eit Food NORTH-WEST

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BARRIERS & OPPORTUNITIES FOR CONTROLLED ENVIRONMENT AGRICULTURE IN NORTH-WEST EUROPE

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UKRI Innovate UK KTN

Contents

1. Summary

Stakeholders from Iceland, Ireland and the United Kingdom have shared their thoughts on strategic opportunities and major barriers related to controlled environment agriculture in North-West Europe.

The EIT Food North-West Regional Office is exploring opportunities provided by controlled environment growing systems. This encompasses both the move towards urban growing systems as well as diversification opportunities for rural producers. Both of these scenarios can make a contribution to increasing the region's food security and improving the living conditions and diet of urban citizens in the first case and the sustainability of the rural sector in the latter.

This report highlights key findings from a consultation undertaken in collaboration with Innovate UK KTN, which sought insights from experts in Iceland, Ireland, and the United Kingdom regarding local, regional and global challenges and opportunities associated with controlled environment agriculture systems.

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2. Introduction

From a ploughed field to an industrial-scale warehouse with artificial lighting, producers exert varying degrees of control over plant growth conditions in every type of crop production system. For the purposes of this report, we define controlled environment agriculture (CEA) to include a broad range of semi- and fully-closed systems, from greenhouses through to vertical farms.

Increased regulation of growing environments can provide improved protection against harsh climatic conditions, pests and diseases, and enables more precise provision of inputs (e.g. light, temperature, nutrients). These qualities of CEA systems mean they can be used to produce crops out-of-season or in regions where they would not be able to survive or yield appropriately in terrestrial production systems. However, despite many potential benefits, the high capital and operational expenses associated with CEA systems mean they typically struggle to compete with terrestrial in-season crop production.

Globally, the controlled environment market was valued at US$15.7 billion, and is projected to reach US$ 31.1 billion by 2027 (CAGR of 11.8% during 2022-2027, Research and Market, 2022). Vertical farming in particular has seen rapid growth (CAGR of 10.3% from 2021 to 2026) and is expected to reach a global value of $US18.9 billion by 2026. Large investments in CEA producers (e.g. the £100M GrowUp farm) and system providers (e.g. the £42.2M raised by IGS) are becoming more common.

Growth in the CEA market is partially underpinned by advances in related technologies that can dramatically improve production efficiency. As explored in this report, recent developments in nutrient delivery systems and lighting technologies, as well as anticipated progress in robotics, sensors, machine learning and artificial intelligence systems tailored for use in CEA, have generated considerable excitement.

Discussions of CEA often focus primarily on vertical farming operations that exist in urban areas. It is important to remember that CEA also includes greenhouse production in rural and semi-rural areas; these systems are advanced and a critical part of our food system. Additionally, a growing number of rural producers who have historically used field production systems are looking to explore a broad range of CEA capabilities, although as discussed, there remain several barriers to large-scale rural expansion.

As islands with climates that are not suitable for year-round production of many crops, Iceland, Ireland, and the UK have a particular interest in CEA and its potential to reduce reliance on imports. The recent departure of the UK from the European Union and corresponding changes in trade relationships has further increased interest in enhancing domestic production of food.

In January and February 2022, Innovate UK KTN and EIT Food North-West consulted their AgriFood networks regarding challenges and opportunities as well as available and needed resources for the CEA community. The consultation included 17 stakeholder interviews, each representing a different organisation. Interviewees included academics, technology providers, growers, network facilitators, and retailers from Iceland, Ireland, and the UK. Their views have been compiled to produce this report and the accompanying booklet 'Controlled Environment Agriculture: Tips for New Entrants'.

3. Key findings

The topics below are key areas covered in the interviews. Responses have been collated and summarised. Respondents largely agreed that it is difficult to define CEA and that there is an evolving narrative around what types of production should be included in these discussions. Many were keen to point out that CEA should not refer exclusively to 'high-tech' production. Where relevant, we have distinguished between glasshouse production and vertical farming.

a. Food security

Reliable access to safe, nutritious and affordable food is a key concern for consumers and governments, and the role of CEA in addressing these concerns is complicated. As island nations, domestic food production is particularly beneficial for Iceland, Ireland and the UK to reduce emissions and costs associated with transport.

