The Economics and Optimal Design of Missouri Indoor Farming Supply Chains

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The Economics and Optimal Design of Missouri Indoor Farming Supply Chains

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I. Executive Summary

A type of indoor production model, vertical farms grow food in controlled-environment facilities with artificial light. Many concentrate near population centers — for example, along the coast in the Northeast or in the South.

This project addresses a need for information related to evaluating the financial viability, appropriate scale and siting feasibility of indoor farms. The following summary highlights this project report's four primary elements:

1. It introduces the U.S. vertical farming industry.
2. It identifies areas in Missouri that offer production- and market-related conditions suitable to vertical farm operations.
3. It provides data-driven decision-support for locating and configuring indoor farming facilities and informing the crop portfolio decision.
4. It estimates the economic impact of vertical farm facilities.

Missouri producers and businesses may use the data and information included in this report to assess vertical farm business opportunities and design efficient and effective end-to-end supply chains.

Introducing the U.S. vertical farming industry

To grow food vertically, facilities tend to use three types of production practices: hydroponics, aquaponics and aeroponics. Hydroponics systems expose roots to nutrient- and mineral-rich water. An extension of hydroponics, aquaponic facilities incorporate aquaculture by circulating wastewater through biofilters then to plants, which can absorb nutrients present in the waste. With aeroponics, operators grow plants without soil and mist the roots to supply water and nutrients.

Vertical farms commonly produce greens, herbs, and microgreens, which have high retail prices and short crop cycles which allow facilities to turn inventory with high frequency. However, controlled-environment facility operators have shown interest in producing other crops such as berries and vine vegetables (e.g., tomatoes).

Private financing has contributed significantly to vertical farming businesses. Other pathways to raising capital have included becoming publicly traded (e.g., AppHarvest, Kalera, Local Bounti), securing investments from value chain partners (e.g., Plenty and Driscoll's, Plenty and Walmart), seeking debt (e.g., AppHarvest, Local Bounti, Freight Farms) and capitalizing the business through member-owner investments (e.g., Alabama Farmer's Cooperative and Bonnie Plants, CORE Electric Cooperative and FarmBox Foods).

Examining industry drivers and detractors

For several reasons, vertical farms — and the overall controlled-environment agriculture industry — have attracted interest from entrepreneurs, investors, food buyers and other stakeholders in the food products value chain. Factors motivating the interest include the potential to reduce land needed to grow food; use water more efficiently; decrease labor requirements; minimize transportation costs due to locating food production near consumers; and offer a local, fresh product that may have extended shelf life.

Despite the opportunity for vertical farms, the industry faces multiple challenges which limit their application to niche markets. Examples include high capital costs, high energy use, high operating costs, lack of access to skilled labor and intense product price competition.

Siting vertical farming facilities

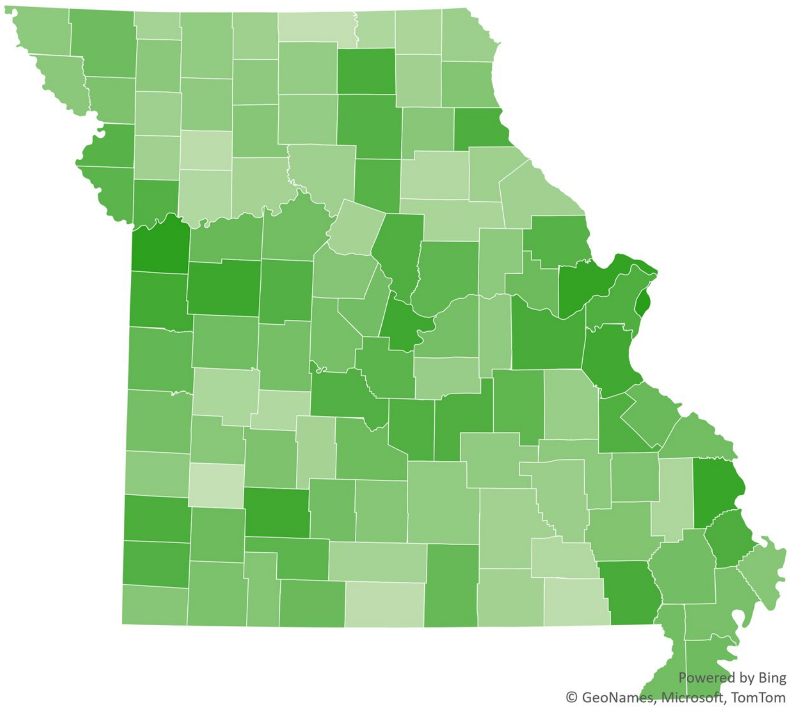
The siting analysis produced for this project considers how well Missouri counties offer market access and production resources needed for a vertical farm to operate viably. The analysis involved scoring counties for their performance on eight market factors and 11 production factors.

