A Nuffield Farming Scholarships Trust Report

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Vertical Farming: does the economic model work?

Sarah Hughes

July 2018

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A Nuffield (UK) Farming Scholarships Trust Report

"Leading positive change in agriculture. Inspiring passion and potential in people."

Date of report: July 2018

Title	Vertical Farming: does the economic model work?
Scholar	Sarah Hughes
Sponsor	AHDB Horticulture
Objectives of Study Tour	• To establish whether new methods in indoor farming provide an economical alternative for growers • To look at real examples following different business models • To find any best practice that can be shared with the UK horticulture industry
Countries Visited	Brazil, Japan, USA Netherlands, Dubai, Germany and UK
Messages	• There are business models where Vertical Farming/Controlled Environment Agriculture would work well • The business model needs to be robust as the technology and running costs are expensive • The technology is available to grow a wide range of crops in controlled conditions • Growing in a controlled environment requires high levels of understanding and technical skill • Securing investment for some schemes can be hard • A hybrid solution could be the best system for current glasshouse growers

EXECUTIVE SUMMARY

Media coverage of Vertical Farming and Controlled Environment Agriculture suggest it's the panacea to all our problems, ranging from: feeding a growing population, solving the environmental issues surrounding conventional horticulture as well as producing a high-quality crop where customers are prepared to pay premium prices. Is there any truth in these claims and if so what are the economics behind this growing system?

As a grower of edible flowers, which are processed and sold into a high value niche market, and living on a mixed sheep and beef farm in a Less Favoured Area of the UK, can the Vertical Farming model have anything to offer me? With increasing land prices, a shrinking and ageing rural workforce, increased climate variability and business challenges and opportunities post-Brexit - can this compact and highly productive growing system stack up economically as a viable way to grow a crop?

The report considers Vertical Farming and Controlled Environment Agriculture systems, the different crops and business models available, the main costs involved in the systems, advances in technology, the effects of automation and robotics, the stakeholders and investors and, finally, where is the UK currently in this industry.

The primary aim of the report was to look at examples in countries identified as being at the forefront in this type of growing system: Japan, the Netherlands, the USA, Dubai and Germany. It also covers other areas of technological advancement in the conventional glasshouse growing system to see if lessons could be learned here too. The findings should prove useful to growers considering investing in this technology, as well as stakeholders and investors considering ventures and partnerships.

The main issues occur when potential stakeholders focus on the growing method first i.e. Vertical Farming production techniques without first finding the best way to produce the crop as part of a robust business model. The technology is available to grow a wide range of crops under controlled conditions, but this requires high levels of technical skill and investment both of which can be difficult to access.

There are business models where Vertical Farming/Controlled Environment Agriculture would work well, such as seed breeding and medicinal plants; however other models, such as niche crops, fodder and leafy greens, appear more marginal.

Some of the arguments for sustainability are difficult to substantiate in relation to energy use, even if it is renewable energy. However they are more convincing when applied to water use. Data collection and plant growing algorithms are a valuable piece of intellectual property for companies, and the advances in light manipulation and the effect it has on plant growing characteristics are a new area of knowledge in this industry.

There is an exciting future for controlled environment agriculture and Vertical Farming, but it may not be in the crop areas which are hitting the headlines now. For conventional horticultural products a hybrid system may be the answer, taking the best of both systems to maximise growing production.

For those thinking of using this growing system the ideal would be to model all the variable costs of each different Controlled Environment Agriculture system to assess its economic viability. This could be revisited if the situation changes: for example as LED lighting costs reduce, electricity costs change, or conventional production method costs increase. This would allow potential businesses to assess when the 'sweet spot' was hit in terms of economic viability.

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1. Personal introduction

I live in Denbighshire, North Wales, UK, and have worked in the food and farming industry for the last 20 years; starting on the agronomy advisory side then moving into agricultural marketing. I live with my husband Philip (NSch 2001), and our two football-mad boys on our family farm, a mixed beef and sheep enterprise. The farm has diversified into tourism with a caravan park, renewable energy including solar, ground source and a farm-based Anaerobic Digester plant.

I run a separate business growing edible flowers outside and in polytunnels (www.eatmyflowers.co.uk) which are then processed into crystallised and edible flower lollipops. They are sold into the wedding, 5-star hotel and high-end retail market in the UK and abroad.


Figure 1: The author, Sarah Hughes

I studied Agriculture and Environmental Science at Newcastle University before training to become an Agronomist with Countrywide Farmers, then moving to work in a marketing role for Novartis and afterwards Syngenta Agrochemicals.

Outside work, much of my time is spent standing on side-lines watching football, rugby or cricket matches! Until recently, I ran the local Beaver Cub Scout group, and I am treasurer of our local village events group. I enjoy cooking, travelling and trying to keep my unruly Springer Spaniel under control. I am also on an ongoing quest to learn Welsh – Diolch yn Fawr!

2. Background to my subject

On our farm we have tried to diversify where possible, whilst also trying to manage our labour and return on investment costs. My own business model (www.eatmyflowers.co.uk) involves adding value to edible flowers. By controlling the whole supply chain through to the customer I can maximise the business's profitability. The limitations are a Welsh climate, high labour requirements and a very customer-focused model.

On my study tour I wanted to see if there were business models that used controlled environment agriculture (CEA) and hydroponic/soilless techniques that I could incorporate into our farm business model. I was interested in Vertical Farming as it seemed to maximise production whilst having a small growing footprint. I wanted to look at different crops being grown, technological developments in the industry, business models and the economics and future opportunities for the industry.

Some of the issues I identified, which we are facing on a national and local level both as farmers and in society, appeared superficially to have solutions in Vertical Farming and Controlled Environment Agriculture.

Issues such as:

1. **Increasing farm costs:** Since 1966 the average cost per acre of agricultural land has risen 4,805%: from £161/acre to £7898/acre in 2017[1], and rents have risen on average 50% in just the last 10 years[2]: which means returns must be healthy to justify investment.

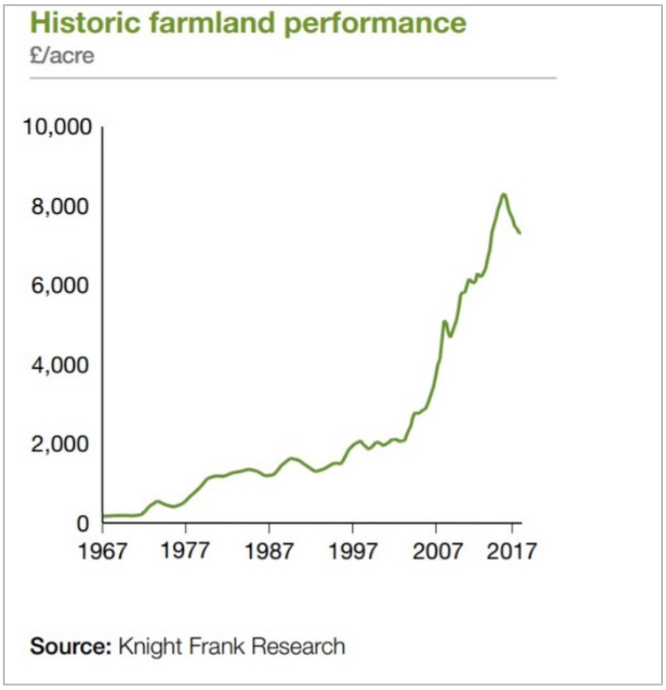


Figure 2: Chart to show historic farmland performance

See chart on next page: Rent/acre over past 10 years.

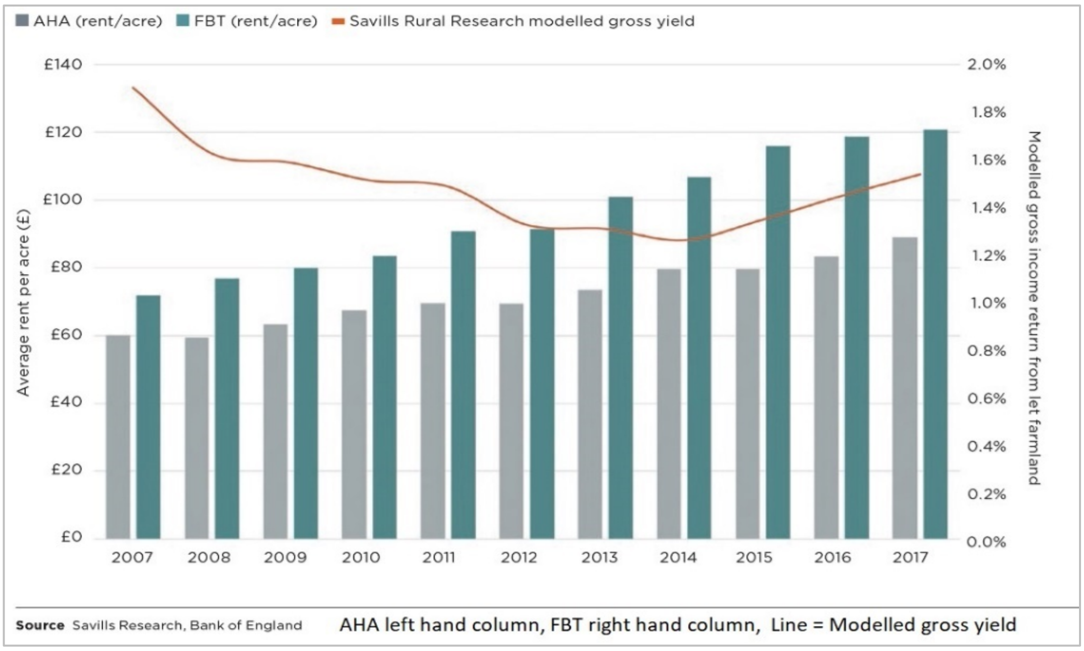


Figure 3: Chart to show farmland rents over past 10 years

2. **Changing rural workforce:** The difficulty facing rural employers in accessing skilled labour particularly in the horticulture industry is well documented and with Brexit this crisis is starting to have economic impact[4].

3. **Global supply challenges:** The UK has a fruit and vegetable self-sufficiency of 36.5% and imports high levels of fresh vegetables. In 2016 the UK imported over 6 million tonnes of fruit and vegetables[5]. With increasing energy costs and fresh produce coming in from all over the world should we be looking at more home-grown options.

4. **Climate variability:** Our usually temperate climate in the UK has seen a disrupted 2017/18 growing season. Starting with the 'Beast from the East' delaying crop planting, followed by the long dry spell, meant that farmers have had to use more irrigation in horticulture, and have had less grass for livestock/dairy farmers. In some regions farmers this summer are having to supplementary-feed their livestock with silage made for winter 18/19.

5. **New business opportunities:** The future of a mixed livestock farm in a Less Favoured Area is uncertain post-Brexit. Climate, topography and soil type all limit cropping options. Controlled Environment Agriculture (CEA) allows total control and an ability to potentially grow crops that would be impossible in normal conditions.

At the World Agtech conference I attended in 2017, Victor Friedburg, CEO of S2G Ventures, made the statement '*We're not at the beginning of closed system and Vertical Farming technology, but we're also not quite in the middle; we're at the end of the beginning*'.

With such a fast-changing technology and developments in data and Light-emitting diode (LED) lighting it is hard to get a balanced assessment of where the industry is. I have tried on my study tour to give a snapshot of current technology, where I think we might go in the future, and the opportunities for the UK in what could be an exciting time in Horticulture.

3. My study tour

March 2017	After the **Contemporary Scholars' Conference in Brazil** I spent an extra week of study in Mato Grosso – looking at farming practices in mega farms	**1 week**
April 2017	**Japan – Tokyo, Yokohama, Kyoto, Nagoya and Osaka** Japan has a high percentage of vertical farms, a wide range of technology and an advanced industry with different models and academic research on the topic	**3 weeks**
May 2017	**Netherlands** Wanted to visit some automated systems and see the advances in different crops and light usage in a very developed horticultural agricultural industry. Spent 3 days at the Global Forum for Innovation in Agriculture Conference and related tours.	**1.5 weeks**
Autumn 2017 -Spring 2018	Visited various academic institutions, attending the **World Agri-Tech Summit**, visited Vertical Farming and related companies in **UK, Ireland and Germany**	**6 days**
February 2018	**Dubai** I combined a personal work trip to Gulfood 2018, the world's largest food, beverage and hospitality exhibition, with looking at new VF projects in the region	**1 week**
April 2018	**US and California – Los Angeles, Central Valley, San Francisco** The West coast of the US has a high percentage of innovative farming systems. It is also the main producer of fruit and veg so I wanted to compare field scale vs 'closed system'. California is also seen as the leader in trends and wanted to see what was coming next – also to see fodder systems and novel crops	**3 weeks**
June 2018	**Netherlands** Trip to Wageningen University and to an intensive pepper and tomato producer using renewable energy. Agrifood Innovation – Vertical Farming Conference	**6 days**
Mar – June 2018	Various visits to sites and growers **in the UK**	**6 days**

4. What is Vertical Farming?

Trying to define the term Vertical Farming can be problematic. It can mean slightly different things to different people. Plant factories, Urban Agriculture, rooftop farms, Controlled Environment farms, Aquaponics, farming in a box are all terms in use. (see Appendix, Fig. 1, for various definitions according to Rabobank 2018).

For this report I have used these definitions:

- **Controlled Environment Agriculture (CEA**) – this includes: Plant factories/Container Farms/Indoor Farms: System for growing plants and vegetables under wholly or partially controlled conditions to allow crops to be grown throughout the year. These systems are soilless, and can control light, temperature, moisture and sometimes carbon dioxide artificially.
- **Vertical Farms**: As for indoor farms but in vertically stacked layers to maximise on growing space/m^2.

For different Vertical Farm or Controlled Environment Agriculture (CEA) systems some or all the growing conditions are controlled artificially. To achieve maximum plant biomass (yield) a crop needs to be grown in the optimum conditions of light, water, nutrients and Carbon Dioxide (CO_2).

This allows the plant to photosynthesise and turn light energy into sugars, releasing oxygen. **If any one of the optimum growing conditions are restricted this will be the limiting factor in achieving maximum yield.**

The chemical equation for standard plant photosynthesis to make glucose is:

6CO2(g) + 6H2O + photons → C6H12O6(aq) + 6O2(g)

(Carbon dioxide + water + energy from light makes glucose and oxygen)

I will go into more detail about new advances in lighting, Carbon Dioxide (CO_2) use and plant growing Instructions (recipes) in Chapter 7.