Staple crops (e.g. cereals, oilseeds, potatoes) that make substantial contributions to calorific intake tend to be grown in field production systems. The potential for CEA production of staple crops is debated. Commercial viability – taking into account growing costs, speed of production, market demand, and relevant regulations – underpins what crops are grown in CEA systems. Contributors noted that the economic case for CEA-produced staple crops in North-West Europe is weak as outdoor systems are efficient and the products (e.g. grain) tend to store well. In other climates it is possible that there may be a future economic case for CEA-produced staples.

However, food security is not just about calories; nutritional security and diet diversification are also important. Fresh produce is a key source of micronutrients, and a broad variety of fruits and vegetables can be grown in glasshouses. Tomatoes, cucumbers, bell peppers, lettuces, and berries are all well-established glasshouse crops, and production of other types of crops such as melons and even wasabi is growing. Comparatively, vertical farming systems produce a narrower selection of produce at scale, although the range is anticipated to expand in the near future (Table 1). North-West Europe currently imports significant quantities of fresh produce. As global supply chains are vulnerable to disruption from global geopolitical issues and other problems like climate change, increasing domestic production provides substantially greater reliability over continuing high levels of imports.

CEA is also useful where biosecurity is of particular concern. For example, climate change and growing disease pressure mean that seed potato production is becoming more challenging in traditional field systems. CEA can enable the production of disease-free seed potatoes and early efforts show that high yields are attainable. Another example is strawberry starter plants, which are typically imported from the Netherlands from a small number of farms.

There is an associated risk of importing soil-borne pests & diseases, as well as challenges with travel-related plant losses and regulatory hurdles in transporting plant material over borders that have become more complex in the UK post-Brexit. Propagating strawberry starter plants in CEA systems in close proximity to where the fruiting plants will later be grown can help to mitigate these risks.

Table 1. Crops & plants with the potential to be grown at scale in vertical farming systems.

Current	Potential for Future
Herbs	Berries and soft fruits
Leafy greens	Bioenergy crops
Microgreens	Brassicas (e.g. to be transplanted)
Mushrooms	Cucumbers
	Pulses
	Rice (CEA varieties being developed in China)
	Root vegetables (including potatoes)
	Spice crops (e.g. saffron, vanilla, chillies)
	Tomatoes
	Tree saplings (to be transplanted)
	High value crops for pharmaceuticals, nutraceuticals, cosmetics, fragrances, food flavouring and colouring

b. Advantages & disadvantages

In discussing benefits and drawbacks of CEA (Table 2), it is important to note that CEA is complementary to outdoor production rather than a replacement. To determine which system is most appropriate for a given crop at a particular time of year, producers must think about potential yields, associated environmental costs and financial costs.