The analysis accounted for these market factors and their respective weights, which indicate their relative importance to a vertical farm facility's viability: supermarket and other grocery store access, 34%; restaurant and other eating place access, 20%; highway access, 15%; food service contractor access, 10%; food product consumption, 10%; population, 5%; per capita income, 5%; and food security, 1%.

Listed in order of their relative weights, the production factors reflected in the siting analysis were electric rates, 40%; water rates, 16%; quality of life, 10%; broadband availability, 10%; unemployment rate, 5%; dew point, 5%; temperature, 5%; proposed renewable energy projects, 3%; ethanol plant access, 3%; and power plant access, 3%. Collectively, these factors suggest the extent to which a location offers a well-suited environment for growing food in a vertical facility.

When a vertical farm operator considers a site, it will want to weigh market and production factors simultaneously to identify whether a site delivers on supply- and demand-side characteristics. To do this, this project's siting analysis applied a 50% weight to the composite market score and a 50% weight to the composite production score. Using a shaded scale, Exhibit 1.1 shares composite scores by county. Note, counties near the I-70 and I-44 corridors ranked relatively high in the analysis. Counties in metropolitan areas tended to also perform well, though pockets of counties in northern and southeastern Missouri also ranked well.

Exhibit 1.1. Overall Composite Siting Analysis Scoring by County



* Darker colors represent counties scoring best overall

The project's siting analysis does have limitations, including narrowly focusing on Missouri rather than a wide geographic area and incorporating a finite set of considerations, not necessarily all factors that will affect a site location decision for a particular type of vertical facility. However, the analysis does offer an initial look into potential suitable Missouri sites. *Businesses and investors should do further research to ensure a particular location meets the site needs for a specific facility*.

Optimizing supply chains

An indoor farming supply chain optimization model provides data-driven decision-support for locating and configuring indoor farms and choosing crops to grow in these facilities. Focusing on the St. Louis area, a case study produced for this project shows how to optimize a facility and its supply chain to maximize net profit.

The St. Louis case study identified 14 candidate locations for indoor farms and 32 grocery stores to be served with 10 different crops. The farms could be configured as greenhouses or indoor farming facilities using Dutch bucket for growing tomatoes, cucumbers, lima beans and okra and nutrient film technique (NFT) or deep-water culture (DWC) hydroponic systems for growing leafy greens and onions.

To make supply chain optimization recommendations, the case study considered the fixed facility costs, including those tied to technology implementation. It also included the variable input expenses: energy, water and labor. Then, it assessed yield potential for the 10 studied crops and tracked their market prices and demand. Given these inputs, the case study estimated the optimal supply chain to consist of 12 facilities: one 10,000-sq.-ft. greenhouse with the Dutch bucket kit technology, one indoor farming facility with DWC and 10 indoor farming facilities with NFT. For this scenario, annual revenue would total $384,130, and costs would total $391,742, resulting in a loss of $7,612 profit.

The analysis then considered other scenarios to measure how changing input data — fixed facility cost, labor costs, market prices and market demand — would affect the case study's results. The base case study and sensitivity analysis arrived at these conclusions for optimizing the supply chain:

- *Reducing the fixed facility cost and variable operating cost* (e.g., labor, energy) is an effective means to improve profitability. This can be achieved by proper facility-level production and resource planning.

- *Increasing market prices may benefit profitability but with diminishing returns*. This motivates firms to improve reputation and competitiveness in the market, though the benefit of these marketing activities will decline when the price reaches a high level.

- *Growing demand or market share does not necessarily improve profitability*, which may feel counterintuitive. Without improving other operational aspects such as reducing costs, increasing prices or boosting yield, attempting to meet more demand might significantly reduce profit or even trigger a loss because satisfying more demand increases facility and operating costs. This partially explains why most indoor farming start-ups face challenges as they scale. The analysis shows that if crop yields improve simultaneously with demand, then profitability can increase as demand and market share grow.