The theory behind Vertical Farms is that you are using the 'vertical' growing plane as well as just the horizontal. (See diagram on next page.)

See diagram on next page which demonstrates massive increase in crop production volume due to multiple layers and multiple cropping cycles in a Vertical Farming system

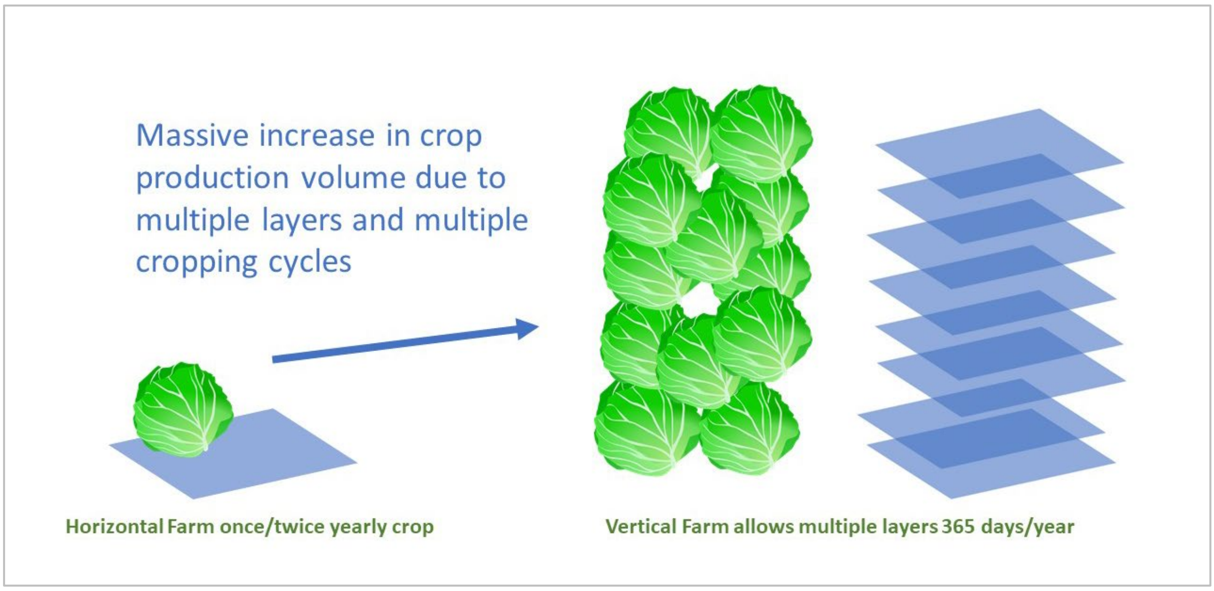
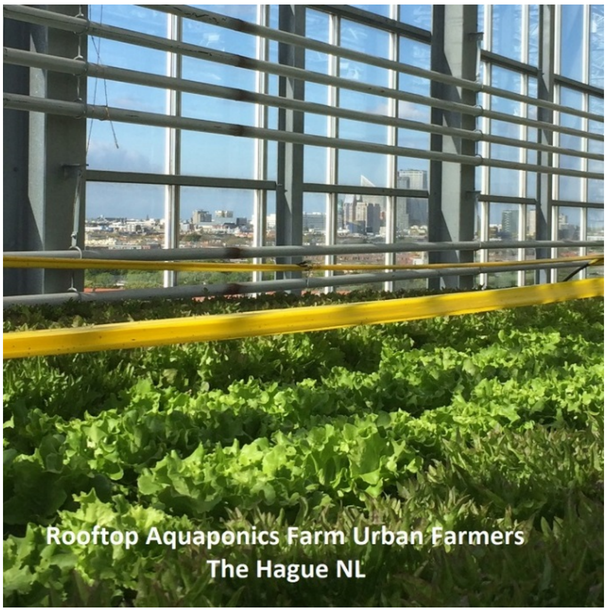


Figure 4: Diagram drawn by the author to demonstrate massive increase in crop production volume due to multiple layers and multiple cropping cycles in a Vertical Farming system

A simplified calculation for growing lettuce on the equivalent of 1ha horizontally might be:

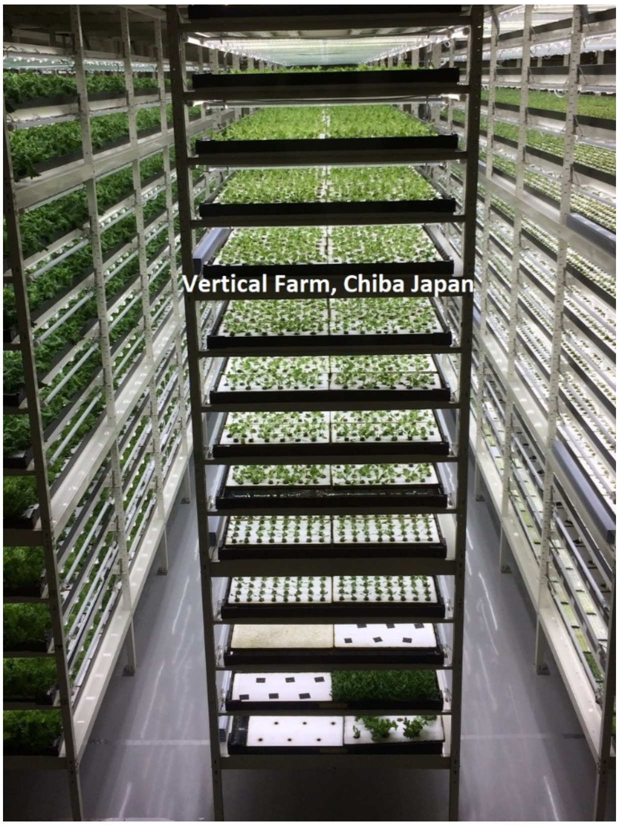
Growing area = 10,000m² ÷ 12 (30 day growing cycle 12* months/year) = 833m²
833m² ÷ 9* (number of stacked layers) = 104m²
104m² = the growing footprint of the vertical farm
*varies depending on crop – some can have 18 cycles per year others have less stacks

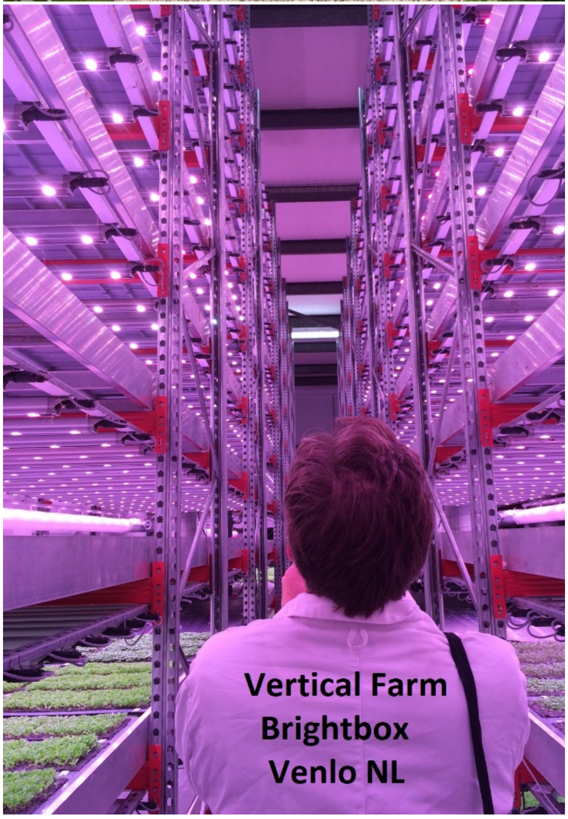
Some of the different Vertical Farming and Controlled Environment Agriculture Structures I saw on my study tour are shown below and on the next page.
(***known collectively as Figure 5***)




Pegasus Agriculture
Dubai


Copyright
Zipgrow Tower System USA


Vertical Farm, Chiba Japan


Vertical Farm
Brightbox
Venlo NL


Hydroponic Fodder System California US


Shipping container
Vertical Farming System NL

Within the types of growing systems there are a variety of methods to get nutrients and water to the plant roots. There needs to be a balance between the solution and also roots' access to oxygen (O_2) which is vital to growth and prevents moulds and fungus growing.

4.1. Different types of nutrient supply systems

Vertical farms always use soilless growing. There are 3 main type of feeding: Hydroponics, Aeroponics and Dryponics.

4.1.1. Hydroponics

These use a range of gutters and channels to move solution (water and nutrients) over the plant roots. For more detail on these see Appendices.

- Ebb and Flow
- Wick system
- Nutrient Film Technique (NFT)
- Deep water culture

4.1.2. Aeroponics

The solution is misted at regular intervals over the plant roots meaning they have a greater exposure to oxygen and can absorb the nutrients well. The disadvantage is the system must be running constantly, which has an energy cost and is more technology-reliant.

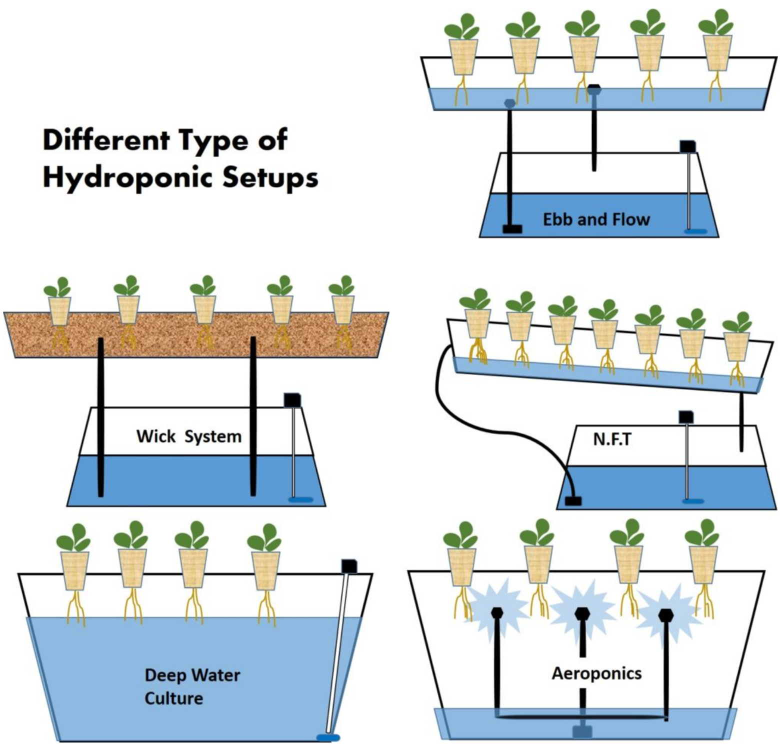


Figure 6: Diagram is widely publicised on internet

4.1.3. Dryponics

This is a new technique developed by Dr Yuichi Mori, Mebiol, In Imec®, a polymer physicist in Japan. Plants grown on a thin film made of hydrogel absorb water and nutrients through nano-sized pores. Viruses and bacteria are blocked by the film allowing a very safe product without the use of chemicals. Because of the film barrier and low water usage the crops grow slightly more slowly than normal which accelerates synthesis of sugar, amino acid leading to high sweetness and nutrition.

Figure 7: Dr Yuichi Mori, Mebiol, In Imec®. ***Source author's own.***

4.1.4. Other systems including Aquaponics

With any new technology there is always improvement and adaption on what is available. In this report I have not featured Aquaponics - which is the inclusion of a fish farming element - in the model, or Solar Algae fish farms (using sunlight to create algal blooms which feed aquatic species).

I visited two Aquaponic systems (Grow Up Box UK, Urban Farm NL) on my travels. In my opinion the fish species, Tilapia, didn't appear to be a high enough value product to justify the extra complications of the system. Both require complicated ecosystems to work, and success both economically and from a quality produce perspective seems very difficult. However, I have not looked further into these systems to gain a meaningful knowledge of the area.

5. Current examples of crops and business models

The popular image of Vertical Farming and CEA is of a world of leafy greens and micro-herbs and, whilst these crops predominate, they are not the only crops grown in these systems.

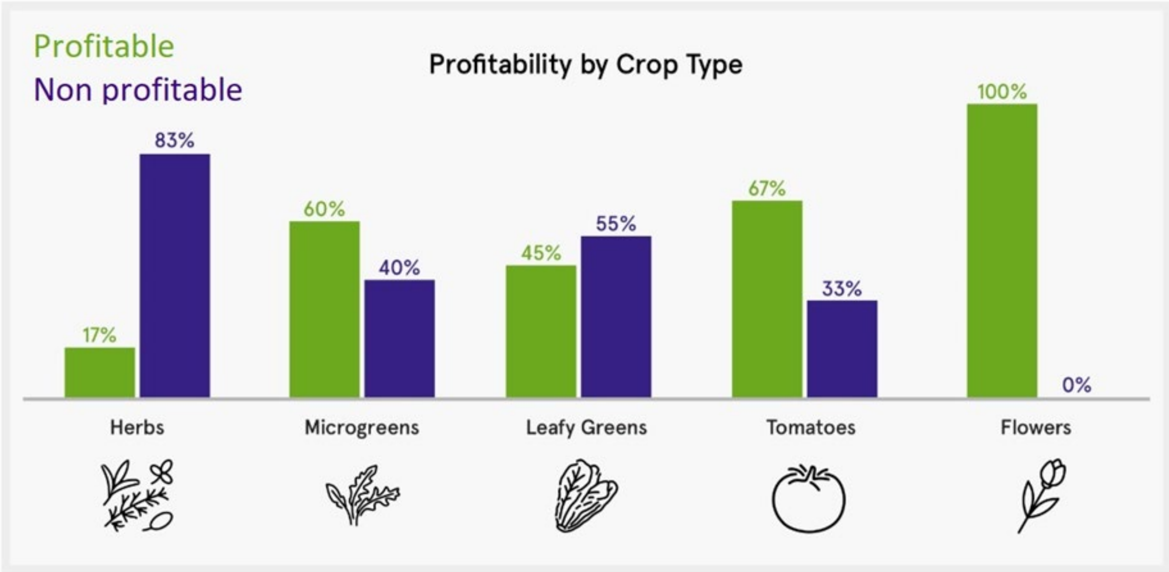


Figure 8: Profitability by crop type in US indoor farms (incl. glasshouses) ©Agrilyst Survey 2017

Looking at business models the overriding theme from experts in the field was: you need to think about your end market before you think about what system you are going to use to grow the crop. At **AgLanta 17 (US)** the panel was asked where to start with Vertical Farms. They said:

> *'What am I growing for whom? This should perhaps be rephrased as: who are you customers and do they want what you propose to grow? If you can't sell what you want for a profit with a sustainable business model you shouldn't even start in Vertical Farming. Market research is critical before you put down roots'.*

In this chapter I have covered some examples of common crop types and business models I have seen on my study tour.

