HAKON SWENSON
STIFTELSEN

Exploring the Viability and Sustainability of Vertical Farming Systems in Retail Environments

Final report of the research project ”Exploring the Viability and Sustainability of Vertical Farming Systems in Retail Environments”

HAKON SWENSON STIFTELSEN

AUTHOR
MICHAEL MARTIN & MARIA J. BUSTAMANTE

REPORT NUMBER
202601

Facts about the project

Name of the Study
Exploring the Viability and Sustainability of Vertical Farming Systems in Retail Environments

Granted funding
2 864 000 Swedish kronor

Project leader
Dr. Michael Martin, IVL Swedish Environmental Research Institute

Project participant
Dr. Maria J. Bustamante, KTH Royal Institute of Technology

Grant administrator
IVL Swedish Environmental Research Institute

Duration
June 2023 - june 2025

Foreword
The Hakon Swenson Foundation

The Hakon Swenson Foundation is proud to have supported the research project "Exploring the Viability and Sustainability of Vertical Farming Systems in Retail Environments". As the retail sector faces increasing demands for sustainability and innovation, vertical farming offers a promising pathway to deliver fresh, locally produced food while reducing environmental impact. This project has explored these opportunities in depth to understand how such solutions can be integrated effectively.

We extend our sincere thanks to the research team for their dedication and valuable contributions. We hope these insights will guide retailers in building more resilient and sustainable food systems.

Lena Litens,
Ordförande Hakon Swenson stiftelsen

Foreword

The research presented in this report was carried out to explore how vertical farming can transform food retail and contribute to more sustainable and resilient food systems. As urbanization accelerates and consumer expectations evolve, questions around food sourcing, quality, and environmental impact have become central for food retailers. Vertical farming, defined as growing food in stacked layers under controlled conditions, represents a promising pathway to achieve local, resource-efficient production, but many questions remain about its potential role in a future food system.

This project was initiated to better understand the environmental performance, business viability, and organizational implications of integrating vertical farming systems in retail environments. By combining life cycle assessment, qualitative case studies, and business model analysis, our goal with the study was to provide new insights into how vertical farming can support the transition toward more sustainable food production and consumption.

This work was done in collaboration with Maria J. Bustamante, postdoctoral researcher at KTH Royal Institute of Technology. We would like to thank the Hakon Swenson Foundation for their financial support of the project. Additionally, we extend our gratitude to the representatives at the vertical farms and retailers who took the time to share their experience and perspectives with us.

Stockholm, November 2025

Michael Martin and Maria Bustamante
IVL Swedish Environmental Research Institute/
KTH Royal Institute of Technology

Summary

In recent years, agriculture has seen dramatic innovations and development to bring food production systems closer to consumers, including an increasing interest in urban agricultural systems. As such, many examples and methods, ranging from outdoor systems in common areas to vertical farming in controlled environment agriculture (CEA) systems are increasingly prevalent. In particular, vertical farming has undergone extensive expansion, technological innovation, rapid growth, and upscaling worldwide (Armanda et al., 2019; Specht et al., 2019). The sector seeks to promote sustainability by, for example, reducing resource use, such as water and pesticides, producing in hyper-local locations, especially urban areas, and improving the quality and nutritional value of available products (Achard, 2022). Yet it struggles to integrate into the food system in a significant way. In 2023, several high-profile vertical farms (VFs) declared bankruptcy or shut down significant portions of their operations (Vertical Farm Daily, 2023), demonstrating that it's still unclear how these new business models will be integrated and scaled in the food system long-term to support the sustainability goals of the emerging vertical farming sector and broader agri-food industry.

Within this global context, through three focus areas, this research explored the viability and sustainability of integrating vertical farming systems into retail environments in Sweden. It combines environmental life cycle assessment (LCA), semi-structured interviews with vertical farms and retailers, numerous site visits, and document analysis to investigate how vertical farming systems can enable more sustainable, local, and circular food production while creating value for vertical farms, retailers, and consumers. Overall, the project showed that, in the Swedish context, vertical farms can be considered sustainable sources of locally produced lettuce and herbs. In fact, several retail farms demonstrate that VFs are a viable partner for food retailers to provide fresh, local produce to consumers. However, challenges remain in moving beyond small-scale, single-store implementations toward scalable, long-term solutions for food provisioning that have positive economic, environmental, and social impacts.

Study 1: Current and Emerging Retail-based Vertical Farming Solutions
Sustainability challenges require organizations to rethink collaboration and innovation processes. Through three qualitative case studies of vertical farming integration in retail settings, we examined how the partnerships evolved with a focus on experimentation.

Key findings suggest:

• Types of experimentation: Integrating vertical farming into retail environments requires experimentation beyond technology and market aspects to include operational elements. Retailers often needed to change how they collaborated, evaluated progress, and carried out daily routines, from maintaining the farms to transporting products from farm to store.

• Local autonomy in large retail systems: Innovation with sustainability goals may work best in large organizations when there is a balance between top-level support and local-level autonomy. Central teams can provide vision and resources, but local units need the space to learn, adapt, and make decisions about new technologies, particularly with respect to the evaluation and measurement of success over the long term.

Study 2: New Service and Data-Driven Business Models for Retailers and Producers
Scaling innovations requires the integration of new business models across multiple stakeholders. Thus, understanding the interaction between the business models of vertical farms and retailers provides insight into potential scaling pathways for vertical farms. We conducted an interview stu-

dy with vertical farms and retailers, coupled with document analysis.

Key findings suggest:
• There are currently two main VF business models found in the Swedish market:
o Product-based business model (PBBM): In this business model, the use of hardware and software in the growing process is largely located at a VF (typically at a peri-urban location), which produces larger quantities of products, which are then distributed to retail stores. The PBBM is much like a supplier model.
o Product-service business model (PSBM): This business model brings the VFs near to or inside the retail store and provides services in addition to products.
• Beyond establishing a new supplier relationship, the PBBM requires little change from the retailer perspective in how it creates and delivers value. However, it is difficult for VFs to compete with current suppliers in terms of the variety of offerings and supply demands of central retail procurement departments, which constrains growth.
• The PSBM requires more adaptation on the retailer side, e.g., worker knowledge and routines. Currently, the sales process is customized by store, which requires substantial time and resources from the VFs and makes large-scale growth difficult.

Study 3: Viability and Sustainability Assessment
The sustainability of vertical farming systems is a key question for partners considering adopting such solutions. To complement existing theoretical evaluations of the sustainability of vertical farming, we collaborated with a vertical farm to conduct a life cycle assessment of a modular cabinet vertical farm producing lettuce and basil for the end user.

Key findings suggest:
• In Stockholm, modular in-store systems can provide crops with greenhouse gas (GHG) emissions comparable to or lower than conventional sourced options.
• The largest share of all environmental impacts comes from the electricity use for the cabinet farm. Thus, the potential GHG emission savings will vary depending on location. Sweden, in particular, has good preconditions given the large share of renewable energy in the current energy mix.

In summary, the results suggest opportunities to integrate vertical farming solutions into retail environments to support sustainability goals, particularly in Sweden, owing largely to the renewable energy mix. However, overall success and the scaling of vertical farming will require deeper cross-functional collaboration and long-term strategic alignment with retailers, indicating that greater experimentation with business models and operational elements is needed alongside the ongoing technical experimentation and improvement in the industry.