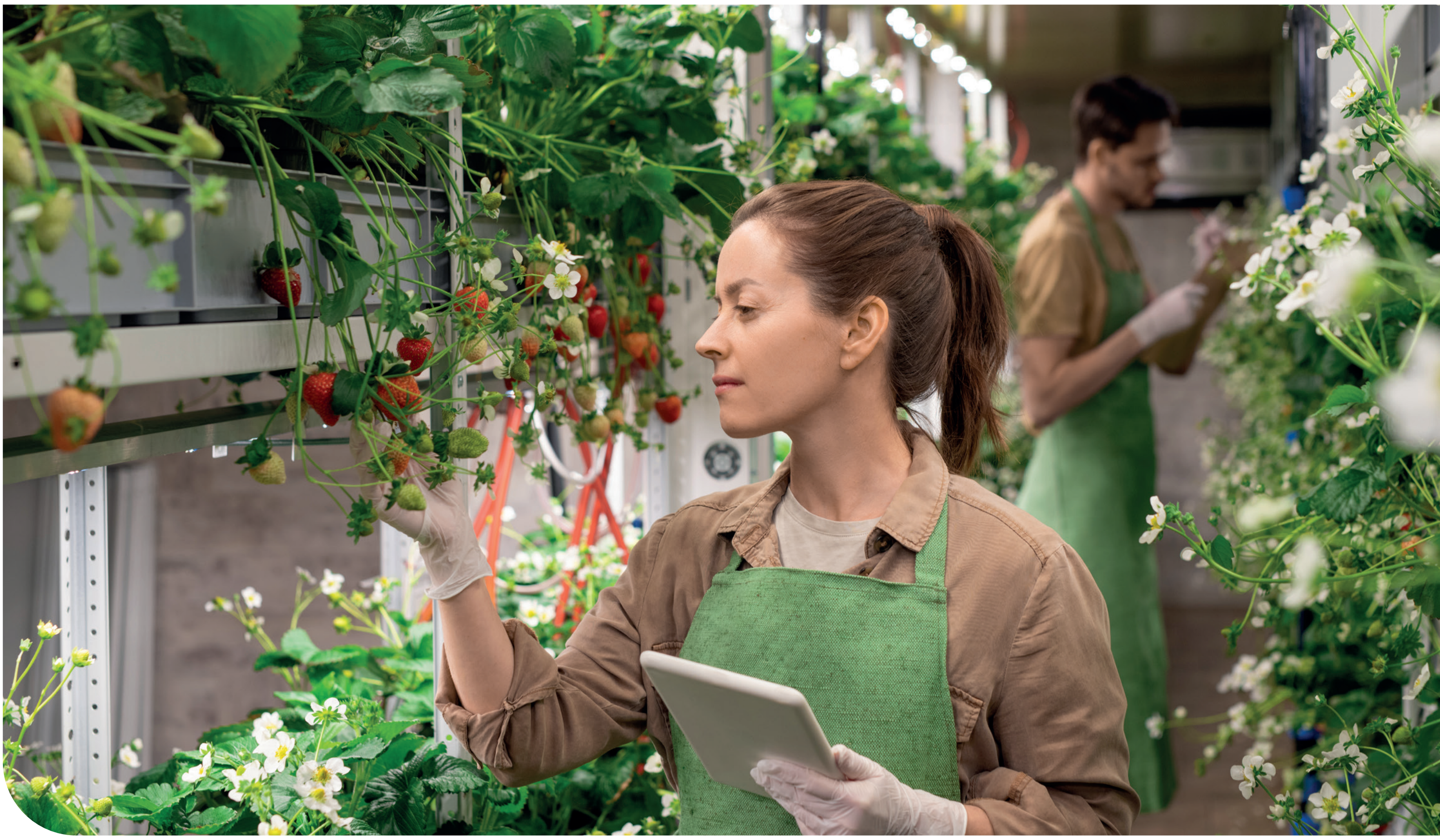
Table 2. Advantages & disadvantages of CEA systems compared to traditional outdoor production.

Advantages	Disadvantages
Consistent quality and quantity of produce, which can lead to less food waste	Expertise bottleneck – few people know how to operate a vertical farm
Can grow produce 'out of season', reducing need for imports	A lot of related technology is not available at scale yet (e.g. robotic harvesting)
Flexible - can quickly switch production to another crop in reaction to market changes	Highly artificial system, may not be viewed favourably by some consumers
Can use abandoned or 'undesirable' spaces (e.g. brownfield sites, old farm buildings)	Energy intensive
Takes pressure off systems that produce intensively / degrade soils	Absence of pollinators
Lower risk food safety issues as can operate as semi- or fully-closed system (sterile)	Dependence on technology can be a risk, as even short-term technical issues may severely impact output
Reduced / no use of pesticides & herbicides compared to outdoor production	Depending on rate of adoption, potential to de-stabilise rural communities
Yield, quality & nutritional value optimised via use of sensors and other agritech R&D	Growing media may be unsustainable (e.g. peat-based), may need to be shipped long distances, may have limited lifetime
Can grow near consumers, shortening supply chains and reducing transport CO_2 emissions	High capital and operating costs, and vulnerable to fluctuations in energy prices
Can treat & recycle effluent water and nutrient solutions, thus substantially reducing water use compared to outdoor production	Difficult for urban operators to scale – at a certain size, logical to move out of cities for space & supply supermarkets which have strict compliance criteria
Potential to take pressure off environment so former field production sites can be used for alternate purposes (e.g. restoring ecosystems)	If pests / diseases are detected in the system, can involve large-scale shut-down for cleaning and associated production losses
Efficient use of space, particularly in vertical systems – less land needed than outdoor production	Current focus on crops relevant for North American and European markets, less information for crops relevant to Global South
Removes need for seasonal harvesting labour (pinch-point for outdoor production)	

Advantages of CEA systems can be broadly categorised as benefits to the consumer, benefits to retailers, benefits to operators / employees, benefits to the environment, and benefits to society.