5.2. High Value: Low Volume - herbs and micro-greens

Many VF systems are focused on growing Rocket (Arugula) and herbs such as Basil, Coriander (Cilantro), Oregano, Mint and micro-greens and edible flowers. The crops are easy to grow using this system and can be grown without pesticides (in the US they have Organic status).

These crops are being grown for the high-end consumer and restaurant trade. Micro-greens are the seedlings (cotyledon stage) of the larger plants. Much like the cress of the 1980s they've been re-branded as the must-have garnish to any discerning gourmet and chef. Growers of micro-greens claim that they have 40 times vitamins C, E, and K, lutein, and beta-carotene[7] of the full-grown leaf (but are considerably smaller!). By manipulating the growing conditions (light spectrum and nutrients) growers can bring out different characteristics such as flavour, shelf life and colour which can be individually tailored to specific customer needs.

POSITIVES: High value customer
High value crop
Crop suited to Vertical Farming

NEGATIVES: Difficult to scale (niche market)
Labour intensive
Affluent urban areas only
High levels of customer service

Figure 9: Image from ©Farmers Cut

Study Tour Example: Mark Korzilius, founder of Farmers Cut, Hamburg, Germany

Farmers Cut use a dryponics system to grow their micro-herbs, mini-vegetables and edible flowers. They feel this provides efficiency, compactness, hygiene and handling benefits over other systems. Mark, whose background was in the restaurant trade, freely admits that growing in a CEA system is not as easy as advertised and there is a lot of trial and error to get the system running smoothly and efficiently. He feels that their uniqueness to their customers (restaurants) is their ability to grow to order, the quality of their product and, due to his background, he feels the company really understands their customer providing them with the correct produce tray sizes that can be integrated directly into a kitchen setting.

5.2. High volume - Close to Customer: leafy greens and salads

With this type of business, the end consumer and shortening the supply chain (particularly regarding transport which reduces fuel usage and increases shelf life) is the focus. The customer could either be the consumer of the produce, a retailer or a distributor. The main benefits of this model are the financial and environmental gains in the economies of scale; automation; reduced supply chain; improved shelf life; and positive marketing messages for the end consumer.

For the larger farms it's this model that we often read about because it has had large, multi-million-dollar investments from private investors. The main reason for this is that to make the business model work the system must be large and highly automated. Either case is expensive to build.

There are downsides such as prohibitive rent or land purchase costs and there can still be distribution challenges. There is a risk that salad and herb crops can become a commodity and growers need to retain a premium price to cover the higher growing costs.

Study Example: Aerofarms CEO Dan Schechner

Aerofarms use a patented aeroponic growing system claiming 390 times the yield per square foot or per acre than field-grown. Their nine farms are mainly based around New Jersey US and they have just built the world's largest 70 000ft^2 vertical farm (based on output). *'The purpose of your VF will depend on your cost structure'.* They favour a closed-loop system and no pesticide use. They also partnered with US technology company Dell when developing their data software.

They believe the future crops will be varied, not just leafy greens, and envision a VF in every major city worldwide. Having a strong retail brand 'Dream Greens' is something that is a key part of their model. They have been very successful in attracting outside investment (see Chapter 8).

A hybrid of this system in CEA can be located on top of urban buildings such as supermarkets. There are already examples of this such as Gotham Greens located on a Wholefoods store in NYC, USA. Greensense Farm's Robert Colangelo sees the future of VF/CEA crops being at distribution centres. As supermarkets downsize due to new players in the food market (e.g. Amazon) he thinks there will be space to spare.

POSITIVES:
Shortened supply chain
Economies of scale
Can incorporate automation
Improved shelf life
Attractive to certain types of investors

NEGATIVES:
Expensive set up costs
At risk of producing a commodity crop
Expensive rent or property costs if in urban area

5.3. Plant Breeding: seed crops

Controlled Environment Agriculture/Vertical Farms can be useful in 2 ways for plant breeders:

a) It speeds up the lifecycle allowing more generations per year and therefore shorter timescale for breeding programmes.
b) It allows current seed catalogues to be tested in CEA conditions to monitor performance and then to be sold into the CEA market specifically.

Seed breeders are limited by geographical location as to number of crop lifecycles. With the advancement in CEA you can effectively create the perfect breeding climate all year round allowing for numerous generations in one year (See Chapter 9: Where are we currently in the UK?).

Nunhems Vegetable Seeds (BAYER) found that some tomato varieties leaves turn yellow and died under LED lights and the ones that thrived didn't always perform under glasshouse conditions.

POSITIVES:
Multiple crop generations
Can create specialist growing environments
Allows selection of seed for CEA growing
Extends current seed portfolio
Can breed for specific characteristics (e.g sweetness)

NEGATIVES:
Need to know final growing conditions (outdoors/indoors) to make sure the seed performs well there too.

Study Example: Monsanto: Dr V K Kishore - Solanaceous Breeding Lead

Several Vertical Farming systems in Japan grow a Monsanto variety of lettuce which grows well in CEA growing conditions. Monsanto believes that the role of genetics in seed/plant breeding will drive the industry forward. They feel barriers to entry into the vegetable industry can be relatively low both financially and from a knowledge level, hence expect to see more innovations in this space and high competition. Their aim is to breed more light-efficient varieties meaning you could increase light and decrease growing period or vice versa (reduce energy needs). Some of the growing traits of interest are:

- Early and uniform fruiting
- Rapid biomass & multi-harvest capability
- Photo-induced quality traits (using LED's to change colour or flavour)
- Auto-harvest plant architecture (allowing automation for harvesting)

5.4. Medicinal/ Plantceuticals/Biofactories

As society becomes more affluent there is a move to creating bespoke food for the customer. The industry for medicinal or plantceutical plants is new but appears to have large growth and value potential. As treatments such as medicinal cannabis become legalised and other medicines or treatments able to be grown in plants are developed, this becomes a financially attractive business model and crop.

Study Example: Dr Celiene Nicole Senior Plant Researcher Signify NL (previously Philips lighting).

Dr Nicole has shown that by manipulating the growing conditions specific plant characteristics can be enhanced. Whilst working on reducing Nitrate levels in CEA-grown lettuce (an issue in low light level growing) Philips created a pre-harvest growing recipe that accelerated the nitrate reductase enzyme whilst also reducing nitrate levels in the irrigation. Whilst monitoring other nutrients during the project they found that the Vitamin C mg/kg in rocket and spinach was significantly higher than in a kiwi fruit.

Study Tour Example: Prof. Aalt Bast Professor Toxicology Maastricht University

Prof. Bast suggested that the future of managing health conditions might be through the food we eat. Plants specifically grown to be high in anti-oxidants or Flavonoids – (which is the only cure for non-alcoholic fatty liver disease affecting 90 million in the US) comes from colour in vegetables – which following on from similar colour control results in Lollo Rosso lettuce could possibly be manipulated using LED spectrums?

POSITIVES: High value crop
Consumers want personalised nutrition and will pay for the privilege
Positive population health implications
Total control allows consistent high-quality plants
High biosecurity levels suited to the 'pharma' industry

NEGATIVES: Potentially closed industry (highly regulated contracts)
Will personalised nutrition only be available to the wealthy?

5.5. Guaranteed Customer: fodder and energy crops

My Scholarship journey started on this crop section as I felt there was good potential to integrate it into a livestock system. With up to 6-8 weeks of lost forage this year in Wales due to difficult weather conditions I wanted to see if the economics of 365-day growing could compare to conventional silage production in North Wales.

I visited some farmers who were using hydroponic fodder systems: some on a small scale and others on a larger scale. They were all using barley as the grain and sprouting it for about 7 days to form an edible carpet (or biscuit in US) which is fed entire, including the roots, to the livestock. I wanted to look at whether it was possible to grow an energy crop using this system as we have an Anaerobic Digestor at home and, along with our livestock, have a ready market depending on time of year and grass availability for this. As calls increase to remove effective 'double subsidy' on growing maize as an energy crop I thought there may be some mileage into looking into this area. Whilst finding lots of information and proposed projects on growing new or novel energy crops (see Fig.29) I couldn't find one that was up and running to visit[8].

Study Tour Example: Gina Bornino Miller - Templeton Farms San Luis Obispo CA

Gina and her husband built a state-of-the-art 52-acre sport horse training facility in nearby San Luis Obispo, Ca. They provide 5-star livery and facilities for sport horses and have housed and trained many champions. The horses are fed on tailored diets much like elite athletes and Gina was keen to offer them fresh fodder year-round in a region with water availability issues and a climate not ideal for unirrigated pastures.

She investigated growing barley sprouts (hydroponically grown green fodder) and purchased a system from the company Fodder Works©. Gina feels the system has worked well for her: it is simple to use once they got used to it. She admits that not all clients want to pay extra for fresh fodder as part of their ration but she feels that nutritionally it is a good choice and has had it analysed by her equine nutritionist (See Fig.30).

Study Tour Example: Dr MD Steve Collins, MBE a beef farmer, in West Cork Ireland also has a doctorate in human nutrition.

Steve, who co-founded the Dingle Dexter Beef Company, fed his 60–70 mountain Dexter cattle on a mix of hydroponically grown barley and straw using a 'Fodder Solutions' system. He has been using the system each day for 6–7 years and fills 42 trays with 2.0kg grain/tray. This results in 400-500kg fodder on a 6-7 day growing cycle (grain to fodder) requiring approximately 1hour of labour/day to manage. The system provides a consistent, daily supply of fresh feed. The feed contains high protein levels, but with less starch than grain. Over 90% of the feed is digestible and the entire mat of feed is edible so there is no waste. This is what Steve felt were the positives and negatives of the system:

POSITIVES:

- Compared to organic ration, costs were much less for the barley fodder €350/MT organic barley grain c.f. €550 for organic ration. The energy content/MT is slightly higher for the barley. The labour is an added cost to the system of about 1hr/day.
- Increase in availability of micro nutrients by breaking down phytates which bind minerals in the digestive tract (for example in rolled barley). The animals remain in good health.
- Increase in the content of some essential amino acids such as lysine (lysine is not synthesised by livestock so needs to be taken from the diet)
- Increased Vitamin content – e.g Vitamin A increases hugely
- Simple system to use, very low inputs
- Uses organic barley off-the-combine as long as it is double cleaned (sometimes problems with quality and viability of the barley) resulting in poor germination so fodder biscuit doesn't bind as well.

NEGATIVES:

- He felt there was no increased weight gain on a Hydro barley diet. Carried out some technical trials with a local research college - Tralee IT - which showed that when they were given a diet with equivalent energy content, those fed on concentrate gained weight faster.
- Contamination of sprouted barley by fungi is a risk if it is longer than a 6 – 7 day cycle
- Some difficulty in feeding the 'feed carpet' as the cows are so keen on the fodder that they throw it around and eat every scrap off the floor. This can lead to wastage and also inadvertently picking up pests (worms) from muck on the floor
- Energy loss in the sprouted grain and was this compensated for by the increased nutrient availability?

His future recommendation would be to mix with straw and chop feed through a diet feeder to prevent some of the physical feeding issues and also to co-sprout some legumes with the barley to increase protein – or to include some protein concentrate in the diet. (See Fig 10 for Nutritional Cost comparisons between different types of winter feed.)

5.6. Specific parts of lifecycle: floriculture and seedlings

I came across this business model which seems to have evolved as a practical solution to growers (often for larger plants unsuitable to Vertical Farming) to allow them to 'fast forward' parts of the growing cycle to gain a competitive advantage:

Study Tour Example: De Hoog Orchids NL

Greenhouse solution company Certhon NL worked with Orchid specialists De Hoog, focusing on a specific period required in middle of the orchid lifecycle where they need to be kept at a constant cool temperature to aid flower set and create a consistent number of flower buds. Using LEDs and automation with Vertical Farming to aid this they created a solution that has worked well. *Image below is courtesy of ©Certhon NL*

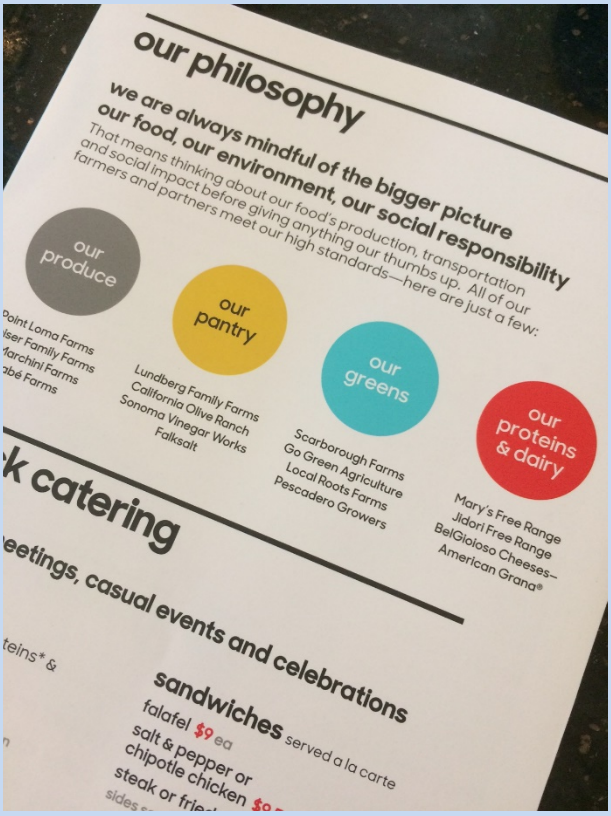
Another example is of the Dutch lettuce grower Deliscious. (Chapter 7.5: Use of robotics) who grow their seedlings using this method.