Table of Contents

1. Background

To secure sustainable and resilient food systems, new approaches, innovations, techniques, and processes are needed for both food production and consumption. With an ever-expanding population and global food market, it will be important to find solutions for more resilient food production methods closer to consumers (Benke & Tomkins, 2017; Romeo et al., 2018). Vertical farming has been identified as a promising solution to secure food supplies and reduce pressure on agricultural land; see e.g. (Despommier, 2009; Kozai, 2013; Kozai and Niu, 2016) and identified as a promising option for northern regions (Graamans et al., 2018; Orsini et al., 2020). The methods for vertical farming can be summarized by controlled environments, which are less affected by climate change or other outside factors that might affect the production, typically with the help of LED lighting, a controlled atmosphere, and typically employ hydroponic systems for nutrient and water management (Kozai, 2013). Benefits of vertical farming include the potential to increase productivity, reduce environmental footprints associated with production and transportation, and provide controlled growing conditions in climate-controlled indoor spaces, such as fresh, local food year-round (Benke and Tomkins, 2017). However, high electricity demand and upfront investment costs persist as limiting factors.

In Sweden, interest in vertical farming has accelerated over the past decade. Grönska was the first farm to sell vertical farm produced products on the market in November 2016 at Stockholm-based Paradiset. Since these products debuted, the sector has experienced substantial growth in the number of start-ups developing vertical farming technologies and products, including Agtira in Härnosand, Swegreen, Nära, CubeGreens, and Farmy in Stockholm, and Ljusgårda in Tibro, among others. In addition, large retailers, including ICA, IKEA, COOP, and AxFood, have been working with these vertical farming companies or suppliers on different types of collaborations that range from pure product offerings to a combination of product and technology offerings, such as installing modules or integrated systems in-store. Yet, the percentage of vertical farm produced plants and herbs sold remains small overall, and the sector has seen a number of bankruptcies and restructurings throughout the last decade, following global sector trends.

Retailers are increasingly recognized as key actors in shaping sustainable food systems. Positioned at the interface between producers and consumers, they have a unique ability to influence supply chains, consumption patterns, and innovation trajectories. They currently play a vital role in advancing vertical farming products and business models. While many retailers acknowledge the potential value of year-round, locally produced produce for meeting customer demand, there are also concerns about the overall sustainability (both from an environmental and economic perspective) of working with and/or implementing in-store solutions (Jürkenbeck et al., 2019; Martin, 2022). Long-term viability also raises questions about energy needs, workforce knowledge, product expansion, pricing, and the need to understand the various integration options.

2. Purpose and Research Questions

Vertical farming has the potential to address several sustainability challenges in the agri-food system, including resource efficiency, local food security, and supply chain transparency. However, realizing this potential requires understanding how such technologies interact with existing systems, business models, and consumer expectations. The purpose of the project was to investigate the technical, environmental, and organizational dimensions of vertical farming as a sustainable innovation for retail environments. This was done through three structured focus areas.

2.1 Study 1: Current and Emerging Retail-based Vertical Farming Solution

Addressing sustainability challenges requires organizations to rethink how they design business models, form collaborations, and manage innovation, especially when their goals extend beyond simple financial performance (Breuer & Lüdeke-Freund, 2017; Seebode et al, 2012). Research shows that collaboration between organizations can be a powerful driver of innovation by bringing together diverse resources and capabilities. This is particularly important for innovation for sustainability, where the desired outcomes reach far beyond the interests of any single firm (Urbinati et al, 2023; Wiener et al, 2020). However, collaborations aimed at sustainability often face added complexity: partners may prioritize environmental, social, and economic goals differently, leading to conflicting expectations or organizational logics (Watson et al, 2025). Even so, involving partners in the innovation process is widely recognized as crucial for advancing sustainability, making collaboration not just beneficial, but essential.

The overall objective of this work package was to explore and analyze the current development, methods, and diversity of vertical farming in the Swedish market. A key part of this work was understanding how experimentation unfolds between vertical farms and retailers, and important elements during collaboration that are required to bring VF systems into retail environments. The research questions that guided this work were:

1. How does experimentation between vertical farms and retailers materialize?
2. How does collaborative experimentation between retailers and vertical farms affect the development of VF solutions?

2.2 Study 2: New Service and Data-Driven Business Models for Retailers and Producers

Research acknowledges the need for innovations and business models in the agri-food sector to support sustainable food systems (Schut et al, 2020). Remote monitoring and centralization of tasks aided by digital technologies is a key value proposition of vertical farming solutions, which are moving from the traditional sale of products to incorporate services in the form of growing-as-a-service or farming-as-a-service models (Martin & Bustamante, 2021; Drottberger & Langendahl, 2023). Yet, with several high-profile vertical farms declaring bankruptcy or shutting down significant portions of their operations in recent years, it remains unclear how these data-informed practices and data-driven business models will be integrated into the food system over the long term to support the sustainability goals of the emerging vertical farming sector and the broader agri-food industry.

The agri-food industry faces challenges when it comes to business model innovation and scaling solutions (e.g., Miranda et al, 2023; Tell et al, 2016). Collaboration across firms will be vital. Retailers hold significant power in both the buying of products and the shaping of consumer choice, yet research suggests that sustainability work and changes to assortments and promotions will require significant changes within retail organizations (Blom et al, 2023; Gravely & Fraser, 2018). Thus, understanding the challenges and opportunities that vertical farming products and services represent for retailers is a vital aspect for further business model innovation of these emerging systems that encourage long-term adoption and scaling, enabling both vertical farms and retailers to build sustainable value. Research questions that guided this work package included:

1. What main business models are vertical farms employing in the Swedish market?
2. How do these business models interact with retailer business models, and what implications may this have for scaling vertical farming solutions?

2.3 Study 3: Viability and Sustainability Assessment

Vertical farming is frequently advocated in the literature as a sustainable method for food production (Despommier, 2011; Benke & Tomkins, 2017). However, there are very few analyses of the environmental implications of vertical farms in the scholarly literature (Orsini et al., 2020; Martin & Orsini, 2023). Much of the research on vertical farms is devoted to theoretical evaluations that compare their effectiveness with other systems, such as open-field agriculture and greenhouses. While this lack of research may reflect the novelty of these systems, it is important that researchers more rigorously investigate vertical farming's stated promises of resource efficiency and reduced environmental impacts (Martin & Orsini, 2023).

There has been more attention on large commercial systems, but there is also a growing use of smaller systems, especially in the Swedish market. These vertical farming systems are typically installed in existing spaces, where the vertical farm provides customized solutions to customer needs, whether the plants are used for consumption (e.g., in restaurants or cafes) or for resale (e.g., in food retailers). Therefore, in this project, we partnered with a vertical farm to perform a life cycle assessment of an on-site cabinet farm. The main research questions were:

1. What are the sustainability implications of in-store vertical farming systems?
2. How does this compare to conventional systems?

3. Method of the Study

Throughout the project, researchers have collaborated with both vertical farming start-ups and retailers in Sweden and abroad to examine the opportunities and challenges of scaling vertical farming solutions in the food retail sector. Both qualitative and quantitative data collection methods were utilized to best fit the purpose of each focus area.