Estimating economic impact

A proposed controlled-environment, or "indoor," farming operation analysis was conducted to better understand the impact of this business activity on Missouri's economy. The results reflect a different set of outcomes than those presented in the case study section. For convenience, both the case study and economic impact analysis focused on the St. Louis region.

In the analysis scenario, a St. Louis-based indoor farming business generates $384,104 in annual sales from customers within the region, and an initial investment of $361,200 is estimated to be required to build the business' 10-facility footprint.

The indoor farming operation directly benefits Missouri by making sales and employing workers, but supply-chain purchases and worker spending also create positive economic ripples in surrounding communities.

The indoor farming operation and supply chain activities create 4.8 jobs with a labor income impact of $282,036 and generate $398,032 in gross domestic product (GDP). The farming operation's direct sales of $384,104 would create total sales, or output, of $818,602 in Missouri.

Every $100,000 in indoor farming business sales creates 1.25 jobs, $73,422 in labor income and $103,619 in GDP when indirect effects are considered.

For every *$100,000* in Missouri sales:

1.25 jobs are created.

$73,422 is generated in labor income.

$103,619 is contributed to GDP.

Consumer preferences for foods raised in vertical farms

Because consumer preferences drive food purchase decisions, a component of this project involved surveying consumers to measure their preferences for nine foods raised in vertical farms: leafy greens, microgreens, herbs, tree fruits, strawberries, tomatoes, peppers, mushrooms and honey. The survey collected input from 1,730 consumers in Missouri and neighboring states.

Of the nine foods, respondents most frequently purchased leafy greens, tree fruits and tomatoes. Respondents most commonly shopped at grocery stores or supermarkets when buying the nine products. Depending on the product, supercenters or farmers markets ranked as the second most-shopped.

The survey also assessed attributes that consumers find to be important when buying products emphasized in the survey. For most products, respondents tended to bundle three attributes as the most important: freshness, product appearance and taste. Therefore, their preferences lean toward attributes vertical farms can manage: freshness because these farms offer a local supply, appearance because they closely control disease and pest pressure and taste because they manage soil fertility and other factors to enhance flavor.

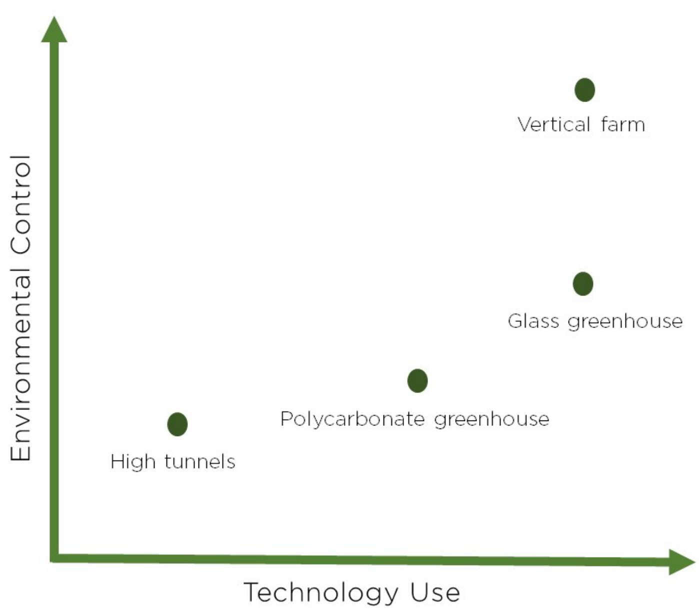
II. State of the Vertical Farming Industry

Vertical Farming

Vertical farms are a type of indoor production model. They raise food in controlled-environment facilities with artificial light. Frequently, facilities use one of two approaches to grow plants vertically: stacking racks of plants and placing grow lights above each tray or producing plants in vertical towers in lighted rooms (indooragcenter.org/what-is-indoorfarming).