5.7. Working collaboratively: various crops

If too many similar ventures open in a small area the risk can be that there is over supply and the price drops: good for the buyer but not the grower. One way to combat this is to work collaboratively with other producers. For example, one CEA grows leafy greens, the other basil and the other micro-herbs. They may all supply into the same distributor, but they are not directly competing. Other collaborations benefit both partners from an ethical or practical perspective.

Study Tour Example: Local Roots Farm LA:

Los Angeles restaurants use the ethos and local credentials of Local Roots produce as a marketing aid for their restaurant. By association the two companies complement each other. *See photo of their menu below.*



Study Tour Example: Agriport 7, Netherlands

From a brown fields site on the outskirts of Amsterdam, Agriport 7 has developed to be a high tech, large scale glasshouse development of separate companies who work together to gain advantages in energy, CO_2 and supply chain sourcing. Companies specialise in individual crops (e.g. orange peppers, green peppers, tomatoes etc) but supply into a central distribution system. This involves lorries arriving at the site regularly and collecting produce from each grower which, combined, provides the whole spectrum of vegetables but has big savings in supply chain costs for the co-operative..

5.8. Larger crops: tomatoes and peppers

Due to their higher value both financially and nutritionally there is a wish to move towards growing crops such as strawberries, tomatoes and other vegetables using CEA. I didn't visit any systems using a complete CEA but did visit tomato and pepper growers using hybrid systems. They were grown under glass using solar energy, hydroponic nutrient systems, with some using inter-row lighting and enhanced Carbon Dioxide (CO_2) in the environment. Due to the sophistication and investment in many glasshouse systems the return on investment isn't favourable to growers. I will be looking into some glasshouse developments later in the report.

Study Tour Example: Chiba University, Japan Professor Toru Maruo

Professor Maruo manages the Plant Factory at Chiba University. This includes hybrid glasshouses/polytunnels, a vertical farm and various other facilities growing tomatoes under different natural and artificial lighting systems. Within the facility they are researching how to grow high yield varieties such as Torisia and Levanzo in a glasshouse CEA by controlling variables such as CO_2, light levels and nutrient levels. They found that by limiting Nitrogen (N) they can enable higher planting densities by reducing the leaf area of the plant whilst still retaining yields.

Figure 10: Dr Maruo and PhD student

5.9. Speciality crops: Saffron

Due to the startup and running costs of Vertical Farming Systems the aim is often very high value crops. I wanted to see if there were other high value crops that could be grown vertically or hydroponically. Having seen **Laan Tulips in Avenhorn NL** and how they forced their tulip bulbs for flowers I wondered if other crops could be grown in a similar fashion.

5.9.1. Saffron

At Milan Farm in San Francisco they have successfully grown saffron hydroponically, which demonstrated that it was technically possible. However saffron, whilst retailing at £520/100g, requires 100 000 flowers per 0.5kg of spice. With each stigma needing to be processed by hand it starts to look less appealing.

Figure 11: Saffron growing hydroponically

I asked **Robert Colangelo of Greensense Farms US** where he saw the future of crops for VF? He said:

'It won't be commodities or tomatoes/peppers etc as they're grown so well in conventional greenhouses. Growers should become experts on all types of leafy greens, seedlings to grow on, botanicals and plant-ceuticals'.

In the next chapter I will look at some of the main costs involved in these types of systems.

6. What are the costs involved?

Overview

The major argument against CEA and Vertical Farms is the high build and running costs. In this chapter I have focused on the main costs and how some of the farms I visited have tried to offset them. I also wanted to look into the real costings, financial and environmental, and spoke to experts in their field who had researched this area specifically. It was difficult to gain an accurate handle on actual costs and profits as the 'headline' figures were generally always positive. The spotlight regarding costs and profitability is very much shone on new start-ups in a growing business. More established businesses tend to avoid such scrutiny, either through years of ironing out operating cost glitches or due to the fact no-one questions them carefully on their business model and costs.

Robert Colangelo (Greensense Farms) explained how he thinks you need to make Vertical Farms profitable: '*Automation – this is important but doesn't have to be all the way through. Backend, inputs and delivery are the most important. Also, location of the farm near to the consumer or distribution hub'.*

Some of his costings on his farms are outlined below, alongside some average costs for Japanese Vertical Farms.

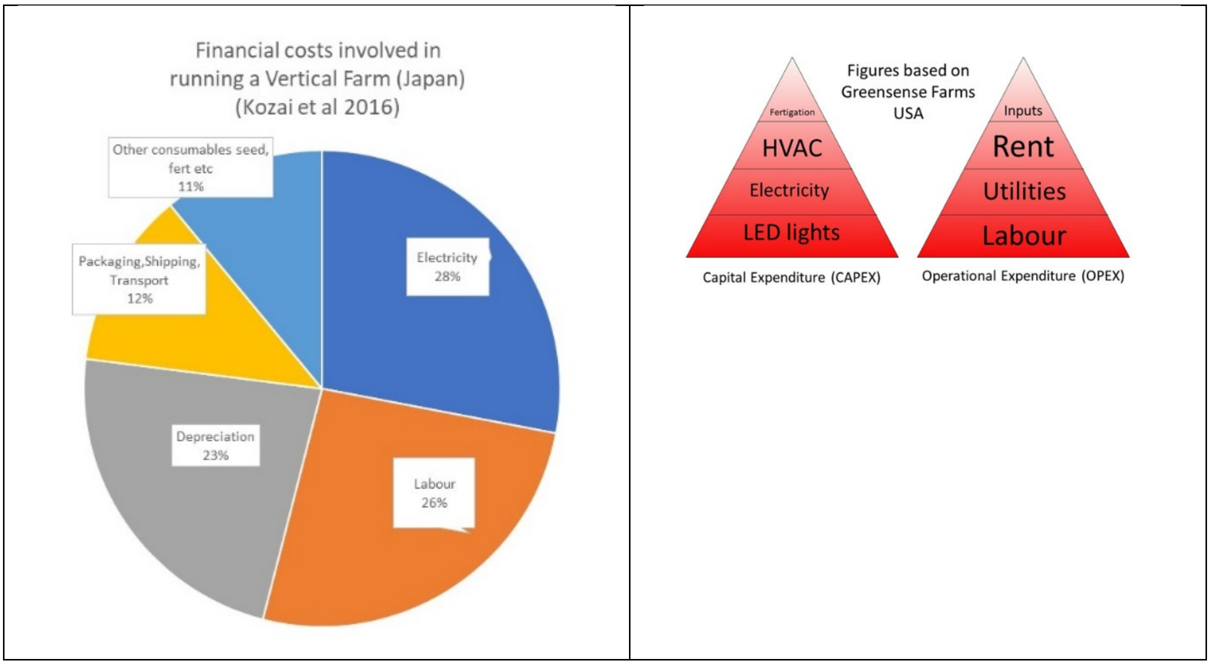


Figure 12: Some of the farm costings for Greensense Farms alongside some average costs for Japanese Vertical Farms

6.1. Build Costs

Build costs will be affected by the complexity of the growing system.

Example: Shipping container model Freight Farms[9] Leafy Green Machine™ USA. They have a Turn key 'farm in a box' (shipping container) system starting at $85,000. A real-life example they use is a Seattle-based chef-turned-grower who has two LGM™ systems growing 50% Basil, 50% Romaine. The workload is 25–35 hours/week. His revenue is $121,212 with costs of $17,712 for Labour/supplies and $49,332 for Rent, Distribution & lease. The NET = $54,168 [*Source: Freight Farms]*

At the other extreme a large scale fully automated (data and mechanically) system may cost upward of €800/m^2. Figures from VF & Glasshouse Automation specialists **Logiqs NL** suggest an investment split per m^2 of €300 lights, €300 structure and €2-300 automation. To make an automated system work as an investment they suggest you need 50,000m^2+ of growing space to be economical.

6.2. Energy – heat and power requirements

As everything is artificially controlled, all lighting, climate control HVAC (heating, ventilation and air conditioning) require an energy source to run. The more drivers you use (temperature, CO_2, lighting, nutrition, water) the higher your yield/m^2/ year.

Proponents claim that CEA and Vertical Farms have strong sustainability credentials. While this may be the case regarding water (see below) **Dr Cecillia Stanghellini (Wageningen University)** thinks it is not so clear when it comes to energy. She has compared glasshouses and CEA energy usage.

6.2.1. Economics of glasshouses and solar energy

Conventional glasshouses are solar collectors – some (PAR and near infra-red NIR) is trapped as heat. Too much can cause issues for plant growth, so ventilation is used to control temperature. A closed system needs to use fans and air conditioning to remediate this. Different parts of the globe require different glasshouses depending on solar levels.

It's assumed that in warmer climates closer to the equator growers have an advantage due to higher solar radiation. The figures do not back this up. Work carried out by the Dutch shows that production costs, whilst being cheaper in Spain, also result in a shorter growing season with lower value crop in comparison to a Dutch tomato grower. Working with PhD student Esteban Baeza Romero who compared the costs of both systems, they demonstrated a better cost:benefit ratio due to the higher yield in the Dutch greenhouse. This combined with a higher sale price means it is more profitable to grow in a Northern climate than in a Mediterranean climate.

See diagrams on next page.

It's cheaper to add energy than it is to take it out. Therefore, the UK and other northern hemisphere climates have a competitive advantage on sub-tropical regions with glasshouse production. Fig 27, World Isolation Map, shows the amount of solar energy in hours, received each on an optimally tilted surface during the worst month of the year.

Plant factories (CEA) needs high levels of energy to produce crops. The energy required to produce 1kg /dry weight lettuce in a plant factory is 1500 MJ kg_{dw}^{-1} whilst in a Dutch glasshouse it is 600 MJ kg_{dw}^{-1} due to the use of solar energy[10].

The other argument in favour of plant factories is sustainability. While this works with water, Dr Stanghellini doesn't believe the figures stack up for energy usage.

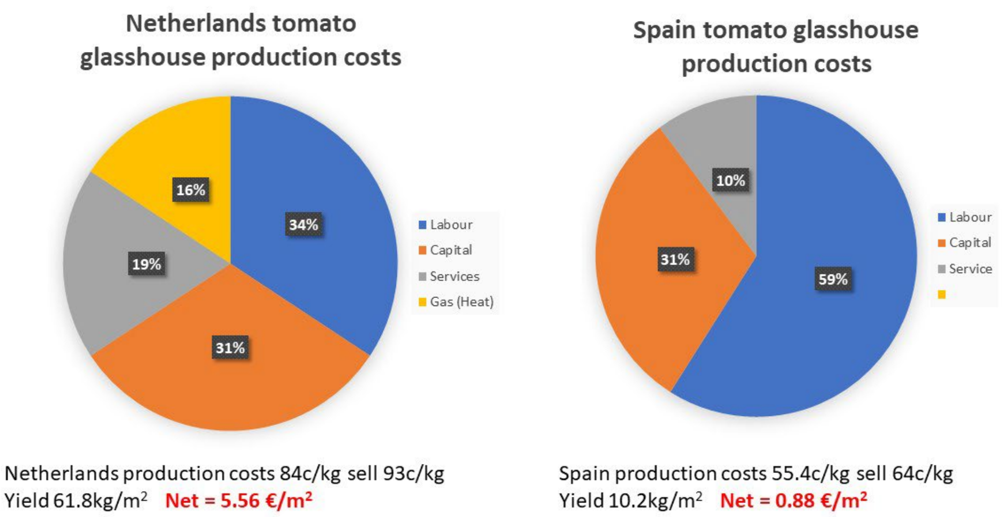


Figure 13: Charts compiled by the author

For anyone wanting to find out more detailed comparisons in energy use Dr Stanghellini and her colleagues recently published a paper.[10]

6.2.2. Renewable energy and co-location

Using the figure that Dr Stanghellini and her colleagues provided for the energy needed to produce 1kg/dry weight of lettuce, they then translated it into a CO_2 cost (often used to measure carbon footprint of a system).

She explained that the carbon footprint of the energy producer (whether conventional or renewable) would need to be below 25g/KWH CO_2. If this is compared to the chart showing the carbon footprint of renewable energy sources only some are below 25g/KWH CO_2 , one being nuclear.

I couldn't find a definitive figure for the carbon footprint of an Anaerobic Digestor, but I imagine it would vary depending whether it is run on food/animal waste or a crop has been grown for feedstock (e.g. maize).

(continued over page)

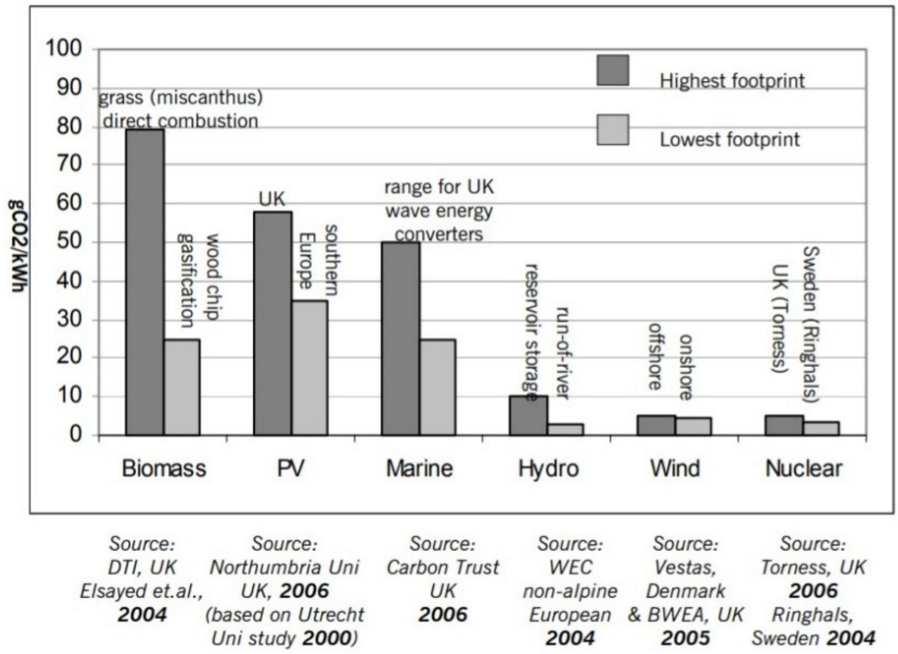


Figure 14: Range of carbon footprints for UK and European "low carbon" technologies.
Source: UK government

Co-location to address energy requirements

It seems an obvious solution that CEA and VF should be built next to producers of excess heat, CO_2 or energy. However, the negative can be that the grower isn't in control of when the 'waste' resource is available. A UK grower told me the they had investigated co-location where heat was a waste product. However, this was produced at times when not always needed in the glasshouse (production was linked to electricity feed-in tariffs). It's important to have an aligned interest between the two parties with a clearly contracted 'resource' agreement for the economic duration of the project.