Some disadvantages may be addressed with time. For example, in some regions it is currently challenging to find experienced CEA operators, particularly for vertical farms. Expanding the number of facilities where people can receive on-the-job training would create more opportunities to upskill people and grow the size of this labour pool, although it is difficult to establish new facilities without funding and existing trained labour to operate them. With time and investment, this should become less of an issue.

Similarly, the large energy requirement of CEA systems means they can be expensive to run and challenges the idea that indoor agriculture is inherently more sustainable than outdoor production. However, potential co-location with renewable and waste energy sources (e.g. geothermal heating of glasshouses in Iceland and anaerobic digestors) could help mitigate this challenge. This is explored in greater detail in the next section.



c. Net-zero potential

As noted above, the energy requirements of CEA systems, especially technology-heavy vertical farms, is a major challenge in working towards net-zero greenhouse gas emissions targets. Contributors defined three critical avenues of future research & development related to energy use: (1) co-location with renewable energy sources, (2) advances in input production, and (3) life cycle analyses of total supply chains.

(1) Renewable energy sources

Based on the massive energy requirements of most CEA systems, many contributors thought net-zero ambitions would only be achievable via use of, and ideally co-location with, renewable energy sources. Use of solar panels, building sites near wind turbines, or linking operations to anaerobic digestors were all discussed. Similarly, as many enclosed CEA systems artificially increase CO_2 levels for plant growth, co-locating with industrial sources of food-grade CO_2 waste or carbon capture technology may make sense for future operations. In Iceland, co-location with hydroelectric or geothermal energy production is common.

For other regions, there may be considerable challenges associated with renewable energy use. In urban areas, space limitations make co-location difficult, thus many operators obtain electricity from the grid. Energy availability was a frequently cited issue; even if operators select green-certified providers, there are questions about how effectively renewable energy production can keep pace with demand.

Opportunities to flex operations in response to energy demand are being explored. For example, companies are experimenting with running lights at night when demand is lower and cheaper, and it is typically windier so the grid is more reliant on renewable energy sources.

Developments in the energy sector may, over long timescales, reduce the cost of energy which would impact the ability of CEA systems to scale-up and produce a broader range of crops. Advances in batteries and energy storage could mitigate issues associated and, alongside the potential development of the hydrogen sector, may underpin a step-change in CEA systems.