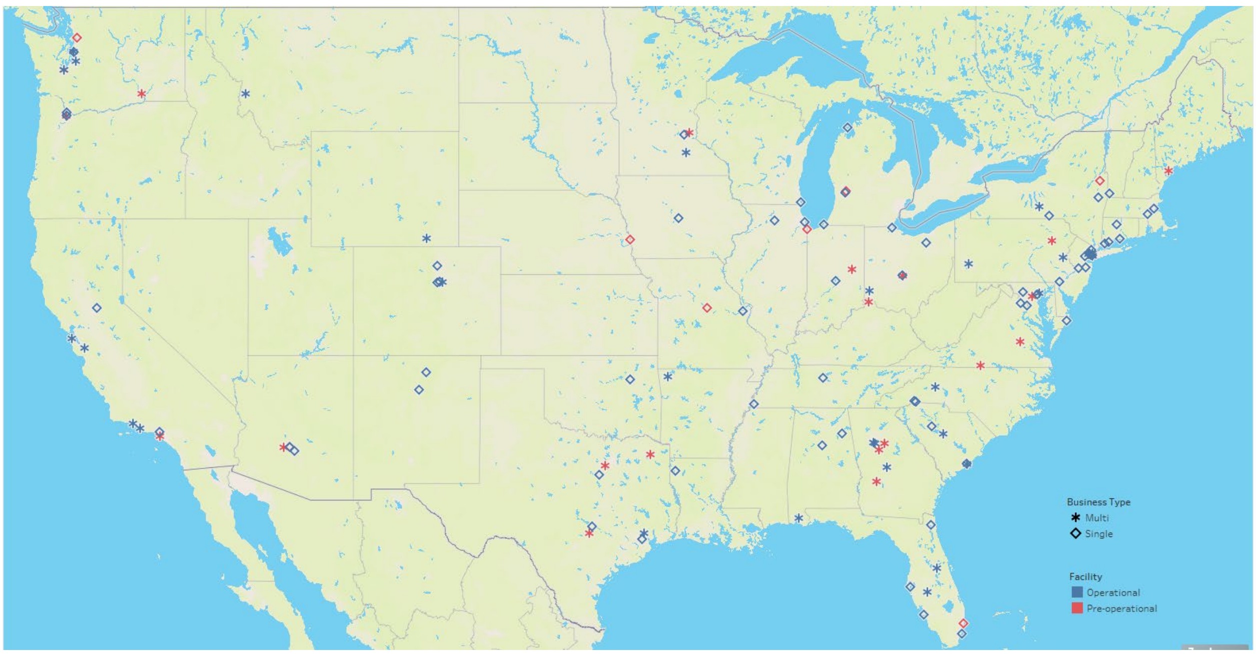
Controlled Environment Agriculture (CEA) systems have a wide range of technology integration to optimize plant growth. Exhibit 2.1 compares CEA production models that offer more environmental control and require more technology than traditional field production. Of these systems, greenhouses have been used to grow flowers and ornamental plants for more than a century. More recently, they have produced food crops, such as tomatoes, greens, herbs and squash (indooragcenter.org/what-is-indoorfarming). Unlike vertical farms, greenhouses grow product on one level, so they rely on natural light for the most part. A greenhouse's technology use and sophistication depend on the facility. Constructed of glass, high-tech greenhouses extensively use automation and technology. Polycarbonate and glass greenhouses may more moderately automate production, and high tunnels constructed with steel and plastic covers use little or no automation (artemisag.com/artemis-releases-2020-state-of-indoor-farming-report). Vertical farms emerged as a production system within the past few decades.

Exhibit 2.1. Controlled-Environment Agricultural Production Models



Several vertical farm facilities have started operations in the U.S. or planned to begin operating. Exhibit 2.2 pinpoints these facility locations, based on information compiled during summer and fall 2022. As illustrated, concentration of facilities aligns with population concentration in the U.S. Many have opened along the coast in the Northeast or positioned themselves in the South. Many of these facilities are single-site businesses. Note, the facilities included in this map are those primarily aligned with a vertical farming business. All sites operating with a single container facility or a vertical farm included in a restaurant aren't reflected in this map.

Exhibit 2.2. U.S. Vertical Farm Facility Locations, 2022*



* Business type refers to the number of facilities operated by a company. A single-facility business had one operational or planned site. A multifacility business had more than one operational or planned site. Operational facilities were those that had raised product. Pre-operational facilities had been announced or were under construction.