3.1 Data Collection and Analysis: Study 1

A case study methodology was used to focus on current and emerging retail-based vertical farming solutions. Three cases of Swedish retailers partnering with VF start-ups were identified through media reports and the researchers' professional networks. A total of 20 interviews across three case studies were conducted in order to understand how experimentation unfolded during the collaborations. To complement the primary data collection, internet sources (e.g., press releases, news articles, company websites, social media posts, and podcasts) were compiled for each case and provided important information and facts on timelines, expectations, and insight into innovation processes and sustainability goals. Some retailers and vertical farms shared internal company documents to support understanding of strategy and lessons learned, and the researchers conducted observations and site visits for some cases. Table 1 summarizes the data collection efforts for this focus area.

Data analysis was done in three steps. First, we incorporated interview transcripts, research notes from observation and visits, and online data into individual case narratives. In a second step, each narrative was analyzed and categorized based on a conceptual framework grounded in the sustainability-oriented innovation and experimentation literature. The main areas included identifying the prominent roles of vertical farms and retailers and examining how and what types of experimentation unfolded during the period under study. As a final step, the findings from the individual cases were compared to identify cross-case patterns and differences.

Table 1: Summary of data collection for Study 1

Case	*# Interviews*	*Interviewee position* CR = Central Retail Org LR = Local Retail Org VF = Vertical Farm	*Interviewee*	*Additional Data*	*Source (additional data)*
Alpha	4	Project Leader, Urban Farming (CR)	A1 (2x)	Lessons Learned PPT	Internal
		Project Leader, Urban Farming (CR)	A2	Case study PPT	Internal
		Chief Executive Officer (VF)	A3	Email communication	Internal
				News articles, press releases, blog posts	External
				Podcast interview	
				LinkedIn posts	External
					External
Beta	9	Project Manager (CR)	B1	News articles, press releases	External
		Innovation Manager (CR)	B2	Corporate & store-level websites	
		Group Lead, Innovation (CR)	B3	VF website	External
		Head of Sustainability (LR)	B4	Social media posts	
		Head of Fruits & Vegetables (LR)	B5	Site visit	External
		Chief Innovation Officer (VF)	B6		External
		Lead, Customer Success (VF)	B7		Internal
		Key Account Manager (VF)	B8		
		Sales manager, Fresh produce (LR)	B9		
Gamma	7	Senior Sustainability Strategist (CR)	C1	News articles, press releases	External
		Head of Group, Fruit, Vegetable & Flowers (CR)	C2	Corporate & local-level websites	
		Store Manager (LR)		Social media posts	External
		Head of Growing (VF)	C3 (2x)	VF visit	
		Founder & Chief Executive Officer (VF)	C4	Event observation	External
		Customer Support (VF)	C5		Internal
					External
			C6		
Total	*20*				

3.2 Data Collection and Analysis: Study 2

We conducted an interview-based study to understand the business models of vertical farms and how these models interact with and affect retailers' business models. The data consisted of 17 semi-structured interviews with representatives from vertical farms (n=10) and retailers (n=7). Interviews ranged between 20 and 90 minutes in length. Roles represented from the vertical farms included founders, sales & business developers, and customer service. Representatives from retailers included store managers, sustainability managers, and managers of fruit and vegetable departments. The interviews were complemented with site visits and document analysis (both internal and external).

Data were analyzed through multiple rounds of coding using the data analysis software NVivo. A first round of coding helped uncover key business model elements, opportunities, and challenges from the perspectives of both vertical farms and retailers. The second round of coding focused on developing an integrated perspective on how the business models of vertical farms and retailers interact and on the potential effects on scaling.

3.3 Data Collection and Analysis: Study 3

To understand the environmental performance of in-store vertical farming, the project employed life cycle assessment (LCA), an established scientific method for evaluating the environmental impacts of a product from raw materials through end use. The LCA focused on the GrowOff modular vertical farm developed by Stockholm-based Grönska Stadsodling and compared its results with conventionally grown lettuce and basil.

The analysis was based on a functional unit of 1 kilogram of edible produce available for use, which allowed lettuce and basil to be compared with conventional supply chains. Data for the GrowOff system came directly from Grönska's test facility. The assessment followed a cradle-to-grave perspective and included the construction of the GrowOff unit, energy use, material consumption, cultivation, and waste generated during production and use. Since the system is typically installed in kitchens, cafeterias, or retail environments, where produce is harvested and used on-site, no additional packaging, cold storage, or transport was included.

Environmental modeling was done in OpenLCA using the Environmental Footprint v3.1 method, which is a widely used life cycle impact assessment method used across Europe and recommended by the European Commission. The study examined impacts such as greenhouse gas emissions, land and water use, nutrient pollution, and resource consumption, categories commonly used in food sustainability studies and comparable across horticultural systems.

Two baseline scenarios were developed.

- GrowOff-Lettuce: About 240 kg of lettuce produced annually (around 2,400 lettuce plants, weighing 100g each).
- GrowOff-Basil: About 144 kg of edible basil annually (around 3,600 pots with 40g of edible basil)

From an energy perspective, the baseline scenarios are based on the average Swedish electricity mix, which includes hydro (39%), nuclear (41%), wind (10%), combined heat and power (9%), and solar (less than 1%) (Swedish Energy Agency [SEA], 2021). As such, the study can be sensitive to the choice of electricity employed. The Swedish electricity mix was compared with datasets for different sourcing. This included sourcing only from hydropower, in addition to a mix including 50% wind and 50% hydropower-sourced electricity. Infrastructure disposal was excluded from the baseline scenarios due to ownership complexities, but we tested how its inclusion would affect the results.

To compare the results of the GrowOff's produce with conventional supplies, the sourcing of the lettuce and basil production from conventional production methods was included for lettuce and basil from typical importing countries to Sweden, including Spain, Italy, and the Netherlands, which includes cultivation, packaging, processing, and transport to end users.

4. Results

4.1 Study 1: Current and Emerging Retail-based Vertical Farming Solutions

In this study, we examined three cases of vertical farming implementations in retail settings (Case Alpha, Case Beta, and Case Gamma). The initial setup of the partnerships centered on a shared value proposition to offer local, sustainable food. For the retailers, in-store or co-located farms offered a novel product offering to their customers. For the vertical farms, the partnerships represented valuable opportunities to test new technologies, experiment with business models, and learn directly in retail environments. While each case was unique, patterns emerged across the cases.

4.1.1 Collaboration between multi-level organizations and start-ups

The retailers involved were all part of multi-level organizations, but the ways in which the vertical farming projects connected to these levels varied. At the time of writing, the vertical farming collaboration with Case Alpha has been discontinued, while Cases Beta and Gamma are still ongoing. When reflecting on the different outcomes of the cases, a key difference was the retailer's degree of local decision-making autonomy. In Cases Beta and Gamma, store managers and staff drove the decision-making and day-to-day experimentation, with little to no involvement from the central organization. Thus, local leads played an active role in shaping the vertical farm partnerships and had the authority to adapt, solve problems, and move more quickly. Case Alpha, on the other hand, was driven mainly by the retailer's central innovation team. Central-level personnel actively collaborated with the vertical farm on technology, conducted pilot tests, and supported the store team. When strategic priorities shifted at the central level, the project had less protection and was more easily evaluated on traditional measures such as cost alone, making it harder for the sustainability goals to take root. This finding suggests that innovation aligned with sustainability goals may be most effective in large organizations when there is a balance between top-level support and local-level autonomy. Central teams can provide vision and resources, but local units need the space to learn, adapt, and make decisions about new technologies to enable their growth. The findings also raise important questions about how new production methods are evaluated within retail organizations. Vertical farming products cannot currently compete on price alone, so without integration of values, including sustainability of the method, customer experience, and novelty, their adoption will be slow. However, for stores evaluating bottom-line profitability, incorporating such evaluative characteristics requires a shift from store-level management.