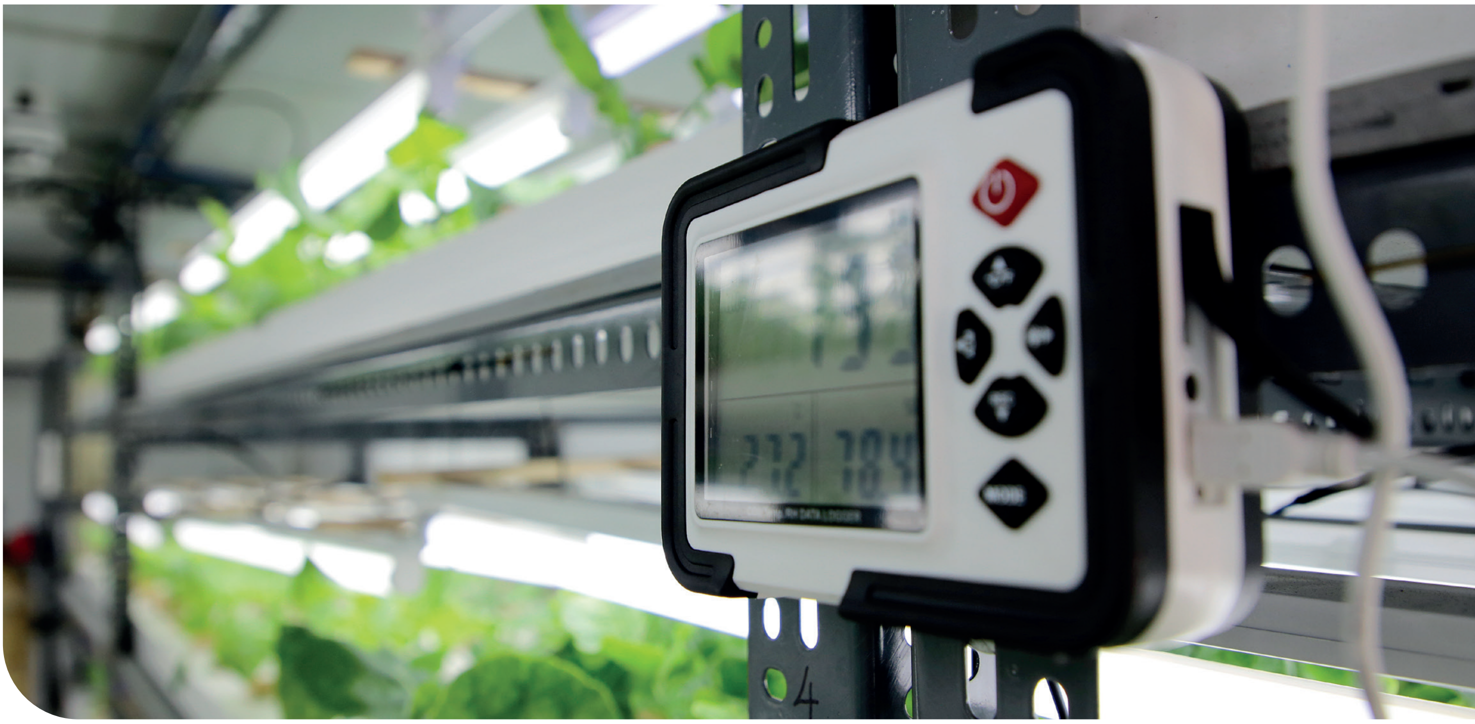
(2) Input provision

Emissions associated with producing and sourcing inputs are another concern. Like outdoor production, CEA requires fertilisers composed of mineral salts that are mined and imported, thus have considerable associated emissions as well as potential issues around ethical supply chains. Bio-based fertilisers (e.g. using algae, food waste, bacteria, etc) are in development; as an example, anaerobic digestors can provide liquid fertiliser fractions. However, according to contributors there is not yet a consistent commercial offering.

Growing media is another potential sustainability issue. Some manufacturers still use peat, which has severe environmental implications and is facing impending regulatory barriers across North-West Europe. Alternative growth media (e.g. coir) may have issues with consistency and often also has associated emissions profiles, as it may need to be shipped from distant locations and has a limited lifespan, therefore needs to be frequently replaced. As the CEA community grows, increased demand and limited supply might mean high costs for operators.

(3) Life cycle analyses and reporting standards

To justify expansion, the CEA community needs to show that growing indoors has a measurable carbon benefit over importing, and this needs a mechanism for verification. Individual organisations have attempted to quantify the emissions associated with production, but these do not allow for comparisons across companies or industries. Carbon calculators exist for outdoor production systems, and many outdoor producers pay for carbon audits; this is a requirement for many assurance schemes. Similar tools and services tailored to CEA systems would be hugely valuable. Some relevant resources noted by contributors include the GHG Protocol (carbon accounting standard), the Global Reporting Initiative (overall sustainability reporting standard), the Science-Based Targets Initiative (emissions reductions targets), and B Corp certification (certification of social and environmental performance).



d. Adjacent technologies that provide opportunities for innovation

There are a number of areas where timely intervention and innovation tailored to CEA systems could be game-changing (Table 3). In many cases, research & development is already underway although the commercial offerings remain limited or non-existent.

Table 3. Opportunities for innovation and technology development in CEA systems.

Automation

- **Mechanised pollination:** to replace expensive and time-consuming manual pollination.
- **Robotic / mechanical sowing and harvesting:** could reduce costs and dependence on difficult-to-source labour, and enable otherwise autonomous systems to remain closed.

Data analytics

- **Data cloud systems:** to gather, aggregate and analyse data on plant growth, yield, and quality in response to variations in lighting, nutrient concentrations, etc.
- **Machine learning (ML) and artificial intelligence (AI):** data collected from a CEA system can feed into ML & AI models to optimise that system. A commercial offering could be a game-changer, particularly in helping to minimise inputs to reduce waste.
- **Life cycle analysis:** capturing the biodiversity, water, and land use value of CEA systems in a consistent and reliable way across companies and sectors.
- **Distributed ledger technology:** can be used to improve traceability and transparency of CEA supply chains.