Industry Sales and Drivers

In 2020, U.S. vertical farms earned more than $1 billion in revenue. According to CoBank, estimates suggest that sales will increase through 2030 at a compound annual growth rate (CAGR) that ranges from 10% to 20%. Assuming a 15% CAGR, revenue would exceed $5 billion in 2030. If sales grow at a 20% CAGR, then revenue would reach $8 billion by 2030 (cobank.com/documents/7714906/7715347/VerticalFarming-Nov2022.pdf/97557b2e-1df4-2293-9895-bd8dd03b0963?t=166742471622).[1]

[1] For comparison, 2022 Missouri value of corn and soybean production was $7.4B (nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MISSOURI)

For several reasons, vertical farms — and the overall controlled-environment agriculture industry — had attracted interest from entrepreneurs, investors, food buyers and other stakeholders in the food products value chain. However, as vertical farms started up and their profitably was not meeting forecasts, the growth rate of vertical farm startups slowed dramatically. The following discussion highlights factors that have driven the interest.

Land use

Technology and space-saving growing techniques allow vertical farms to reduce the area needed to grow food. Some estimates suggest that land use declines by 75% to 90% in vertical production systems compared with traditional farm production (indianaenvironmentalreporter.org/posts/vertical-farms-hold-promise-for-local-sustainable-produce). Yield data show vertical systems may lead to greater production per unit of space. According to a USDA Agricultural Research Service researcher, vertical farms can record yields per acre that are 10 times to 20 times better than yields in open fields (ars.usda.gov/oc/utm/vertical-farming-no-longer-a-futuristic-concept).

The ability to increase land productivity has piqued international enthusiasm about vertical farming. In an April 2022 brief, RSK Group, which offers environmental, engineering and technical services, described how large cities in Asia face land constraints. As a result, the population has considered practices to maximize resource use. Vertical production represents an opportunity. For example, Sky Greens farm grows 10 times more food in its vertical facility per land unit than a traditional field could produce. Located in Singapore, which relies heavily on imported food, this farm offers a solution to food security (rskgroup.com/insights/vertical-farming-in-south-east-asia).

Although vertical farms may have an advantage in terms of space needed to grow food, these facilities may indirectly use land for other purposes. For example, they demand great amounts of energy, and attention has turned to generating renewable energy for them. Facilities relying on renewable energy would indirectly use land to produce solar or wind power. Research published in *Nature Food* and summarized by Agritecture suggests the total land footprint may not vary significantly between open-field and plant factory production or vertical farming. In some cases, the plant factory would require a larger total footprint. Two U.S. cities were included in the analysis: Boston, Massachusetts, and Phoenix, Arizona. Open-field production had the greater footprint in the Boston scenario. The plant factory would demand more land in Phoenix (agritecture.com/blog/2022/5/9/a-holistic-look-at-vertical-farmings-carbon-footprint-and-land-use).

Water

Worldwide, agriculture consumes 70% of freshwater, according to a World Bank analysis published in March 2017. At the time, the organization also said water withdrawals would need to increase by 15%. More water would support growing more food and sustaining the globe's growing population (blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture).

Vertical farms tend to use water more efficiently than other production models. For example, a study published in 2015 assessed water needs when producing lettuce hydroponically or growing it conventionally in Arizona. The hydroponically grown lettuce required 8% of the water needed for conventional production (mdpi.com/1660-4601/12/6/6879). Several factors lead to this difference. First, vertical farms enclose the growing environment, which discourages moisture loss into areas outside the facility. The moisture that does evaporate within the facility can be captured and reused. Second, the plants have more ready access to water, and their roots have direct water exposure. This means they conserve energy that would otherwise be needed to absorb moisture present in the soil. They can then apply that energy to grow (agrilinks.org/post/how-vertical-farming-can-save-water).

Labor

Worker shortages have affected U.S. businesses since the pandemic. For the first time since the pandemic began, the number of open positions exceeded the number of unemployed workers in spring 2021. The gap between job openings and workers to fill those positions has continued to be a challenge. The U.S. Chamber of Commerce reported that the country had 11 million job openings in December 2022 but just 5.7 million unemployed workers (uschamber.com/workforce/understanding-americas-labor-shortage).

Vertical farms introduce technology and systems to reduce labor needs. In many cases, this shift demands a different type of worker. Skilled labor is required to manage technologies and systems, which reduce assignments that blue collar workers would otherwise do. OptimIA, a USDA-funded research program focused on indoor leafy greens, conducted a labor requirements pilot survey in 2022. About 75 respondents who operate indoor agriculture facilities or greenhouses and produce greens responded. The survey found indoor farms required less labor time per square foot than greenhouses. The median time reported by indoor farms was 0.207 minutes per square foot. For greenhouses, it was 0.369 minutes per square foot. Indoor farms did have some outliers. The maximum daily labor requirement was 12.5 minutes per square foot compared with 8.6 minutes per square foot for greenhouses (verticalfarmdaily.com/article/9483245/labor-requirements-in-indoor-agriculture).