4.1.2 Multiple types of experimentation simultaneously

Since vertical farming is still relatively new to the Swedish market, all the retailers and vertical farms were learning, which led to several kinds of experimentation:

- Technical experimentation: testing hardware, lighting settings, software tools, and plant varieties.
- Market experimentation: trying out different product offerings, pricing strategies, and ways of engaging customers in-store.
- Operational experimentation: learning how to share responsibilities, adjust in-farm and in-store routines, and build new working relationships.

The findings show that experimenting with new sustainable solutions is not only about testing technology or markets. To integrate vertical farming into retail environments, retailers often needed to change how they collaborated, evaluated progress, and carried out daily routines, ranging from farm maintenance to transporting products from farms to stores.

4.2 Study 2: New Service and Data-Driven Business Models for Retailers and Producers

In Sweden, vertical farming companies generally rely on two business models – product-based business models (PBBM) and product-service business models (PSBM). Across both business models, the retailers and vertical farms share the idea that vertical farming is an opportunity to provide local, sustainable and fresh products to consumers. However, how value is created and delivered differs, and these differences shape how the models fit into existing retailer business models and potential scaling opportunities for the vertical farms.

4.2.1 Vertical farm business models and existing retail structures

The first business model is a product-based business model (PBBM), where the hardware and software used to grow products is housed within the vertical farming site, separate from the retail environment. The VF then sells its harvested greens to retailers, as with any other supplier (See Fig. 1). In the PBBM, value delivery is straightforward. The retailer buys packaged produce, places it on shelves, and sells it. Because this mirrors their usual approach to working with suppliers, the retailer's business model requires only minor adjustments.

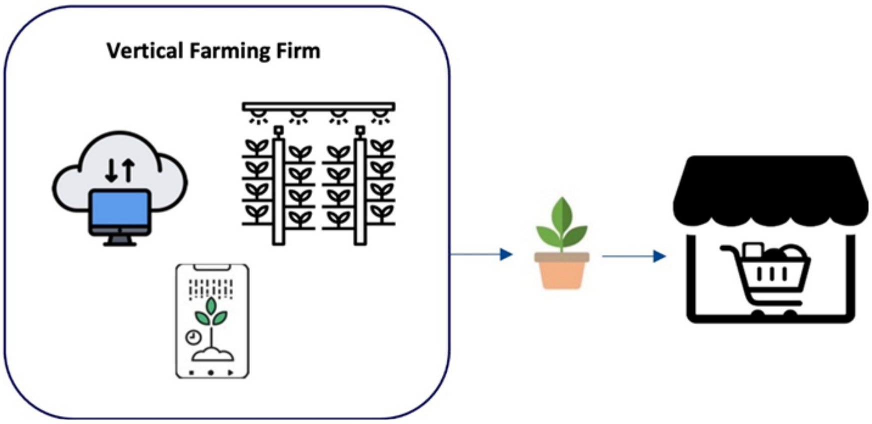

Fig 1. Illustration of the Product-based Business Model. Hardware and software are monitored and controlled by a vertical farming firm. Final product delivered to the retailer.

The second business model is a product–service business model (PSBM), where the vertical farm provides both the technology and the service of growing food directly inside the store or co-located next to the store (e.g., in a container behind the store). In this business model, the vertical farm delivers value not only through the product itself but also through services and customer experience (See Fig. 2). The PSBM creates new types of value, but it also demands changes from the retailer as well in the form of new routines, closer collaboration with a supplier, and a long-term investment perspective. This is driven by the fact that the vertical farm creates value through technology and services, yet the retail sector still captures value by selling physical produce. The dynamics of how these business models interact with current retail structures also affects how vertical farming is scaling in the Swedish market.

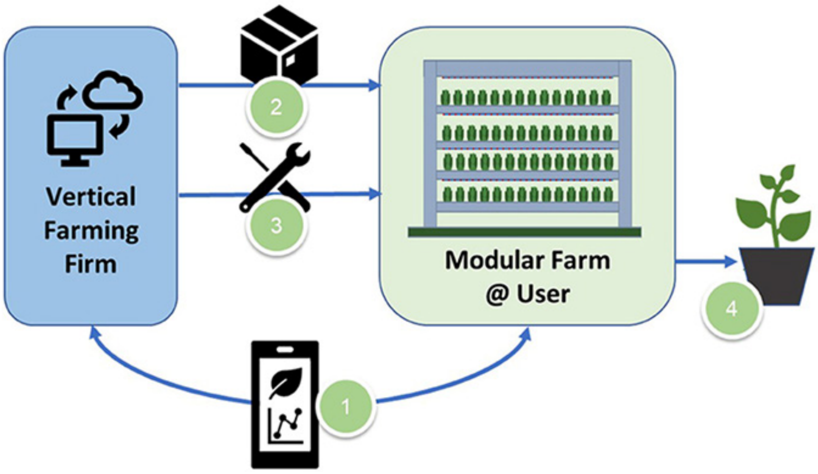

Fig 2. Illustration of the Product-Service Business Model (adapted from Martin & Bustamante, 2021). 1) Cloud-based application to monitor and provide feedback, 2) Consumables and other inputs, 3) Maintenance support, 4) Optimization of final products through system and personal feedback.

4.2.2 Scaling pathways: drivers and barriers

Store-by-store expansion

Both business models initially sought to grow by selling systems or producing for individual stores, largely because many retailers in the Swedish market are structured in this way. Over time, vertical farms using the PBBM have found this too slow and labor-intensive and have begun shifting toward larger, centralized contracts. PSBM firms are still mostly relying on store-to-store sales, using tailored in-store solutions to spark demand. However, this requires significant relationship-building with each store, thereby slowing adoption and diffusion.

Large retail contracts

Swedish food retail is dominated by a few large chains, and securing central procurement contracts is challenging. Retailers require guaranteed volumes before signing big agreements, but vertical farms often need those agreements first in order to attract investment and expand production. This mismatch of supply and demand mechanisms makes rapid upscaling difficult.

Changing existing supply chain habits

Vertical farms suggest that retailers could accelerate upscaling by reducing their reliance on imported leafy greens. But for retailers, this would mean shifting long-standing supplier relationships and narrowing the range of available products; something vertical farms cannot yet fully replace. This reveals deeper lock-ins at both the economic and sectoral levels that present barriers to alternative production methods driven by smaller-scale actors, such as vertical farm start-ups.

Overall, the study shows that scaling vertical farming is not just a matter of improving technology or increasing production. It requires alignment between the business models of vertical farms and food retailers, who hold considerable power over supply chains. PBBM integrates more easily into retailer structures but faces investment and volume constraints. PSBMs offer novel forms of value but require deeper collaboration and operational change.

4.3 Study 3: Viability and Sustainability Assessment

The objective of this study was to examine the sustainability of on-site production through vertical farming. To do so, a life cycle assessment (LCA) of a modular vertical farming cabinet installed in Stockholm was conducted. The environmental impact was assessed for a functional unit of 1 kilogram of edible lettuce and basil, and the results were compared with those for conventional lettuce and basil supplied through typical European food chains. Figure 3 illustrates the system boundaries of the LCA.