Energy

- **Integration:** with renewable energy sources.
- **Batteries:** to store surplus energy to use in times of low renewable energy production.
- **Smart/flex energy systems:** use grid energy when it is cheaper.
- **Systems to optimise cooling in glasshouses:** opening windows during high summer temperatures may not be desirable in systems using atmospheric CO_2 enrichment.

Sensors

- **Size:** most agricultural sensors are large as they are made for field use and it is more expensive to make small offerings; advances are being made in size and associated costs.
- **Real-time:** fluorescence sensors are in development that can ascertain chlorophyll fluorescence of plants as a proxy for rate of photosynthesis, can be used to determine the impact of different variables on plant growth.

Materials

- **Coatings, glass and polymers:** developed for CEA systems for smart control of wavelength penetrability, according to outside environment and/ or crop production needs. Commercial offerings are already available, and improvements continue.

Other

- **Business model:** mechanisms to match up CEA producers (particularly vertical farms) with customers.
- **Circular economy:** explore what can be done with technology at the end of its lifecycle, how component parts can be replaced or re-used, how to reduce materials waste.
- **Cross-sector collaboration:** insect farms and aquaponics use similar processes, resource flows and outputs; need to break down silos to learn from each other.

e. CEA systems in rural areas

CEA is often thought of as an urban or 'peri-urban' activity. However, many types of CEA systems can be found in rural settings, and there is a growing community of outdoor producers looking to engage with CEA capabilities. Opportunities and challenges are discussed below.

(1) Opportunities

One benefit of rural CEA systems is the potential to co-locate with renewable energy production facilities which require more space than is often available in urban areas. Additionally, rural locations can in some cases be more convenient and cost-effective than city-centre sites for supplying large-volume retail hubs.

Many outdoor producers already have skills, land, equipment, customers, capital, and buildings that can be used to establish CEA facilities. Existing rural infrastructure (e.g. empty poultry sheds) with links to water mains and energy sources are in many ways ideal for CEA retrofitting, which can then be a diversified strand to the existing farm business with the benefit of relatively predictable and consistent yields and quality of produce compared to outdoor production. CEA systems could also be used to propagate starter plants on site that could later be transplanted into fields; this could support earlier, more consistent, and more convenient starter plant production.

There are also potential societal benefits to establishing CEA facilities in rural areas. In remote communities where fresh produce tends to be expensive and difficult to source, particularly in winter, CEA systems can be used to grow produce out of season or to propagate starter plants that can then be grown in local polytunnels or fields, reducing the need for long-distance shipments.

CEA has the potential to reduce the total land area needed for food production. Some landowners may choose to allocate more land to environmentally-focused activities leading to benefits to the general public and possible access to subsidies (e.g. Defra's Environmental Land Management schemes in England).

Mobile CEA systems (i.e. that can be moved to different sites) may have the potential to alleviate pressure on land that has been heavily farmed using conventional agriculture as well as decrease compaction caused by permanently siting a CEA system in a set location.

(2) Challenges

Potential barriers to establishing CEA systems in rural areas are largely about access – to labour, to transport links, and to markets (Table 4). Some of these issues (e.g. poor access to key roads and rail) may be inherent to an area and difficult if not impossible to address. However, many of the identified barriers are a reflection of the early stage of the CEA (particularly vertical farming) industry and are anticipated to change with time. As the community grows, it is reasonable to expect that the pool of experienced labour will also grow and that supply chains will become more developed. There are also steps that can be taken in the near-future (e.g. organisation of rural vertical farms into cooperatives) that could address some of the potential barriers identified.

Table 4. Key barriers to broad uptake of CEA production in rural areas.