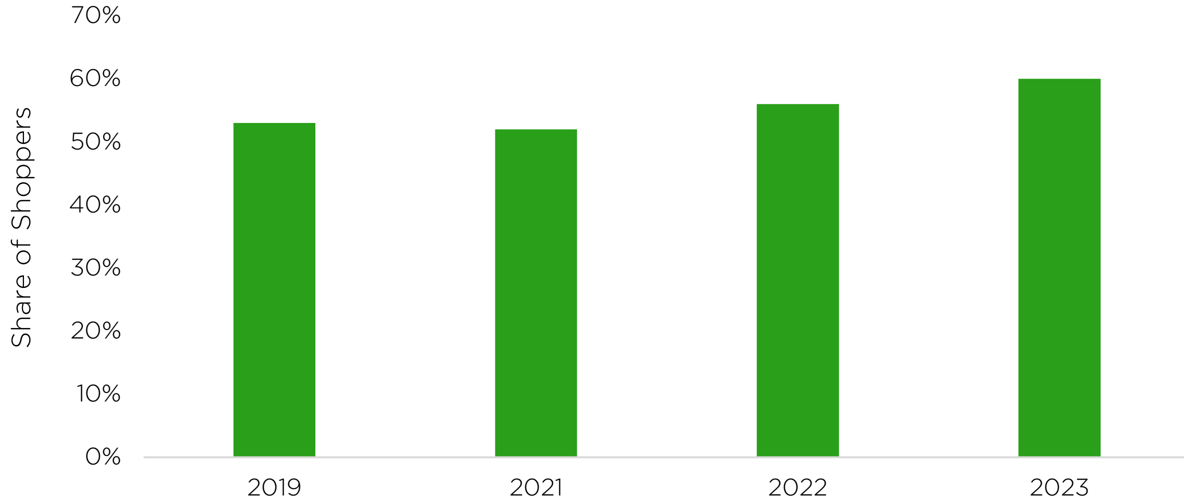
The OptimIA pilot survey also measured the extent of production and support task automation in greenhouses and indoor farms. More than half of the indoor farms that responded to the survey had automated activities such as nutrient solution preparation, media preparation and food safety control. Other tasks that had been partially automated in some facilities included seeding, packaging, logistic coordination and integrated pest management. Most indoor farms had fully automated system and data control responsibilities, and more than 40% had fully automated harvesting activities (verticalfarmdaily.com/article/9483245/labor-requirements-in-indoor-agriculture).

Transportation
For any food producer, delivery and transportation costs hinge on factors such as load size and location (agfundernews.com/the-economics-of-local-vertical-and-greenhouse-farming-are-getting-competitive). With vertical systems, food production may locate closer to the shoppers who ultimately buy and consume food products (ars.usda.gov/oc/utm/vertical-farming-no-longer-a-futuristic-concept). Close proximity to buyers can reduce transportation costs. Plus, it may lead to food reducing spoilage risk (foodinstitute.com/focus/investment-in-vertical-farming-market-continues-steady-rise). From an emissions perspective, however, some estimates suggest local indoor production may yield more emissions than those generated in an outdoor model that involves shipping product a farther distance. The difference is due to energy needs for indoor climate control.

Consumer preferences
Produce from vertical farms has several attributes that may attract buyers: local, fresh and possible extended shelf life. Data from the 2023 Power of Produce report from FMI-The Food Industry Association suggests some of these characteristics' importance. Of the shoppers surveyed for the report, 39% said the locally grown attribute would prompt them to purchase produce they had not planned to buy. In 2022, one-quarter of respondents felt this way (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023).

Exhibit 2.3 presents the share of shoppers who said they would like produce departments to carry more locally grown fresh fruits and vegetables. In 2019 and 2021, just more than half of surveyed shoppers indicated they wanted to see more locally grown items. By 2022, that share had increased to 56%, and in 2023, 60% of participating shoppers said they wanted produce departments to carry more locally grown fresh fruits and vegetables (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023).