Study Tour Example – Agriport 7, The Netherlands and Microsoft

At orange pepper growers Barendse-DC, part of the Agriport 7 greenhouse development, they started by using natural gas to run three Combined Heat and Power (CHP) engines to produce electricity and heat for their glasshouses. A waste product from the process is CO_2 which is purified and used in the glasshouses. Whilst they still use the CHP, due to the price fluctuation in piped gas, they have invested in a geothermal heat exchanger along with 8 other local companies. The project at Agriport A7 uses heat pumped up from the ground from 90C-35C at a 2.8 km depth.

A new project they are now embarking on is to provide power to a new €2 billion 11 Ha Microsoft server hub being built and, in return, will receive Microsoft's excess heat which will be used to heat the glasshouses.

6.3. Water and Nutrients

It is suggested that around 95% of all water taken up by plants is lost through transpiration. In closed systems nearly 100% of the water transpired can be filtered and returned to the system. Although some water is lost in cleaning and in the growing medium, it is stated that these systems use 90% less water than an open field and 20% less than enclosed hydroponic systems (see Fig. 28 in Appendices: Average daily water use).

Study Tour example: California USA Water issues

Whilst travelling around the horticultural growing areas in California I saw irrigation being used on a massive scale. The systems varied from flood, to spot treatment to spray systems. California has major water usage issues with increasing urban and agricultural requirements. Recent prolonged droughts have resulted in depleted reservoirs and consequential over-pumping of aquifers which is only a short-term solution. If the recent weather patterns become a norm the US's most prolific horticulturally productive region will be facing big water access issues.

6.4. Labour

Labour is the largest operational expenditure (OPEX) that VF/CEA's experience. As well as the wage costs there is also an issue for farms being able to access the required skilled labour needed to work in these specialised conditions.

In Japan finding labour in agriculture was a big issue as the majority of young people had moved to the cities for office-based work. At a high profile indoor agriculture example I visited in Tokyo, (Parsona Group HR). They had incorporated CEA into their whole working environment which they felt had enormous building, worker welfare and worker retention benefits. As a secondary benefit it also allowed them to develop a new department within their company which was training agricultural workers to fill the demand for highly skilled indoor farmers.

Figure 15: Head of indoor agriculture and staff training Parson Group JP

The farms I visited were often highly sterile environments more akin to laboratories than conventional farms. Employees wore protective clothing and sometimes face masks to carry out their tasks. If this is combined with optimum growing conditions such as high temperatures, increased CO_2 (whilst still being safe to work in), changes in light spectrum (e.g. pink) and the possibility of working at height using scissor lifts - it may not be an appealing job for many people.

Robert Colangelo (Greensense Farms) suggested at GreenTech 2018 that on a 20,000ft^2 farm (approx 0.2Ha which is 2.4Ha (0.2 x 12 crop cycles/year)) you would need about 10 people to operate it.

At the same event **Jan Westra from Priva** quoted from the 2017 Agrilyst report on Indoor Farming suggesting 56% of Operational Expenditure was labour (see Appendices. Labour Type by Facility).

6.5. Light-emitting diode (LED) lighting

Currently the majority of horticulture and floriculture crops are grown under solar light under glass and a move to LED lighting is seen as too expensive. **Esteban Baeza Romero**, a Spanish PhD student from Wageningen NL, investigated the optimum conditions for plant growth. Plants were being grown under glass in a project to optimise winter light (by an increase of 10%) in Bleiswijk, NL. In Northern Europe, light is the limiting factor for the growth of the crop in winter. He found that a clear glass and a permanent, high light-transmitting, diffuse layer of plastic film parallel to the glass produced the best results for crop growth. Other research looked at using filters to blocking natural UV light. The results showed:

POSITIVES	Faster growth in young leaves and salads
NEGATIVES	Possibly effect pollinator activity Produced 'softer plants'

They also looked at ‘smart glass’ that became opaque when dry, and clear when wet, to reduce solar radiation in hotter climates.

They found that the most efficient gain in light levels, amounting to a 10% increase, was to keep the roof clean: a cheap and low-tech solution. (*Kempkes WU*)

Figure 16: Smart glass. Photo courtesy of Esteban Baeza Romero, Wageningen University, NL

7.0. What's new in Technology and Automation?

In this chapter I cover some of the new things I have seen being used in the CEA industry, and look at how the move to automated systems is trying to cope with the issues surrounding labour.

7.1. Lighting

As mentioned in the previous chapter, light levels are crucial in growing success. Light Emitting Diode (LED) lighting is a key variable in vertical and CEA. There has also been major advancement in the understanding of how different light spectrums, intensity and frequency can affect the phenology (plant characteristics such as size, shape, colour, physical structure and flavour) without using genetic interference [Dr Celine Nicole].

The efficiency of the best LEDs has improved by 40% over the last 5 years. However, whilst some in the industry think there are more gains to be made, others such as **Neil Mattson**, a professor of plant science at Cornell, suggest that these gains will start to slow down as there is only a finite amount of light at any one spectrum.

AHDB Horticulture have funded work at Stockbridge Research Centre on 'Manipulating Light for Horticulture'. At a workshop they demonstrated findings showing the scope of this technology.

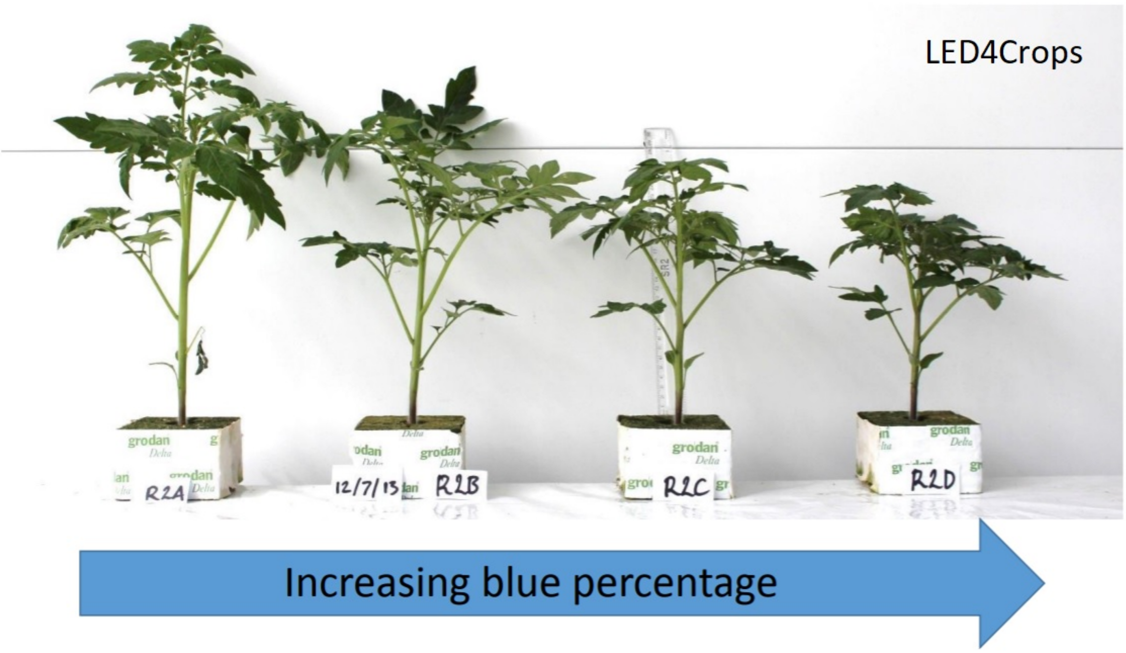


Figure 17: Manipulating light for horticulture. ***Source AHDB***

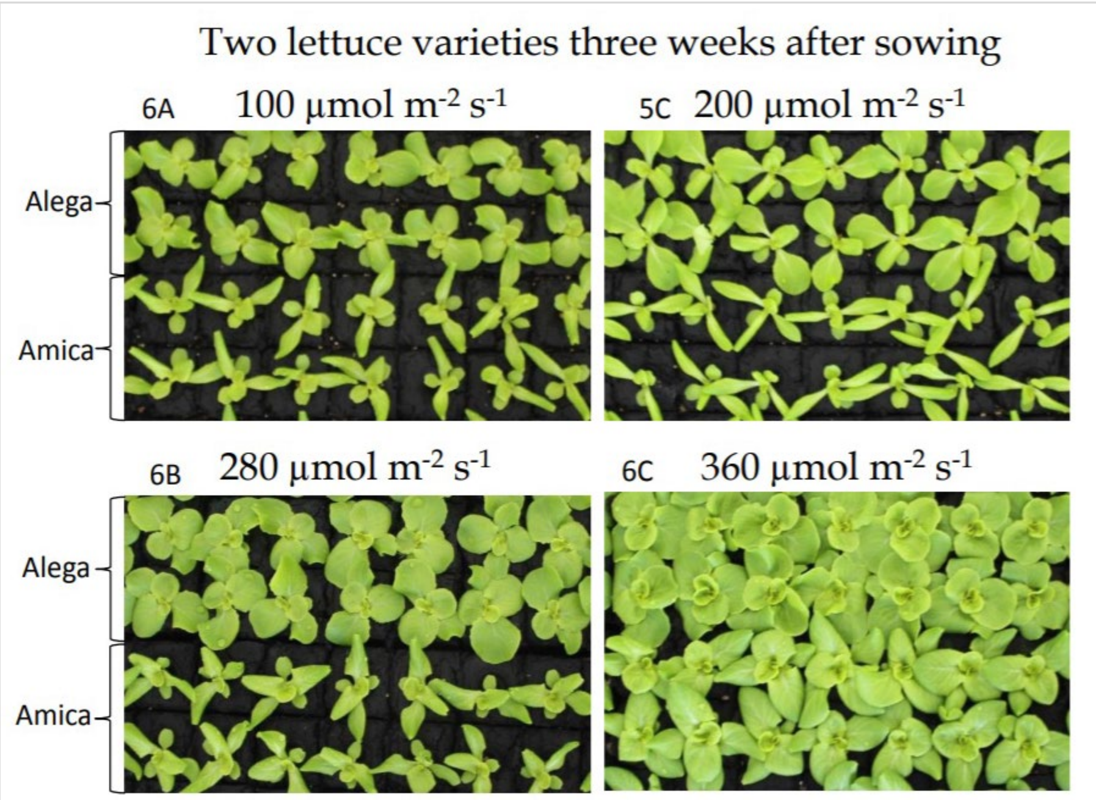


Figure 18: Image showing the effect of increasing the light intensity resulting in faster growth rates and more robust plants. [*source Stockbridge research AHDB*]

Study tour example: Osram GmbH Germany
(image courtesy of ©Osram GmbH)

Sebastian Olschowki, Plant Biologist, explained that they have developed a new tuneable Horticulture LED Research Light (Phytofy® RL) which can deliver light treatments with varying wavelength and intensity e.g. far-red end, Ultra Violet and night interruption light. The company hopes that system will be used to develop plant-specific light recipes (algorithms) in the growing research phase of different crops. They feel the future could be medicinal, such as Calendula spp. or growing antivirals in tobacco plants.

Dr Celine Nicole (Signify) thinks that the biggest effects on growth and quality are on the edge of the visible spectrum. Two leading companies in the LED field are Philips (now Signify) and Osram.

7.2. Carbon Dioxide (CO_2)

To optimise yield you must optimise all the inputs vital to plant growth. One of these is CO_2. More advanced CEA systems are using between 800–1200 ppm CO_2 in climate enrichment systems, which is still a level that can be worked in safely by humans. As mentioned in the sub chapter on co-location (6.2.2), CO_2 can be a biproduct which is then re-used or, alternatively, it is pumped in directly to the growing system. Dr Celine Nicole explained that optimum growing parameters need to be known for each crop before you plan the growing system. If you are not enriching the CO_2 levels, there is no point increasing light as that may not be the limiting factor.

7.3. Data – plant recipes and algorithms

Collecting and analysing data about growing in CEA and Vertical Farming conditions appears to be the way that many CEA companies are using their Intellectual Property to commercial advantage. They discover what the exact algorithm or plant recipe - in terms of lighting mix, temperature, CO_2 and growing conditions - requires time and research. Often companies will be selling a turn-key, sometimes fully automated growing system, but retain control of the growing recipe which allows them a level of insurance and something other than a physical product in their portfolio.

Study Tour Example: AgTech businesses in California

Eric Ellestad, CEO Local Roots, Los Angeles
Local Roots use a food computer to create algorithms for each crop. They see themselves as food scientists allowing each plant to have an optimal recipe for maximising growth, yield and flavour characteristics. Artificial Intelligence (AI) and Deep Learning (mining data and then adapting the outcomes depending on the results) by the computer allows the algorithm to be constantly tweaked to create the ultimate plant-specific recipe.

Babak Hodjat, CEO Sentient Technologies, San Francisco, said:

> *'We can now manipulate plants in a non-GMO way (no DNA changes) by varying the light spectrums and other growing variables. By varying the light spectrum in a certain growing phase of Basil the volatiles (flavour chemicals) are increased in some ways. We are creating characteristics of GM crops using non-GM methods.'*

Caleb Harper, Dir. Open Ag MIT Media Lab, stated:

> *'Ideally all the data that comes out of the work done in CEA (Closed Environment Agriculture) would be open sourced. This would allow start-ups and other companies to access the work done and incorporate it into their systems. From a commercial perspective however, many companies have*

invested time and money into their data, algorithms and plant recipes and this is what provides their commercial advantage.

