operational costs include fertilisers, water, seeds and labour. Vertical farms have potentially low labour requirements as many processes can be automated.
- It is important to consider how pests and diseases will be managed in a vertical farm. This can be done through preventative and reactive measures, such as hygiene practices, the use of biological control strategies, and UV light.

Recommendations and Next Steps

- Consider whether a large-scale vertical farm or a small-scale container is required, based on market demand in farming, business ambition, and capital costs.
- Obtain quotes from vertical farming supplier companies.
- Consider potential crops and conduct detailed market research to confirm an outlet, or buyer.
- Contact existing vertical farms to learn and discuss methods, challenges, and successes.
- Find a suitable site with sufficient links to a source of renewable energy.
- Engage with key stakeholders at the chosen site and discuss options for connection to electricity source via a private wire.
- Conduct an outline business case as per the example provided in this report, and complete sensitivity analysis varying crop price and input costs to determine resilience of the business case.

- If the results of the outline business planning are positive, conduct an in-depth business case to evaluate economic viability.
- Build a supportive team. Vertical farms are expensive and crop production is a specialist endeavour. Get the support you need to maximise the chances of success.