Know-how
- Lack of operational expertise in running CEA systems, both amongst outdoor producers and in terms of the accessible labour pool. - Lack of market knowledge, as new entrants may have difficulty matching produce that they are able to grow to markets. - Lack of successful examples. Rural outdoor producers often want to see examples of peers running a viable business before getting involved, and these examples are hard to come by in such a new industry. - Knowledge and technology transfer between regions / countries could improve overall uptake in North-West Europe.
Supply chain
- Supply chains are in early development, with many CEA systems marketing direct to clients / consumers rather than to merchants, cooperatives or retailers. - Associated transport costs and emissions. Farms need to be in the right place to access retail hubs, ideally near key roads & rail links. Although this is less of a problem in smaller, densely populated countries (e.g. UK).
Infrastructure
- Some real estate requirements (e.g. electrical capacity required, ceiling height) may be difficult to accommodate in existing sites being considered for retrofitting for CEA. - For rural sites looking to rent space to third-party farm operators, adherence to operator requirements (e.g. building efficiency, waste management policies, etc) may be a barrier. - Some rural sites have poor access to energy sources. - Some rural sites have poor access to water mains. - Planning permissions may hinder developments. - Internet connectivity may be an issue in some locations.
Funding
- Funding/subsidies for energy use: contrarily to other industries there is no funding for energy use by farmers and the horticulture sector in particular. - Difficult to get a bank loan: banks often demand secured site and final customer (e.g. supermarket, restaurant), while the final customer demands production site. - High capital investment needed (e.g. to build a facility, buy land, etc) can be a considerable barrier to new entrants.

Challenges may be specific to regional or local contexts and thus interventions to address these barriers may require working together with local stakeholders. Local planning consent for a change of use of land or buildings may be a key consideration in establishing CEA systems in rural areas. The general public often sees agricultural land as an integral part of the rural landscape, and substituting fields of familiar crops with large glasshouses or warehouses with no windows might not be well perceived by rural communities.

Conclusions

Contributors highlighted several opportunities for CEA systems to benefit producers and the larger food systems in Iceland, Ireland, and the UK.

- Further development and deployment of CEA systems may enable enhanced local production of a wider range of fresh, nutritious crops for longer periods during the year, positively impacting food security and diversity for these regions.
- Relatedly, reduced reliance on imports may reduce food-related emissions, with the caveat that energy sources used to run and heat CEA systems must be taken into consideration.
- With changing regulations, shifts in subsidy structures, and increases in input costs impacting farm businesses, CEA may be useful for farmers looking to diversify incomes and move away from relying on a single production system. An added benefit may be the potential to use existing infrastructure (e.g. former poultry sheds).

The following factors were identified as having the potential to substantially impact future growth of CEA production in North-West Europe:

- **Skills:** Training / upskilling is needed to increase the size of the CEA workforce. Operations require a breadth of expertise (e.g. agronomy, engineering, data science), and a mix of education and on-the-job training is needed to develop the labour pool. Sourcing skilled workers for some locations (e.g. rural areas) may continue to be a particular challenge.
- **Energy:** Access to relatively low-cost, renewable sources of energy would enhance the competitiveness of CEA systems and enable a wider range of crops to be profitably and sustainably produced.
- **Regulatory and planning environments:** Regulatory changes that impact the agricultural sector (e.g restrictions on crop protection products, changing subsidies) may drive producers to seek out alternative production systems. Additionally, planning permissions and land use change requirements may impact the ability to establish growing facilities.
- **Urban demand for local food production:** Awareness of emissions associated with food miles may continue to drive demand for more local food production. Relatedly, ethical considerations are generating a growing desire to know how food has been produced.
- **Active development of new supply chains:** Many CEA producers (particularly vertical farms) sell directly to customers rather than via merchants, cooperatives or retailers. Maturing supply chains will help to de-risk CEA production for new entrants and improve resiliency.
- **Technology and innovation:** New technologies for CEA systems (e.g. automation, sensors) have the potential

to improve the competitiveness and sustainability of these systems, although many of these innovations are still in their infancy.

- **Geopolitical and environmental events:** Both Covid-19 and the war in Ukraine have recently sent shock-waves through our food systems and highlighted vulnerabilities in existing supply chains and production methods. Complex global events have the potential to either support the growth of CEA (e.g. driving domestic food production) or make operations more difficult (e.g. through increasing energy costs).

While time is needed to make advances in the above areas, public sector action could enable the opportunities highlighted above to be realised more quickly. In particular, support for skills development and research & development activities, as well as evidence-based policy making, could underpin step-changes in CEA across North-West Europe.

Credit: Ahmad Mohseni, Flex Farming.

5. Acknowledgements

EIT Food and Innovate UK KTN would like to thank the following contributors from Iceland, Ireland and the United Kingdom for sharing their time and offering their thoughts and opinions.

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We are one of nine innovation communities established by the European Institute for Innovation & Technology (EIT), an independent EU body set up in 2008 to drive innovation and entrepreneurship across Europe.

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