We'd like to see a situation where the CEA systems were used to find the ultimate growing conditions for certain crops e.g. a high protein legume, then using this algorithm or plant recipe to find the right climate and conditions in the world that matches, to then grow if most efficiently.'

Study Tour Example: Netled, Finland

I had intended to try to visit Netled in Finland as I had identified them early on as being advanced in automated growing systems. Logistics didn't work out in the end, but I caught up with **CEO Niko Kivioja** at an International CEA event. They currently grow high value greens and plug plants for the horticulture industry, and have been running a 500m^2 facility successfully for 2 years now in Finland. With a good knowledge base they now offer a turn-key solution for growers. They have developed a patent-pending water-cooled LED lighting that can be combined with a heat recovery system. Automation computer programmes keep the growing environment optimal. In Finland electricity prices can vary hourly so they use their algorithms to adapt conditions to match the economics.

7.4. Pest and Disease control

One of the most impressive things about the vertical farms and CEA I visited was the high levels of biosecurity. I have never worn so many white coats, protective hairnets and blue shoe covers in my life and I even had an air shower (fully clothed!) whilst visiting a facility in Japan.

The reason for this high level of biosecurity akin to food processing plants is that the growers have realised that at the same time as creating the perfect growing conditions for their plants this can often be the very same perfect conditions for a range of pests and diseases. The constantly changing potential contaminant source are workers who go home every night, returning the next day with a new range of potential crop hazards – hence the high biosecurity.

The major positive is that the crop can be grown without the use of pesticides which in the US allows it to have an Organic status. This is not the case in Europe. Producers are fighting back with talk of 'Beyond Organic' labelling, arguing it is the pesticides that consumers have issue with, not nutrients and lighting.

(See diagram on next page)

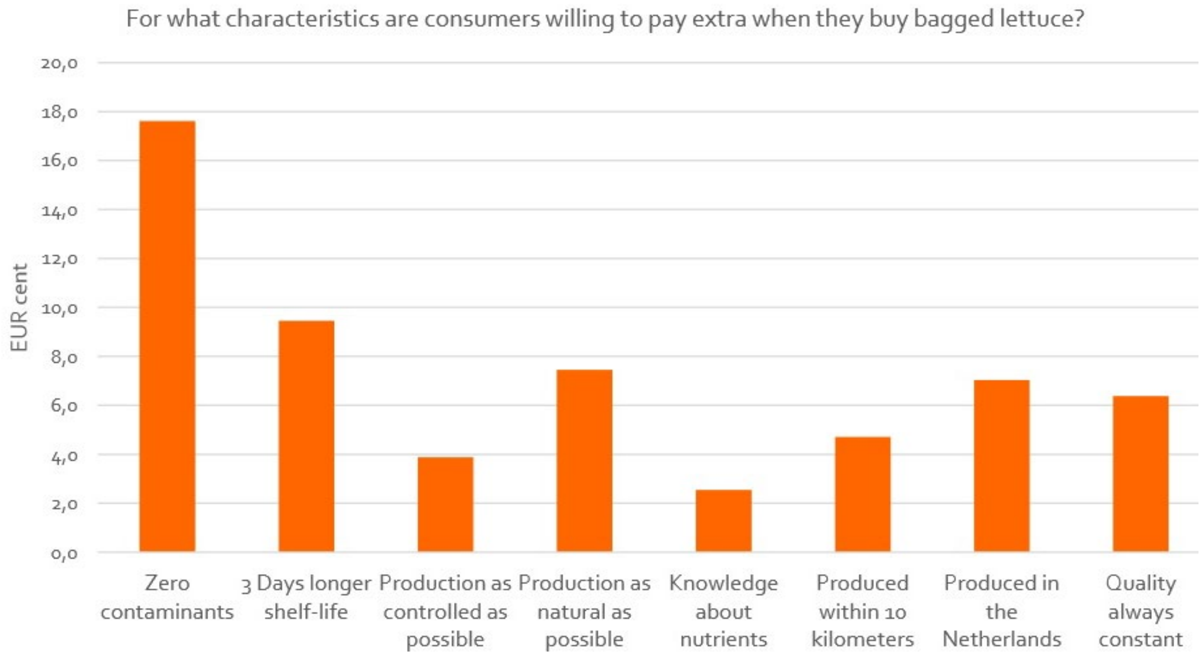


Figure 19: Diagram to show for what characteristics consumers were willing to pay extra when buying bagged lettuce. ***Chart courtesy of Rabobank***

In this Rabobank survey (non-statistical) above, Dutch consumers placed zero contaminants as the most important characteristic that would be willing to pay extra for in a bagged salad.

7.5. Automated Systems

During my travels I was surprised at the lack of automation within the Vertical Farming industry. I imagined an 'Amazon distribution' style system with trays of varying growth stages being moved between growing areas. The reality is that I had to look hard to find examples of where automation had been used and in many cases I looked to the 'conventional' glasshouse and horticulture model to see it in practice.

Most vertical farms use stacked growing trays with corridors in between with scissor-lifts being employed to get the workforce to various heights for tray management and movement. Common sense and some basic maths tell you that this can't be economical or advisable from a health and safety perspective. Some system designs have tried to overcome this issue with differently engineered systems (Pegasus, Ziplock) but there is still an issue working at height. As labour is a key cost within conventional glasshouses - mainly at sowing and harvest - trying to reduce the need for it is a driver with automated systems.

7.5.1. Large scale automation

I've included 2 examples here, not all from CEA, but I feel they all have interesting solutions to problems. *See overleaf.*

Study Tour Example 2: California – bush tomatoes

Whilst visiting Davis University, California, Professor Heiner Leith took me around some of the research they were carrying out on indoor farming. He also took me to a site where bush tomatoes were being planted and explained how the system worked. In a large 60 acre (24ha) field there were only 4 workers planting out the bush tomatoes using the specially designed planting machine. From planting to harvest the seed company, who sell the plant plugs, have developed the machinery to plant and harvest their variety. The breeding of the tomato variety was parallel and crucial to the success of the system. Growers that weren't part of the project and who had opted for other harvesting techniques ultimately went out of business as the new machinery/plant variety offered so much economy and production savings and couldn't be used on other tomato varieties.

7.6. Use of robotics

Study Tour Example 3: Gert-Jan van Staalduinen Greencube – Logiqs NL

The company provides an automated system based on a pallet-and-lift method, with robots going up and down with trays, moving backwards and forwards depending on growing requirements.

It is 50% more productive than conventional non-automated systems. Maximum could automate to 40m (0.9m/layer) = 45 layers of growing. With such a high stack good climate control is needed in the system or the variation between layers will be too great. Three systems are already in place using this model to smaller and larger degrees. With 50,000+ m^2 growing space they're not big enough to be economical, and they suggest that this is why most VF are not automated.

Robotics has been heralded as the answer to most things and on paper it is very appealing: a machine to complete repetitive tasks 24 hours a day in any growing conditions: moving towards 'hands-free' greenhouse/plant factories with robots working 24/7 doing repetitive tasks. Benefits include no down time, and a lean system. The negatives are it is expensive, and technology isn't there yet. At Wageningen University robots are being developed to aid with harvesting of vegetables such as peppers, but it is thought that this will never be a 100% solution: so you will always need humans to control the robots. The ideal is to get automation to the parts of the growing chain where it is becoming difficult to get people to work.

Study Tour Example – Deliscious lettuce growers NL.

Certhon, a greenhouse solution provider, built a very specific vertical farm growing solution for a lettuce seedling cultivation system using LED lights. The growing system needed to use a robotic arm that individually picks the young plants with root ball before placing them onto a growing tray where they then mature using conventional glasshouse methods.

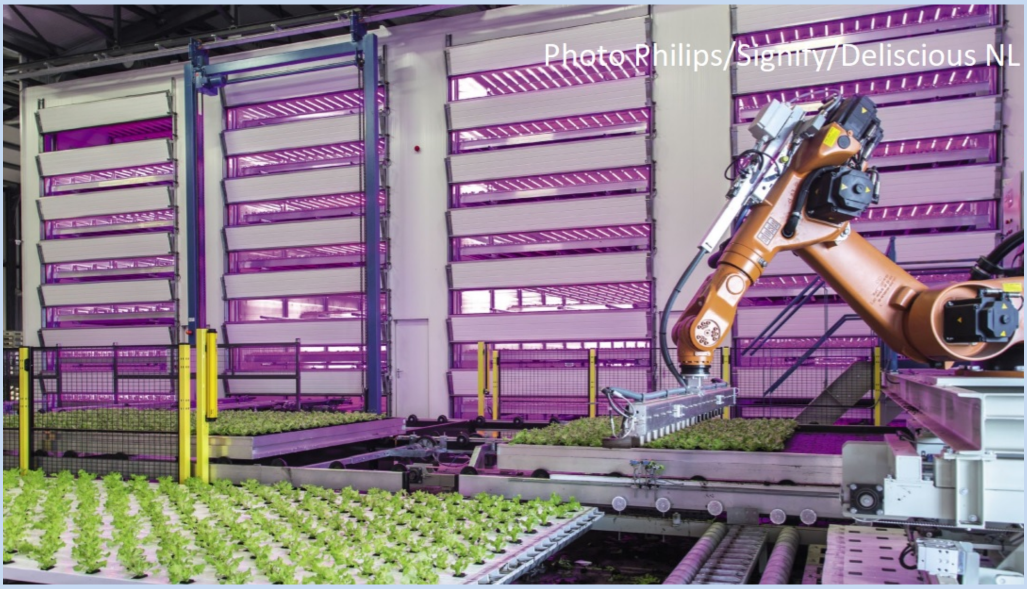


Figure20: Robotic arm

Study Tour Example: Barendse-DC NL

This innovative company produces 30 000kg of orange peppers per day. They export 95% of them, mainly within Europe, to the US and Japan. On the enormous scale they grow (30ha site) both the logistics and practicalities of moving picked produce around is an issue.

As labour resource becomes scarcer they have had to look to new ways to solve the problem. They have introduced automated robotic trollies that follow a pre-marked route taking picked peppers to the packing house from the glasshouses.

See picture of an automatic robotic trolley on next page

Figure 21: Picture of automated robotic trolley at Barendse-DC NL

8. Who are the stakeholders in CEA?

Headlines often talk about "different series rounds of funding" when it comes to Private Investors or Venture Capitalists. (for a basic interpretation of investment series see Appendices.) High profile investors like Kimbal Musk and Amazon boss Jeff Bezos make the headlines - but are these multi-millionaires the only people interested in CEA?

I wanted to look at what other types of stakeholder or investor were becoming involved. With some of the examples I found instances and talked to people involved, whilst others are speculation from what I have seen of the industry and its developments.

8.1. Private Investors and Private Equity Firms

These can be wealthy individuals or firms investing on behalf of wealthy individuals.

Study Tour Example: Wheatsheaf Group UK

When looking at agricultural investments, the Wheatsheaf Group are keen to take the long-term approach: looking at up to 30-year return on investments as opposed to a shorter-term that a conventional venture capitalist might aim for. In 2015, along with GSR Ventures, MissionPoint Capital, and Middleland Capital, they led a $20 million investment in US based Vertical Farming Company Aero Farms (who currently have $95.8 million total investments). Wheatsheaf were impressed by the company structure of Aero Farms, the high quality produce, its strong plant knowledge, and company principles which were all underpinned by a solid understanding and capturing of the data.

Venture Capitalists: SoftBank Vision

Between 2016 to 2017, venture capital funding for vertical farming increased by 653% from $36 million to $271 million. The majority of this went to California-based company Plenty. They received $200 million of their Series B funding from the SoftBank Vision Fund led by Japanese billionaire Masayoshi Son.

It might be argued that the SoftBank Vision fund is more akin to a Private Equity Firm than true Venture Capitalists who want to see fast returns on investment.

8.2. Banks

Study Tour Example: Rabobank – Lambert van Horen Horticultural Analyst

Rabobank have looked specifically at Vertical Farming and CEA to decide what their investment policy would be. They looked at what were the trends driving VF? They concluded that these included:

- Modern retail model
- 365-day production of crops
- Private equity funds are available for seed investment
- Sustainability requirement in food production
- Increasingly urbanisation population
- Food safety and demands for quality
- Limited resource availability e.g. water, sunshine

However, they felt that there were some disadvantages to some business models:

- High initial investment costs
- High energy costs compared to conventional glasshouse using solar light
- Varieties of crops not all are suitable for artificial growing
- Legislation – building regs, worker conditions, is it organic or not
- Social considerations – are VF grown plants accepted by the consumer

They felt that the Organic question could really be the difference in value of the crop in Europe. In the US VF-grown has regained organic status, whereas in the EU it has never been categorised as organic. They weren't convinced that European consumers wanted VF-grown salads. In their consumer survey on a bag of €1 salad consumers said they would pay an extra €0.18 for a 'clean' product – i.e. not grown with any pesticides and no insects.

Private investors have shown a strong appetite to invest. RB don't believe it's the solution to feed an increasing global population as the set up and running costs are too high. They don't feel it will be a viable investment on large scale production in the short term (3-5 years) so investors need to take a long-term strategy with VF.

Economics not technology is the major obstacle for large scale roll out but, if energy prices or LED prices came down, it would look more appealing. They felt there was a role for some business models but not necessarily in large scale leafy greens production.

8.3. Pharmaceutical companies

These would be an obvious investor/partner; however I didn't find any to visit on my travels.

8.4. Seed breeding companies

I saw two examples on my Nuffield Farming Study Tour: Monsanto (BAYER) & Nunhems®(BASF since Apr 2018). I have covered these in Chapter 5.3.

8.5. Joint Ventures

By 2018, Dubai plans to have the world's largest vertical farm producing leafy greens and vegetables for a new joint venture with Emirates Flight Catering (EKFC), a subsidiary of Emirates Group. EKFC and Crop One Holdings (USA) are planning to invest $40 million into the project. Dubai imports 11,000 000 tonnes of fresh produce per day, much from Northern Europe including the UK[12]. Production of short-shelf life greens to supply into EKFC is part of the UAE's drive for more agricultural self-sufficiency.

8.6. Retailers

For grocery stores or supermarkets the concept of fresh greens growing instore could soon be a reality.