Exhibit 2.3. Share of Grocery Shoppers Who Would Like to See More Locally Grown Fresh Fruits and Vegetables in Produce Department

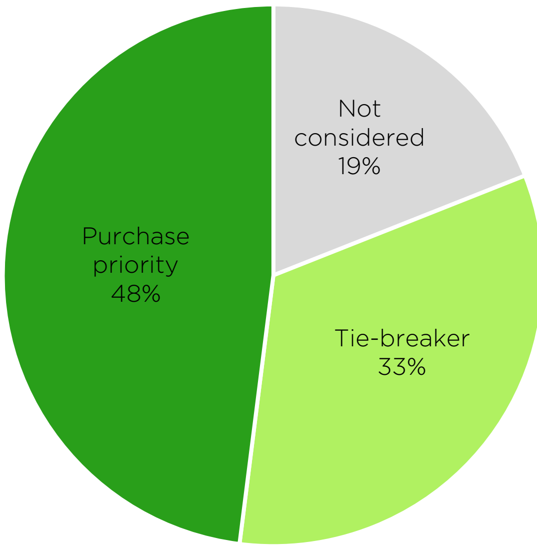


Source: FMI-The Food Industry Association (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023)

The 2023 Power of Produce research also indicates consumer commitment to shelf-life initiatives. Of the environmental, social and governance practices assessed in the survey, the greatest share of shoppers identified "shelf-life initiatives to allow produce to last longer" as a purchase priority. It topped fair trade and wages, environmentally sound growing practices, water conservation and environmentally friendly packaging as a purchase priority. Exhibit 2.4 indicates that nearly half of shoppers said shelf-life initiatives were a purchase priority, and one-third identified these initiatives as a tie-breaker (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023). By prioritizing shelf life, the supply chain has an opportunity to minimize food waste and deliver a product that delivers on freshness expectations.

A disruptive trend occurring in the food industry involves younger consumers eating more, but smaller, meals per day and adopting more of a snacking mentality. Many products are repositioning as snacks. How greens, legumes and leeks fair in this transition is still being determined. The trend to more ready-to-eat salads reflects the transition toward snacking.

Exhibit 2.4. Extent to Which Consumers View Shelf-Life Initiatives as Purchase Priorities for Produce Products



Source: FMI-The Food Industry Association (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023)

Despite controlled-environment agriculture facilities delivering product with some attributes that consumers may value, other features of the systems they use or the resulting products may pose concerns for some consumers. For example, research published in 2022 identified that a segment of consumers perceive controlled-environment agriculture somewhat negatively due to it seeming unnatural (link.springer.com/article/10.1007/s10460-021-10261-7).

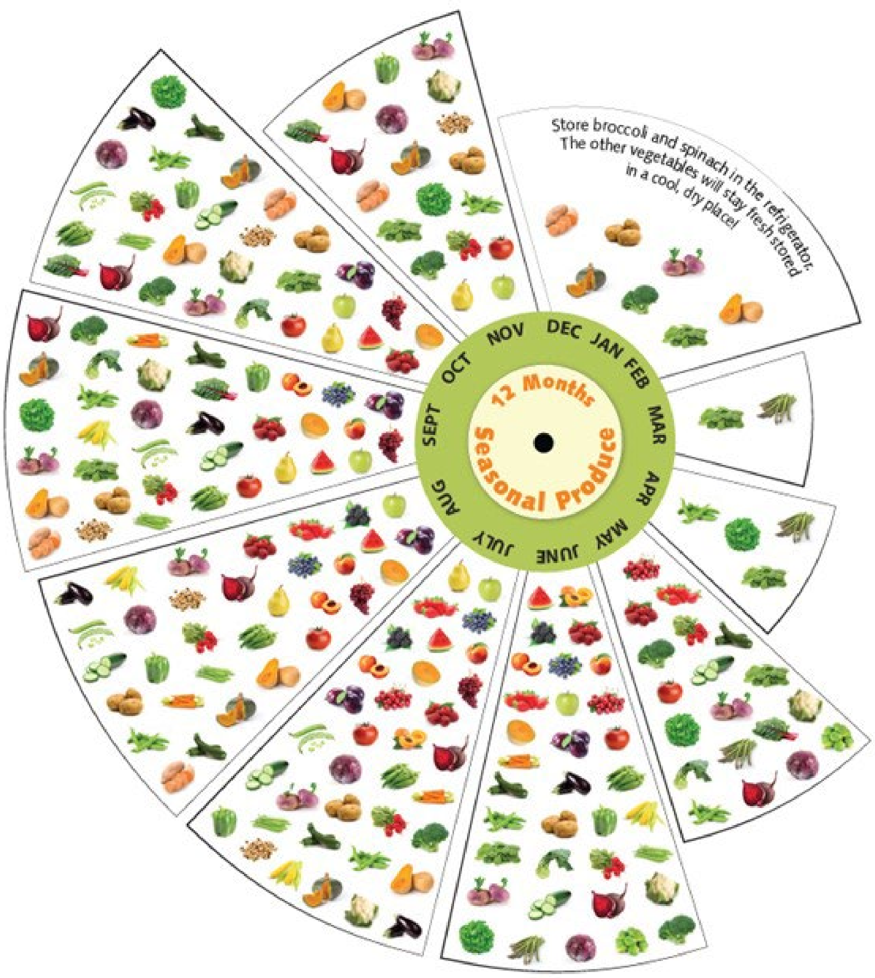
This project funded a consumer survey to measure preferences for food products raised in vertical farms. The survey collected input from consumers who were 18 years old to 100 years old, identified as a primary grocery shopper in the family and lived in Missouri or its surrounding states. Appendix A summarizes several key findings collected from the survey.