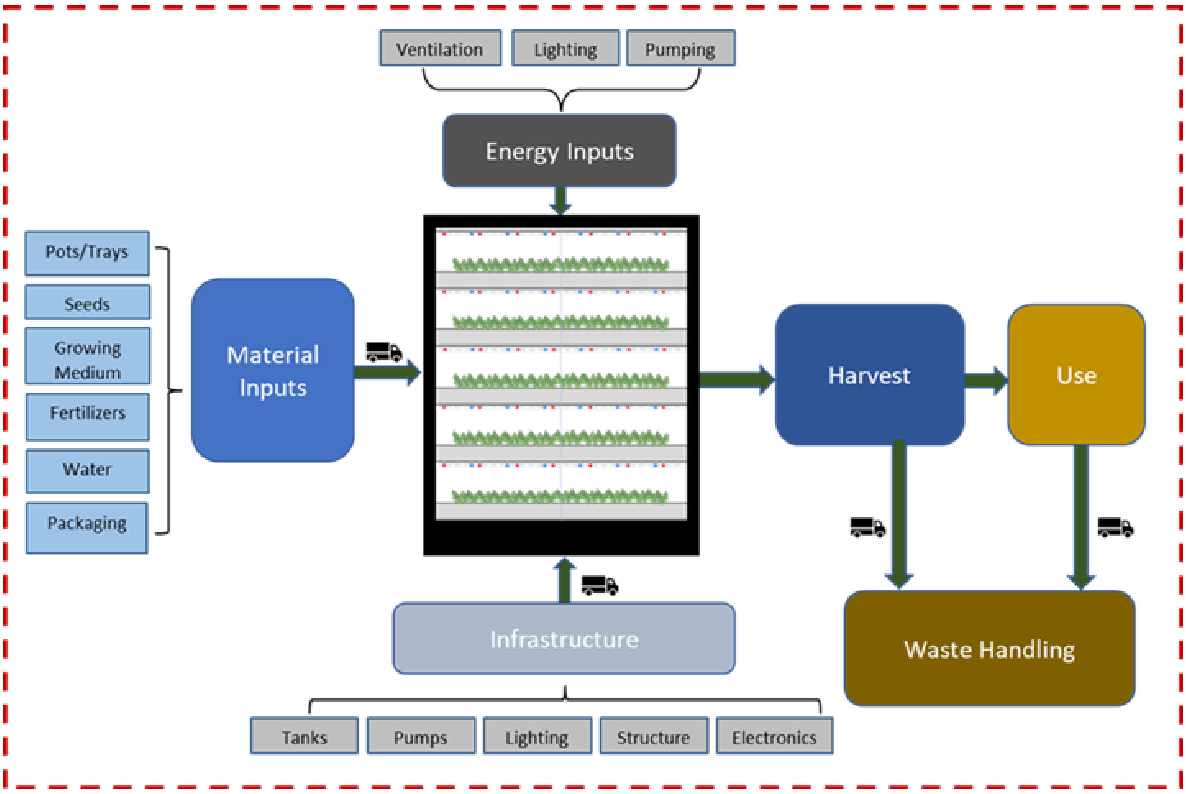

Figure 3: Simplified system boundaries of the environmental life cycle assessment. Figure from Martin et al. (2024)

Overall, the study showed that the modular vertical farming cabinet can produce lettuce and basil with an environmental footprint comparable to or lower than that of conventional imports, particularly when a renewable energy mix is employed. Electricity remains the dominant factor in determining sustainability, but for countries such as Sweden, which rely on renewable energy, vertical farms can offer an alternative production method that strengthens existing supply chains and delivers additional value, such as locally produced, pesticide-free products. Additionally, there may be benefits not fully captured by environmental metrics, such as minimizing the time between harvest and consumption, which can reduce food waste. Freshness and potentially improved nutritional profiles (due to ongoing research on optimizing growing conditions) may also offer added value, though further research is needed in this area. The following sub-sections highlight key results. More detailed results are presented in the published study (Martin et al., 2024).

4.3.1 GrowOff: Lettuce scenarios

The study showed that producing one kilogram of lettuce resulted in 0.78–1.18 kg CO_2-eq. The lower end of that range was achieved when the system utilized primarily renewable electricity (a mix of hydropower and wind) and when only part of the cabinet's infrastructure was assigned to the farm's impacts, reflecting the reality that the units are often leased rather than owned.

Electricity use was the most dominant contributor to environmental impact across almost all categories. LEDs and climate controls accounted for 40-60% of total greenhouse gas emissions. After electricity, the next major contributors were the cabinet's own infrastructure materials (aluminum structure and electronics), the growing media, and the transport of consumables (such as seeded trays and fertilizers).

One of the strengths of the GrowOff model is that it eliminates several steps required in conventional supply chains, thereby reducing packaging, cold storage, and long-distance refrigerated transport. Because the lettuce is harvested and sold at the same site where it is grown, many post-harvest impacts are minimized or eliminated. Even when consumables were shipped long distances within Sweden (e.g., from Stockholm to Gothenburg or Luleå), the effect on total emissions was negligible. As such, the footprint was only altered by 0.01–0.02 kg CO_2-eq per kg. End-of-life (EOL) treatment options for the cabinet infrastructure, including recycling and disposal, were also evaluated. Including EOL impacts increased emissions only slightly (about 3-4%), showing that infrastructure disposal is not a major environmental hotspot in these systems; see Figure 4 below for further details.