Study Tour example: Martin Weber, CEO Infarm Berlin

The aim of Infarm is to provide urban self-sufficiency via an instore leafy green system. Their produce, with branding 'Du hast ech geschmack' ('You have (a) good taste'), promises high quality fresh produce grown instore. Currently they have 24 sites around Berlin with plans to expand nationally and globally. Each unit can produce 600kg/pa on a $2m^2$ x 3-layer system. Martin explained that achieving their target price for produce hadn't been an issue and in many cases the retailer provided the space for free. One issue that had been encountered was that, due to the practicalities of servicing the units until they had skilled staff, they were limited initially to a radius round Berlin.

8.7. Social Enterprises

Aside from financial benefits one key stakeholder can be social enterprises. For many of the founders of the Urban Farming movement such as Dickson Despommier[13], the social and welfare aspect of providing fresh green food in often deprived urban communities has a value above the financial bottom line. The most popular system in inner city urban areas is the 'shipping container' model (*see Chapter 4: What is Vertical Farming?).* This can be where ideals and financial reality can clash as the model often needs external support to make it viable if the end market it not a niche, high value consumer. Government or other external agencies may need to look at the bigger picture such as population health and wellbeing when assessing its value.

8.8. Crowdfunding

In the USA, crowdfunding for CEA on sites such as Kickstarter and Indiegogo saw a 900% increase from $2.8 to $28 million. **Dickson Despommier,** a professor of microbiology and public health at Columbia

University, explained that investment will make indoor agriculture even more commonplace, and encourage other Venture Capitalists to fund vertical farm companies."

"I think that most cities now accept urban agriculture as normal, so the hurdles are mostly with marketing and the consumers who are unfamiliar with the kinds of produce that vertical farms can make available 24-7: leafy greens, root vegetables, berry fruits, and the like," he said[11].

9. Where are we currently in the UK?

I wanted to show where the UK currently stands in relation to CEA and VF internationally.

So I have picked a few companies that I think represent business models or crops I have covered in my report.

9.1. High Value - Low Volume: herbs and micro-greens

- **GrowUp Unit 64 London:www.growup.org.uk**
  One of the first into the vertical faming market, GrowUp combines micro-herb growing with aquaponics to farm tilapia.
- **Vertical Future London: www verticalfuture.co.uk**
- **Growing Underground London: www.growing-underground.com**
  Utilising derelict underground systems to grow micro-greens. High profile link with UK supermarket Marks & Spencer who liked the local food, 365 days, environmental credentials.[14]

Figure 22: Crops growing under a CEA system

9.2. High Volume Close to Customer: leafy greens and salads

City Farm Systems: www/city-farm-systems.com

New venture looking to create close-to-consumer/distributor rooftop growing systems utilising available space and excess heat on top of current buildings.

9.3. Plant breeding: seed crops

Dr Brande Wulff – John Innes Centre. Using enhanced LED lighting in a joint UK/Australian project they have achieved wheat generation from seed to seed in 8 weeks. This technique, called 'speed-breeding,' is a significant step forward for the conventional time taken to grow generations. They will now be researching growing under hydroponic conditions whilst using LED lights.

9.4. Medicinal/Plantceuticals/Biofactories

Julian Ma, Hotung Professor of Molecular Immunology St Georges University London, is researching the development of plants such as tobacco, as production hosts for pharmaceutical proteins. The benefits of plants over traditional methods are that growing plants is more economical than some of the traditional methods of drug production. They use tobacco for their research as it is a widely and easily grown crop and would also have no danger of entering the food chain.[15]

YesHealth Biotechnology announced an £18M investment in a Vertical Farm to be built in York. The company spokesperson of this Taiwanese company said they hoped to provide local consumers with "*fresh and pesticide-free products*". Their website states that '*Yes, Biotechnology centers around novel technologies and innovative approaches that will translate into: Point of care diagnostic tools, Biomarkers that help target therapy, Therapeutic alternatives to antibiotics.'*

9.5. Guaranteed Customer: fodder – meat – energy: www.avocetnc.com

Avocet Infinite PLC, Berwick. I visited Avocet at their demonstration farm on the Scottish borders. They are planning an 'end-to-end' proposition from indoor production of barley fodder, raising of Pietmontese beef, to an on-farm Anaerobic Digestor run using waste slurry to produce energy and fuel. Their proposition is a total system concept, building a brand for the meat and using the integration to create savings and efficiencies. They are planning to expand the business onto a site in Tipperary, Ireland.

9.6. Larger crop: Strawberries: www. sagroup.co.uk

Springfield Nursery South Wales, part of S & A Produce, have integrated LED lighting into their glasshouse system to extend dramatically the production season of British strawberries. S & A's Roger Vogul said that, by using their own specifically-bred varieties, they are aiming for year-round production without compromising on taste.

9.7. Working in partnership

Intelligent Growth Solutions (IGS), Dundee, Scotland, have created a full-scale trial at the James Hutton Institute's site in Invergowrie. The project is in collaboration with global automation business Omron.

10. Conclusions

1. Growers need to start with the crop and a robust business model before they decide on the best growing system to suit their chosen crop. Controlled Environment Agriculture (CEA) and Vertical Farming (VF) are just growing systems like any other and shouldn't be the starting point for a business model.

2. With advances in technology such as lighting, robotics and automation, major steps forward are being made in what can be achieved in CEA. However, industry experts feel that we are not in a fully mature market yet. Knowledge and technology are still developing.

3. The technology is available to grow a wide range of crops under controlled conditions but growing in a CEA requires high levels of understanding and technical skill. There are business models where Vertical Farming/Controlled Environment Agriculture would work well, such as seed breeding and medicinal plants; however other models are more marginal such as niche crops, fodder and leafy greens. The latter's success appears to depend on growing skill, scale and automation and the effect of input variability such as electricity costs.

4. The argument for sustainability is difficult to substantiate in relation to energy use, even it is renewable energy. There are large gains to be made in the reduction of water usage (up to 95%) and supply chain gains such as less transportation required.

5. The collection of data and plant growing algorithms are a valuable piece of intellectual property for companies. However, they are only useful if they are used to improve crop marketability and yield.

6. Northern European countries are ideally located for glasshouse growing as it is easier to add heat than to remove it. Smart glasshouses incorporate some controlled environment variables such as CO_2 enhancement, diffused light through specialist glass, supplementary LED whilst still using solar light which is a valuable free resource.

7. It has been hard to grasp realistic figures on the viability of some of the CEA/VF systems as the headline figures are always positive. Securing investment for some schemes can be hard by conventional methods such as from banks, and it is more probable to get investment from private investors or private equity funds.

8. The differences in Organic status is confusing to consumers and inconsistent across countries (e.g. Organic in US but not in Europe). Consumers say they want contaminant-free produce, but it is questionable how much they are willing to pay for it.

11. Recommendations

1. A Controlled Environment Agriculture or Vertical Farm business model needs to be robust as the technology, build and running costs are expensive. Pick the best system for growing your crop that integrates with your business model. This may not be a vertical farm, it may be a conventional glasshouse model.

2. The limiting factor in maximising crop growth and yield will always be the interaction between Carbon dioxide (CO_2), light, nutrients, water and temperature. If any input is not at the plant's required optimum level it will be this that limits its performance regardless of whether the others factors are increased.

3. There can be easy and economical gains in glasshouse horticulture - such as good crop management and good glasshouse practice (10% light gain for keeping glass clean). Look at hybrid models for glasshouse systems where off-season or intercrop production could be boosted with additional LED lights and CO_2 inclusion. Smart materials and automation may be the future for Northern European countries growing under glass to deal with environmental and labour issues.

4. CEA growers should own the concept of pesticide-free produce as this is a real point of marketing difference over conventionally grown crops.

5. The ideal would be to model all the variable costs of different CEA systems and regularly revisit if the situation changes such as LED lighting costs reduce, electricity costs change, or conventional production method costs increase. This would allow potential businesses to assess when the 'sweet spot' was hit in terms of economic viability.

12. After my study tour

My reasons for embarking on my Nuffield Farming Scholarship were to investigate whether new innovations in growing techniques could be replicated on a practical and economic scale on our farm and for the wider industry.

Whilst I sometimes discovered more questions than answers at times, I feel I have a clear idea as to where the business model would fit within UK agriculture. Whilst I saw some high value opportunities I did not see a model that offered me more than my current model growing edible flowers conventionally as I do. I have started a small-scale trial looking at the use of a bio-complex product and the effect it has on conventional soil-grown flowers.

On our wider farm, my initial interest in hydroponic fodder has allowed me to expand my knowledge of what is available, but I don't feel what is currently on the market would fit our farming system. I would like to revisit this, though in the future perhaps when the automation levels and supplementary lighting have been further developed.

My Nuffield Farming Scholarship has opened my eyes as to where the UK sits in world agriculture and it has re-kindled my interest in conventional primary crop and livestock production. Looking forward in our farming business we are conscious of a level of unknown for our sector and we are looking at ideas to future proof our operation.

I have become part of a series of field-based pharmaceutical trials growing plants for the production of anti-dementia drugs and I am involved in working up a series of pan-Wales field trials and demonstrations farms. On a personal level I am keen to share the knowledge I have gained in the past 18 months, either professionally or through knowledge exchange with growers, developers and investors.

Sarah Hughes

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Dr Brande Wulff:John Innes Centre,

Avocet Infinite PLC UK,

James Hutton Institute.

Dr Peter Wooton-Beard & William Style: Aberystwyth University

14. References

1. Knight Frank Research 2017
2. Savills Research Feb 2018

4. National Farmers Union 'The Great Labour Debate' Countryside Magazine
5. Horticulture Statistics 2016 – DEFRA

7. **Assessment of Vitamin and Carotenoid Concentrations of Emerging Food Products: Edible Microgreens** Zhenlei Xiao, Gene E. Lester, Yaguang Luo, and Qin Wang *Journal of Agricultural and Food Chemistry* **2012** *60* (31), 7644-7651 DOI: 10.1021/jf300459b
8. Floating Dairy Farm, Rotterdam – looked into growing duckweed for feed/ **Nutrient scaling of duckweed (Spirodela polyrhiza) biomass in urban wastewater and its utility in anaerobic co-digestion** Rubia Zahid Gaur & Surindra Suthar
9. Freight Farms, USA
10. Graamans, Luuk & Baeza, Esteban & Van Den Dobbelsteen, Andy & Tsafaras, Ilias & Stanghellini, Cecilia. (2017). **Plant factories versus greenhouses: Comparison of resource use efficiency**. Agricultural Systems. 160. 10.1016/j.agsy.2017.11.003.
11. Business Insider UK 2017
12. Dr Hashim Al Nuaimi, director of the Consumer Protection Department in the Ministry of Economy
13. Despommier, D. D. (2010). **The vertical farm: Feeding ourselves and the world in the 21st century.** New York: Thomas Dunne Books.
14. Andrew Mellonie – Category Manager Fresh Produce M&S – World Agritech Summit 2017
15. Prof. Julian Ma – St Georges University London

15. Appendices

Below is a summary of terms used that refer to growing plants with differing levels of environmental control (controlling light, Carbon dioxide, water and atmosphere):

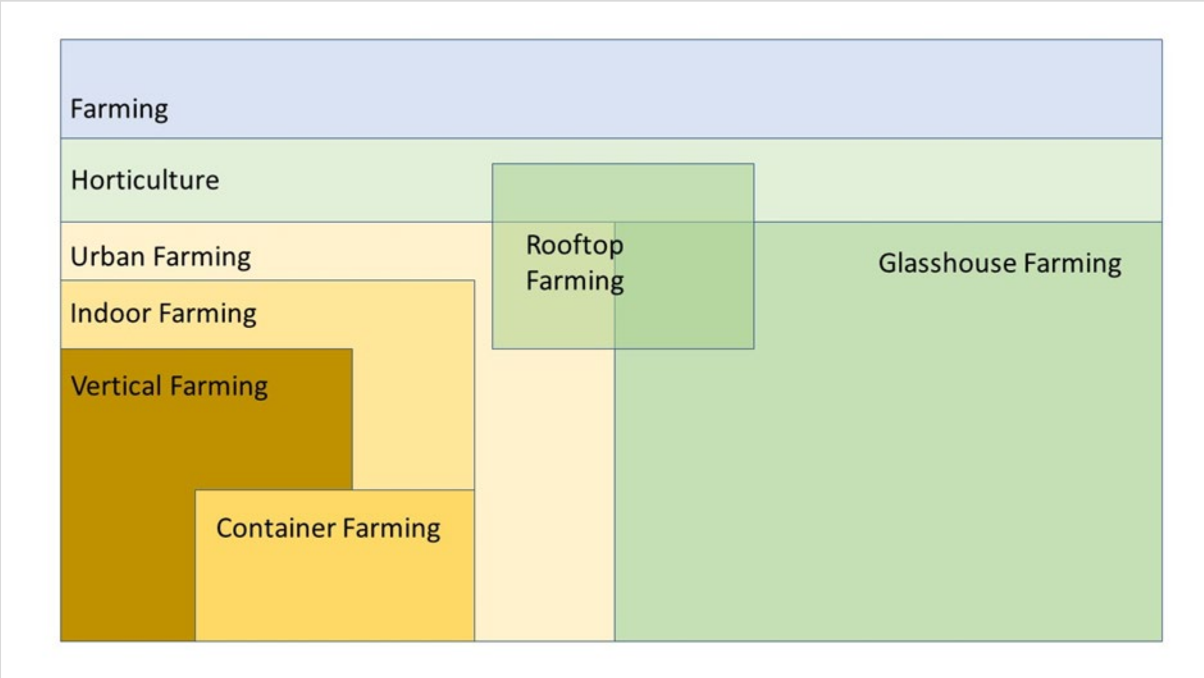

Figure 23: Below: Definitions of plant-based farming - Rabobank 2018

Figure 24: Labour requirements by facility type: Agrilyst survey 2017

Investment Series Simplified

Series	Aim	Investor type	Risk level
Seed Funding	Set up the business with the aim to move it into profitability	Private Investors, Investor Angels and Early Stage Venture Capitalists	High
Series A	Optimising product and user base	Traditional venture capitalists	Moderate-High
Series B	Build the business past development stage	Traditional venture capitalists	Moderate-High
Series C & D	Scale business and Consolidate the market sector	Hedge Funds, Private Equity, Investment Banks	Moderate

Figure 25: Investment Series simplified

Different types of Hydroponic Systems

1. Ebb and Flow – solution rises and falls throughout the day allowing the plant to access it whilst still being exposed to oxygen.
2. Wick system – solution rises up an absorbent wick using capillary action where it is then transported through a sterile growing medium to the roots.
3. Nutrient Film Technique (NFT) – thin layer of solution is always available to the roots whilst still allowing air flow to prevent fungal infection.
4. Deep water culture – the advantage of this system is that there is always solution available to the plants and it is not so reliant on water being pumped around the system. Whilst being an older method it has less technology to go wrong when scaling.