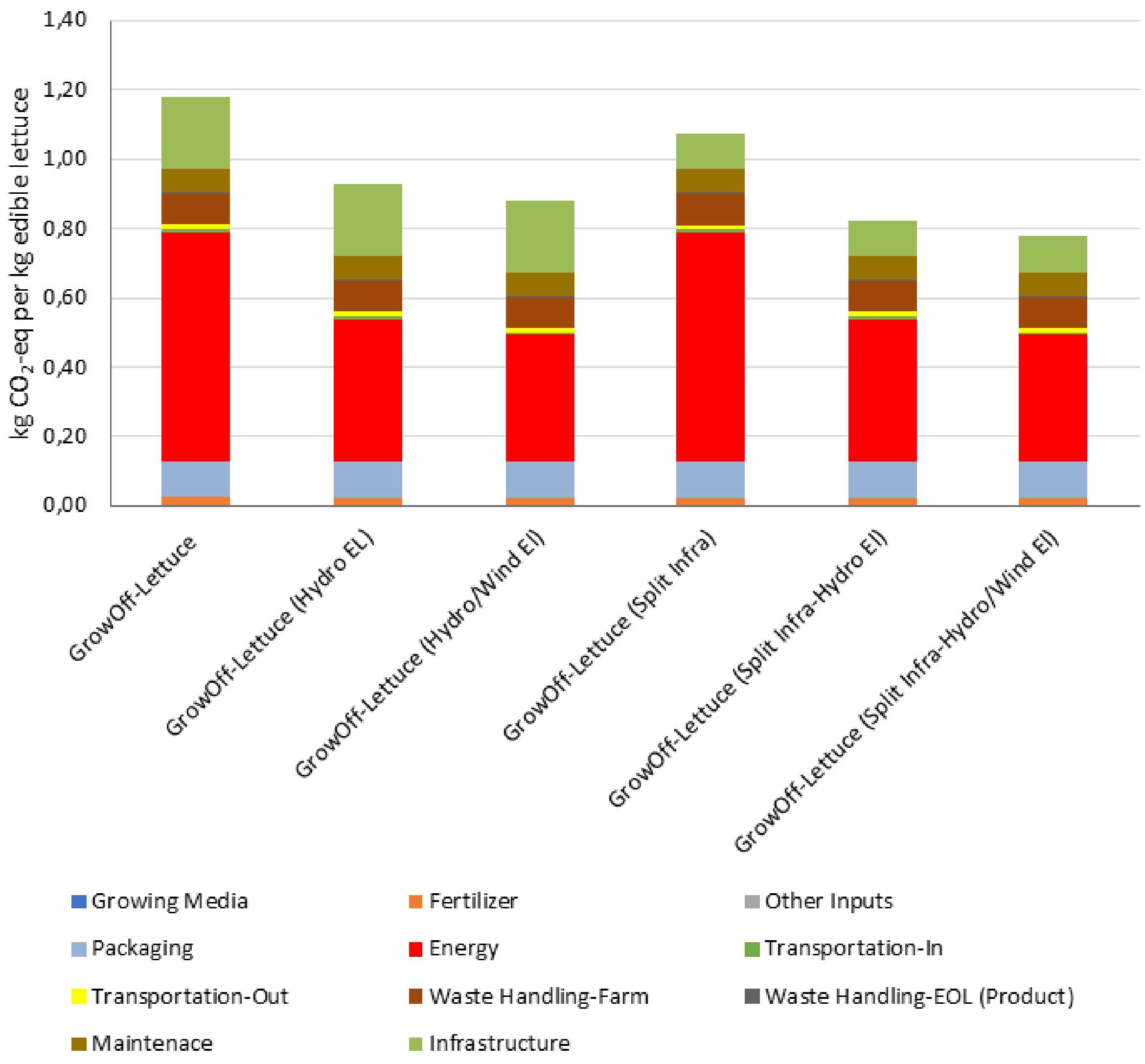

Figure 4: Illustration of the influence of the selection of energy sourcing and infrastructure allocation for 1 kg of edible lettuce for GHG emissions (shown in kg CO2-eq per kg edible lettuce). Figure from Martin et al. (2024)

4.3.2 GrowOff: Basil Scenarios

Basil performed similarly to lettuce in terms of overall patterns, though the absolute values were higher due to the plant's different growth profile. The GrowOff system produced basil with a footprint of 1.45–2.12 kg CO_2-eq per kg, see Figure 5 below. As with lettuce, the lowest emissions occurred when electricity was sourced exclusively from renewable sources, and infrastructure impacts were shared between provider and user.

Basil's shorter growth cycle and denser planting arrangement influenced the system's inputs slightly differently. Basil required somewhat less water and fertilizer than lettuce, but its production required more pots and growing media, thereby increasing resource use per kilogram of edible product. Nevertheless, the overall structure of impacts remained the same: electricity dominated, followed by infrastructure and consumables.

Again, on-site production offered several advantages. Basil is prone to high spoilage and transport-related losses in conventional supply chains due to its fragility and short shelf life. By cutting out these steps, the cabinet system achieved competitive or better results.

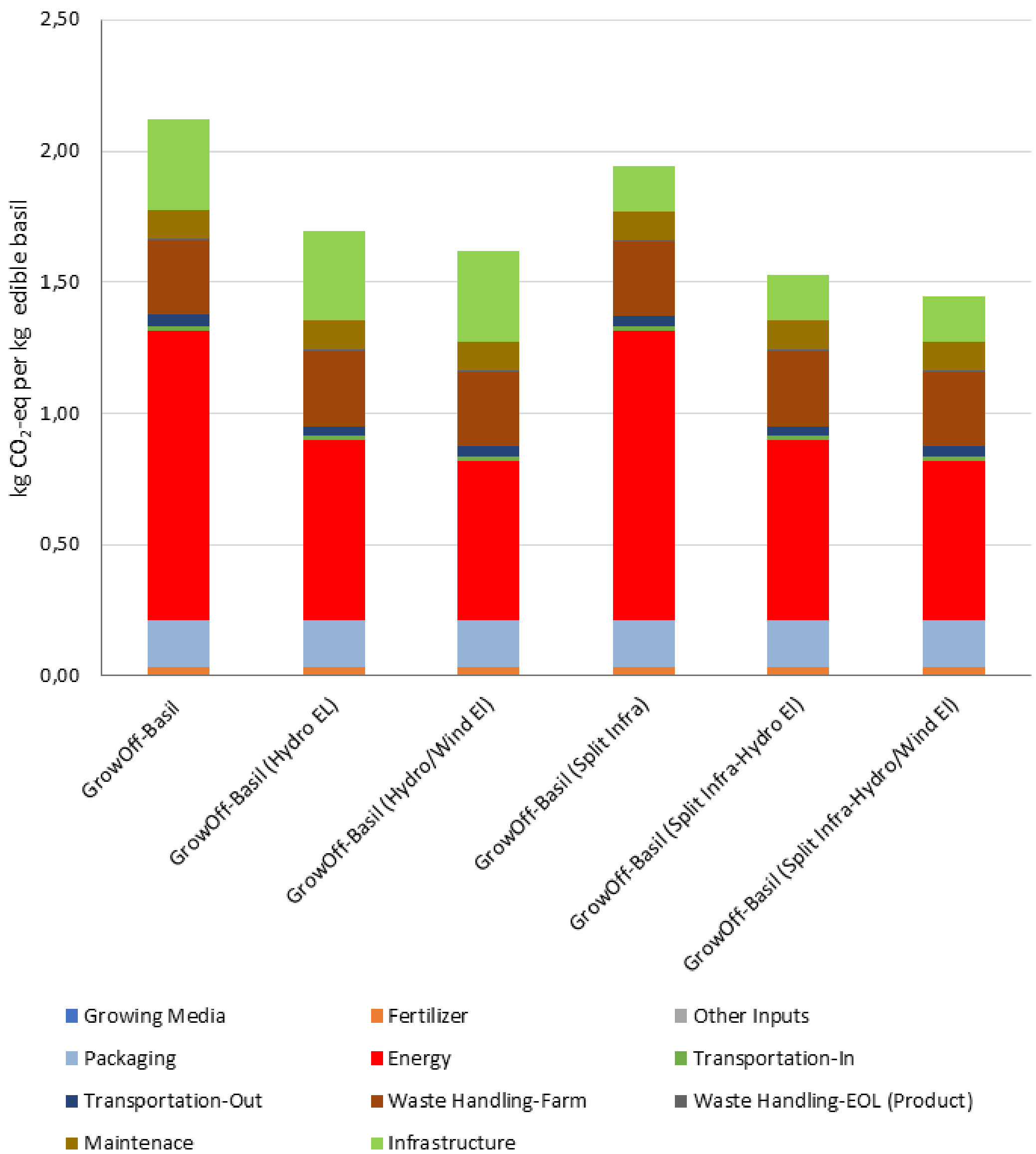

Figure 5: Illustration of the influence of the selection of energy sourcing and infrastructure allocation for 1 kg of edible basil. Figure from Martin et al. (2024)

4.3.3 Comparison to Conventional Lettuce & Basil

Compared with conventional production and supply, the cabinet-based vertical farm performed well. For lettuce, conventional greenhouse and open-field systems in Spain, Italy, and the Netherlands typically fell between 0.75 and 2.07 kg CO_2-eq per kg, meaning the GrowOff system performed as well as or better than most imported lettuce. The results were even clearer for basil. Conventional basil, whether grown in open fields in Italy or in Swedish greenhouses, has been found to have GHG emissions ranging from 2.9 to 6.2 kg CO_2-eq per kg. The GrowOff's performance of 1.45-2.12 kg CO_2-eq, therefore, appears favorable. The main reasons are that conventional basil requires intensive packaging, long-distance transport, and refrigeration, none of which apply to the cabinet farm.

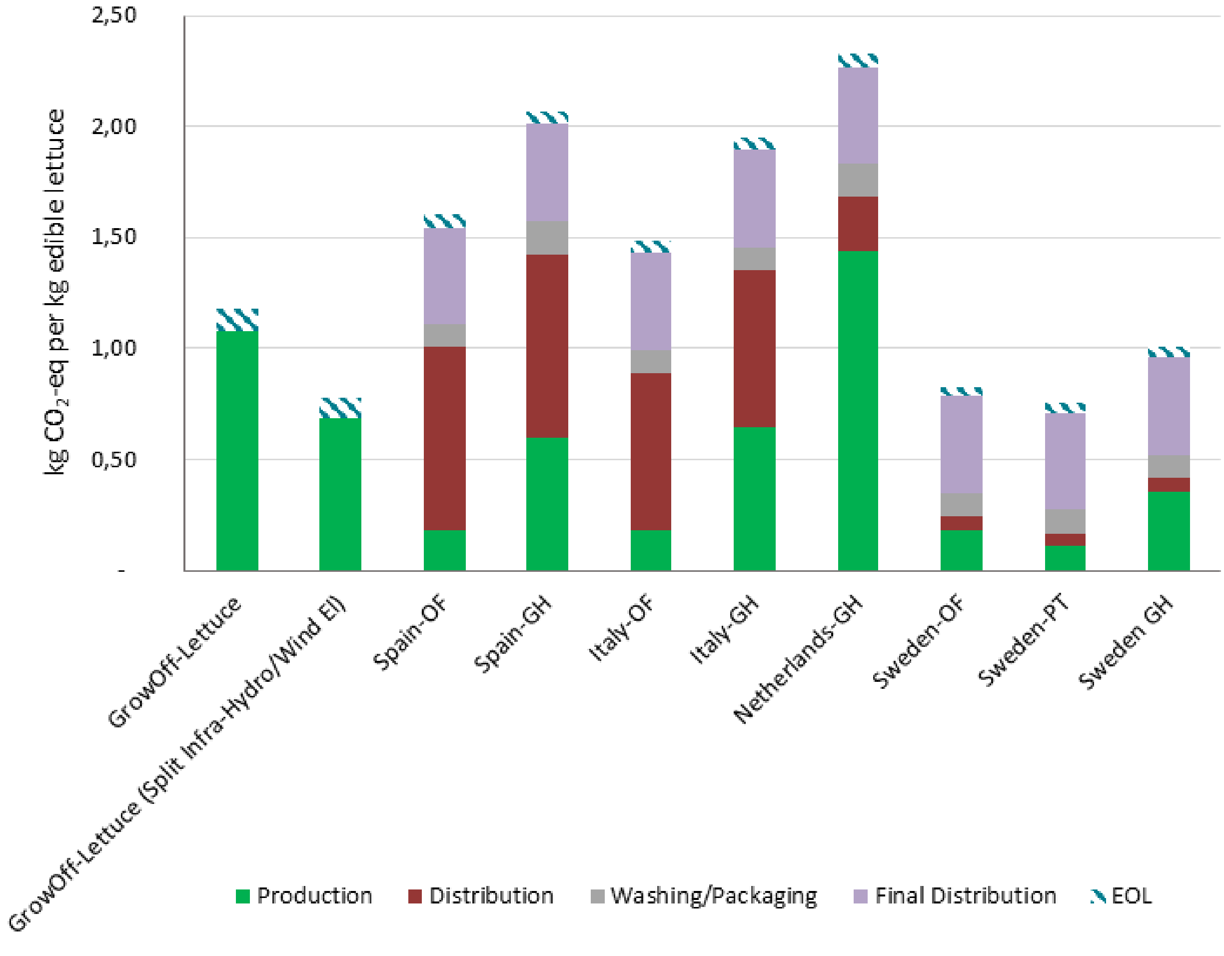

Figure 6: Comparison of the GHG emissions for the GrowOff farm lettuce versus conventionally sourced lettuce (shown in kg CO2-eq per kg edible lettuce). OF-Open Field; GH-Greenhouse; PT-Polytunnel. Figure from Martin et al. (2024)

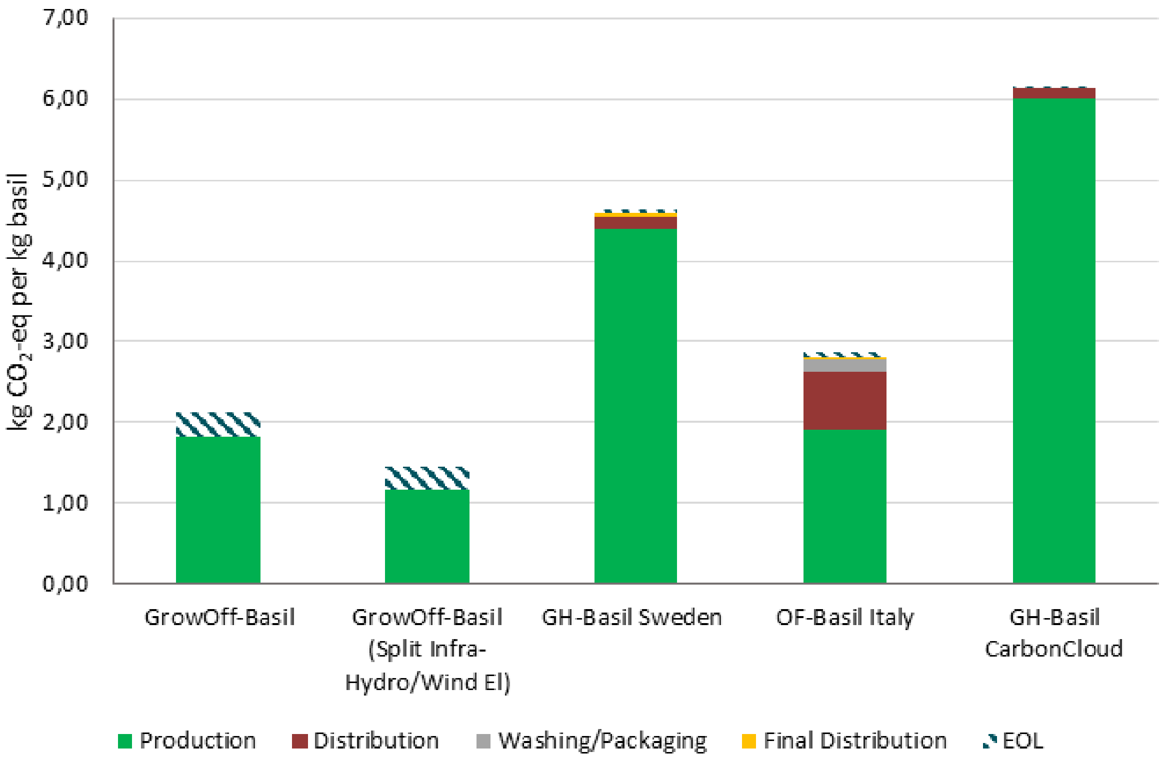

Figure 7: Comparison of the GHG emissions for the GrowOff-Basil and conventionally sourced basil. Figure from Martin et al. (2024)

4.3.4 Notes on Key Factors and Assumptions

The study used sensitivity analyses to test how key assumptions affected the results. Electricity dominated the life cycle impacts. It accounted for 40 to 60 percent of total greenhouse gas emissions for lettuce and 38 to 58 percent for basil, depending on the scenario. Using only renewable electricity from hydropower or a hydropower and wind mix reduced emissions by 20 to 35 percent for both crops. This confirms that electricity choice largely determines performance in energy-intensive systems that rely on artificial lighting and climate control.