Fig. 9. Resource use for electricity (A), CO_2 (B) and water (C) of the plant factory (PF) and greenhouses (SWE, SWE(+), NLD and UAE), normalised for total dry matter production (kg_{dw}).

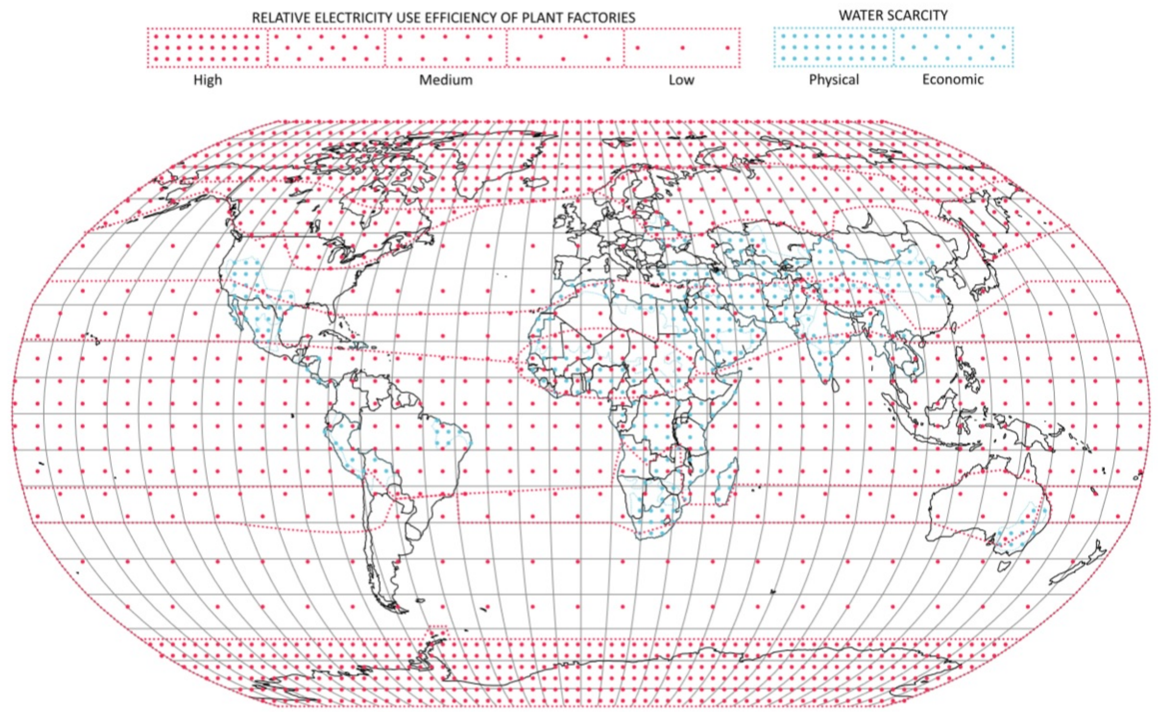

Fig. 10. Estimation of the advantages of plant factories versus greenhouses based on relative electricity use efficiency (red) and water scarcity (blue). Water scarcity is subdivided into (approaching) physical and economic scarcity (UN, 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 6: Estimation of advantages of plant factories vs greenhouses re electrical efficiency and water use (Graaman et al)

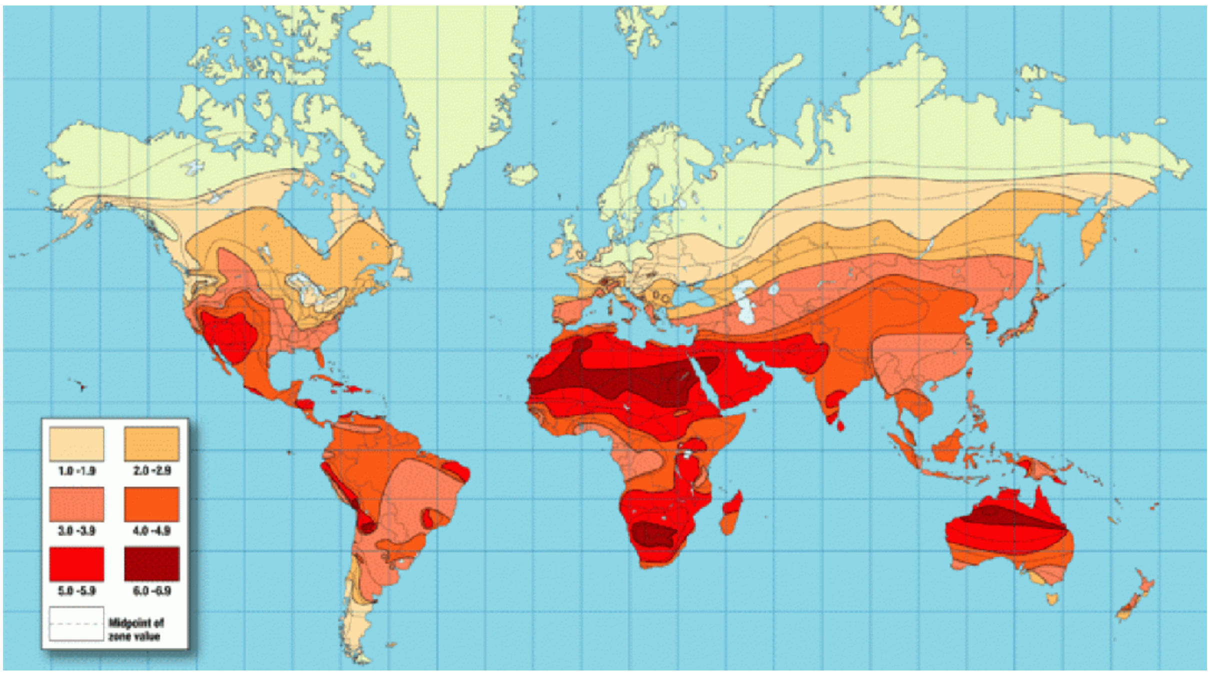

Figure 27: World Isolation Map showing the amount of solar energy in hours received each day on an optimally tilted surface during the worst month of the year.

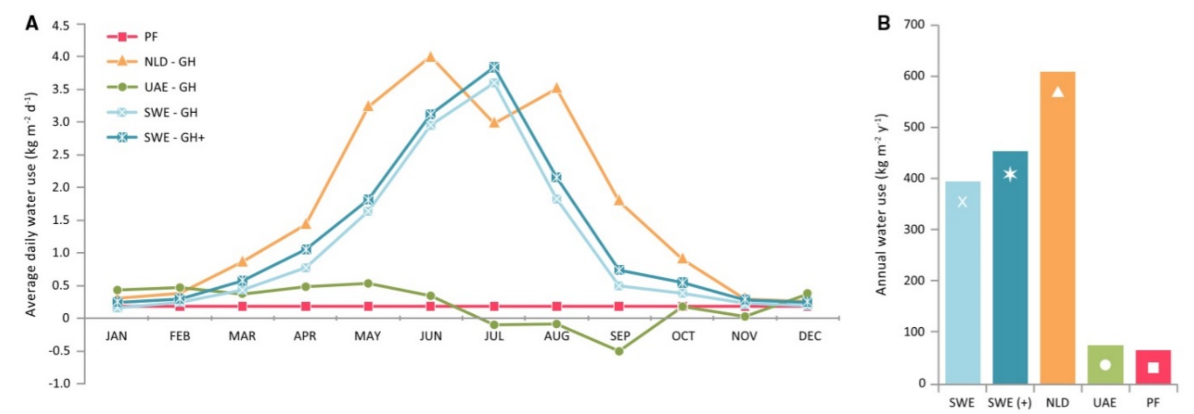

Fig. 6. Average daily water use (kg m^{-2} d^{-1}) (A) and total annual water use per cultivation area (kg m^{-2} y^{-1}) in plant factories and greenhouses (B). The negative values of UAE in summertime can be explained by the fact that the calculations include the influence of infiltration of water vapour. During the summer months the absolute vapour content of air is higher outside the greenhouse. This results in water vapour infiltrating the facility and consequently being condensed and retrieved.

Figure 28: Average daily water uses in different growing systems

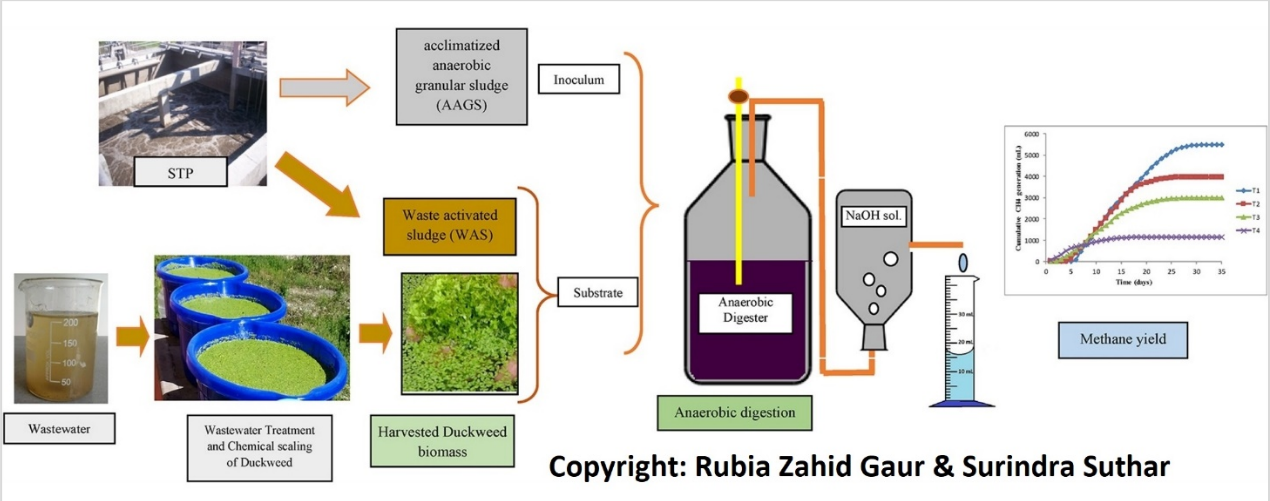

Figure 29: Nutrient scaling of duckweed (Spirodela polyrhiza) biomass in urban wastewater and its utility in anaerobic co-digestion. ***Authors Rubia Zahid Gaur & Surindra Suthar***

Comparing Nutrient Content of Hay and Fodder

Nutrient content of hay, barley grain and fodder comparing on a Dry Matter and As Fed basis per pound

	California Grass Hay		Barley Grain		Barley Fodder	
Nutrient	**DM**	**As Fed**	**DM**	**As Fed**	**DM**	**As Fed**
Moisture (%)	0 %	7.3 %	0 %	9 %	0 %	88.5 %
Digestible Energy (Mcal)	0.929 Mcal	0.86 Mcal	1.66 Mcal	1.51 Mcal	1.31 Mcal	0.15 Mcal
Crude Protein (g)	54.5g	51 g	56.3 g	51 g	67g	7.7 g
Lysine (g)	1.9 g	2 g	2g	2 g	2.9g	< 0.1 g
Calcium (g)	2.17 g	2 g	0.27 g	<0.01 g	0.32g	0.04 g
Phosphorous (g)	1.06 g	1 g	1.77 g	2 g	1.85g	0.21 g
Iron (mg)	99 mg	91.8 mg	31.8 mg	28.9 mg	96mg	11 mg
Copper (mg)	3.9 mg	3.6 mg	2.7 mg	2.5 mg	4mg	<1 mg
Zinc (mg)	12.7 mg	11.8 mg	17.3 mg	15.7 mg	12mg	2 mg
Vitamin E (mg/IU)					28 mg or 43 IU	
Starch (g)	8.52 g (1.9 %)	7.9 g (1.74 %)	248 g (54.6 %)	222 g (48.9 %)	54.2g (12%)	6.2 g (1.4%)
ESC (g)	34.9 g (7.7 %)	32.3 g (7.12 %)	11.4 g (2.5 %)	10 g (2.2 %)	5.5g (1.2 %)	0.6 g (0.1 %)
WSC (g)	49.9 mg (11 %)	46.3 g (10.2 %)	31.1 g (6.9 %)	27.7 g (6.1 %)	147g (32.5 %)	17 g (3.7 %)

Figure30: Nutritional Comparison of Hay and Hydroponic Fodder (*Clare Thunes, PhD Equine Nutritionist*)

Nutritional Content and Cost Comparison Between Different Types of Winter Feed

Feed Type		bale weight (Kg)	dry matter (%)	dry matter weight / bale	protein % (DM)	energy Mj/Kg (DM)	protein / bale or T42 load) (Kg)	energy / bale (Mj)	Cost Per Kg of Protein	Cost Per Mj of Energy
Silage - Low Quality		725	18%	127	9%	9.0	11.4	1,142	€2.45	€2.45
Silage - Medium Quality		679	20%	136	14%	10.0	19.0	1,359	€1.47	€2.06
Silage - High Quality		600	25%	150	16%	11.5	23.7	1,725	€1.18	€1.62
400Kg Barley Fodder + 1 bale straw / day	barley fodder	420	13%	53.2	17%	12.3	9.05	656	€1.70	€1.47
	straw	230	93%	213.9	4%	6.5	8.56	1,390		
72Kg Concentrate + 1 bale of straw / day	concentrate	72	87%	62.6	21%	12.7	13.0	796	€1.82	€2.13
	straw	230	93%	213.9	4%	6.5	8.6	1,390		

Figure31: Comparison of winter feed costs (*Dr Steve Collins IRL)*

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