Infrastructure assumptions also influenced the results. When cabinet impacts were split evenly between the vertical farm and the retailer, emissions decreased by 5-10%. This shows how leasing and other service-based arrangements can spread environmental burdens across actors. Including end-of-life treatment for the cabinet increased emissions by only 2-4 %, underscoring that electricity and material use dominate overall impacts.

The results suggest that other factors played a minor role. For example, transporting consumables over long domestic distances had little effect because volumes were small and deliveries infrequent (and are often conducted utilizing existing logistics and postal shipping methods).

5. Implications and practical significance for the retail industry

The findings from the three studies offer important insights for retailers exploring vertical farming as part of their sustainability and innovation strategies. Overall, the project showed that, in the Swedish context, vertical farms can be considered sustainable sources of locally produced lettuces and herbs, and in fact, there are a number of farms in retail settings that demonstrate vertical farms are a viable partner for food retailers to provide fresh, local produce to consumers. However, challenges remain in moving beyond small-scale, single-store implementations toward scalable, long-term solutions for food provisioning that have positive economic, environmental, and social impacts. The implications outlined below highlight the considerations retailers should address when adopting and scaling vertical farming solutions.

Expect and support multiple forms of experimentation
Vertical farming introduces a new production method inside a traditionally consumer-facing environment, which means retailers should expect experimentation across several dimensions:

• Technical: lighting, software, and crop scheduling
• Market: pricing, product placement, and customer engagement
• Operational: routines for harvesting, staffing, and quality control

Retailers that embraced this broader experimentation approach were better able to integrate vertical farms smoothly into daily operations. By acknowledging that vertical farming is more than technology, retailers can plan for training, ongoing collaboration with suppliers, and iterative adjustments to routines. Engagement from local store teams is key in this regard.

Different vertical farming business models will require different changes

The two dominant models, product-based business models (PBBM) and product-service business models (PSBM), offer distinct benefits and entail different adjustments for retailers.

• PBBM can add Swedish-grown products to the shelves and align more easily with existing purchasing structures: retailers buy harvested greens as they would from any supplier. Yet, the ability to work with start-up companies on supply and demand requirements is necessary to enable vertical farming to improve and scale.
• PSBM can enhance customer experience and sustainability branding by growing food on-site, but it requires deeper collaboration, shared responsibilities, and longer-term investment thinking from the retailer.

Scaling requires new types of retail partnerships
Scaling vertical farming depends heavily on how retailers structure their supply chains. This is particularly true in Sweden, where a few large retailers dominate procurement. Key challenges to rethink include:
• Central contracts require guaranteed volumes that start-ups may struggle to provide.
• Vertical farms need long-term commitments to secure investment and expand.
• Reducing dependence on imported leafy greens requires strategic shifts in sourcing practices.

If retailers want vertical farming to become a meaningful part of their supply chains, they may need to rethink procurement norms and develop phased scaling strategies, starting small yet planning for the long term.

Vertical farming can deliver on sustainability The life cycle assessment results indicate that verti-cal farming can match or outperform conventional supply chains for produce such as basil and lettuce in Sweden. This was largely attributable to Sweden's high share of renewable energy. For retailers, this can provide important alignment with sustainability goals, such as increasing the proportion of locally sourced products and reducing waste at the store level.

In summary, vertical farming offers potential for sustainability and innovation in the Swedish retail industry, but it is not a plug-and-play solution. Retailers and vertical farms will need to continue close collaboration and investment in sustainability initiatives to adjust current practices toward a more diversified, sustainable, and resilient food supply chain.

6. References

Achard, S. (2022) 20 Vertical Farming Companies Ink Industry Manifesto. iGrow News. Available from: https://igrownews.com/20-vertical-farming-companies-ink-industry-manifesto/ [Accessed 9th January 2024].

Armanda, D. T., Guinée, J. B., & Tukker, A. (2019). The second green revolution: Innovative urban agriculture's contribution to food security and sustainability–A review. Global food security, 22, 13-24.

Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. Sustainability: science, practice and policy, 13(1), 13-26.

Blom, A., Rosengren, S. and Perzon, J., (2023) Towards a better understanding of sustainability gaps in retail organizations. The International Review of Retail, Distribution and Consumer Research, pp.1-19.

Breuer, H., & Lüdeke-Freund, F. (2017). Values-based innovation management: Innovating by what we care about. Bloomsbury Publishing.

Despommier, D. (2011). The vertical farm: controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations. Journal für Verbraucherschutz und Lebensmittelsicherheit, 6(2), 233-236.

Despommier, D. (2009). The rise of vertical farms. Scientific American, 301(5), 80-87.

Drottberger, A. and Langendahl, P.A., (2023) Farming-as-a-service initiative in the making: Insights from emerging proto-practices in Sweden. Smart Agricultural Technology, 6, p.100368.

Graamans, L., Baeza, E., Van Den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). Plant factories versus greenhouses: Comparison of resource use efficiency. Agricultural systems, 160, 31-43.

Gravely, E. and Fraser, E., (2018) Transitions on the shopping floor: Investigating the role of Canadian supermarkets in alternative protein consumption. Appetite, 130, pp.146-156. https://doi.org/10.1016/j.appet.2018.08.018

Jürkenbeck, K., Heumann, A., & Spiller, A. (2019). Sustainability matters: Consumer acceptance of different vertical farming systems. Sustainability, 11(15), 4052.

Kozai, T. (2013). Resource use efficiency of closed plant production system with artificial light: Concept, estimation and application to plant factory. Proceedings of the Japan Academy, Series B, 89(10), 447-461.

Kozai, T., and Niu, G. (2016). "Chapter 1 - Introduction," in Plant Factory, eds. T. Kozai, G. Niu and M. Takagaki. Academic Press, San Diego, USA.

Martin, M. (2022). Life cycle management in vertical farming: Insights from vertical farming sustainability assessments. In XXXI International Horticultural Congress (IHC2022): International Symposium on Advances in Vertical Farming 1369 (pp. 235-242).

Martin, M., & Bustamante, M. J. (2021). Growing-service systems: new business models for modular urban-vertical farming. Frontiers in Sustainable Food Systems, 5, 787281.

Martin, M., Bustamante, M. J., Zauli, I., & Orsini, F. (2024). Environmental life cycle assessment of an on-site modular cabinet vertical farm. Frontiers in Sustainable Food Systems, 8:1403580.

Martin, M., & Orsini, F. (2023). “Life cycle assessment of indoor vertical farms” in Advances in plant factories: new technologies in indoor vertical farming. eds. T. Kozai and E. Hayashi. Burleigh and Dodds.

Miranda, L. F., Cruz-Cázares, C., & Saunila, M. (2023). Towards a comprehensive framework to analyse the benefits of openness for sustainability-oriented innovation: A systematic literature review. Sustainable Development, 31(6), 4019-4038.