Production seasonality

Weather conditions restrict the types of foods Missouri farms can raise at certain times of year. Provided by the Missouri Department of Health and Senior Services, the fruit and vegetable harvest calendar in Exhibit 2.5 shows typical harvest dates for Missouri produce. Local selections are limited from December to April. From December to February, local products available tend to be those that can store well. Although leafy greens — a crop popularly grown by indoor farms — may be locally available during many months, mid-summer and winter don't provide the ideal growing conditions for outdoor production (health.mo.gov/living/wellness/nutrition/culinaryskills/pdf/Fruits-and-Vegetables-Harvest-Poster.pdf).

Like most forms of climate-controlled agriculture, vertical production removes variability in climatic conditions. It, therefore, opens the opportunity to access locally produced goods irrespective of season. However, human eating habits are shaped over decades of repetitive eating patterns. There is a low probability that consumers will quickly alter seasonal eating habits to consume large quantities of products during times of the year outside their historical eating patterns for these products. Improvements in global logistics allow consumers to access any desired food at any time throughout the year. Only affluent consumers can afford the price of these fresh food offerings, and this market segment remains relatively small.

Exhibit 2.5. Missouri Fruit and Vegetable Harvest Calendar



Source: Missouri Department of Health and Senior Services

Food safety

Produce grown in indoor settings has protection from the external environment and potential contaminants which reduces the risk of contaminated produce. For example, wildlife are less likely to interact with an indoor-grown food crop than a crop grown outdoors (winsightgrocerybusiness.com/fresh-food/fmi-indoor-farming-carries-its-own-food-safety-risks). When grown indoors, a crop also has protection from smoke contamination, pesticide residues or acid rains.

An indoor growing environment doesn't completely solve food safety concerns, however. Controlled-environment agriculture operations tend to have moist, warm conditions, which can lead to bacterial growth (winsightgrocerybusiness.com/fresh-food/fmi-indoor-farming-carries-its-own-food-safety-risks). In 2021, the Food and Drug Administration traced a food safety outbreak to leafy greens produced in a controlled-environment hydroponic facility. The agency investigated and developed a follow-up report that includes requirements and recommendations for controlled-environment facilities to follow to keep their products safe. Those practices include appropriately cooling and storing harvested products, using uncontaminated water for irrigation and assessing whether nearby properties could create food safety challenges (fda.gov/media/155402/download). Worker training, lack of policies and weak policy enforcement practices are other food safety-related challenges for some indoor farming operations.

Leafy greens producers may pursue CEA Food Safety Certification to demonstrate that they have followed standards to grow and offer safe products. The certification adds to existing practices that are part of the Global Food Safety Initiative. Completing an audit provides verification that a product meets the food safety certification standards. Firms have the option to place a seal on product packaging to show that they have met the certification requirements (ceasafe.org). Nonexempt growers will also need to ensure they comply with the Food Safety Modernization Act, and the CEA certification is not a substitute for good agricultural practice certifications.

Products

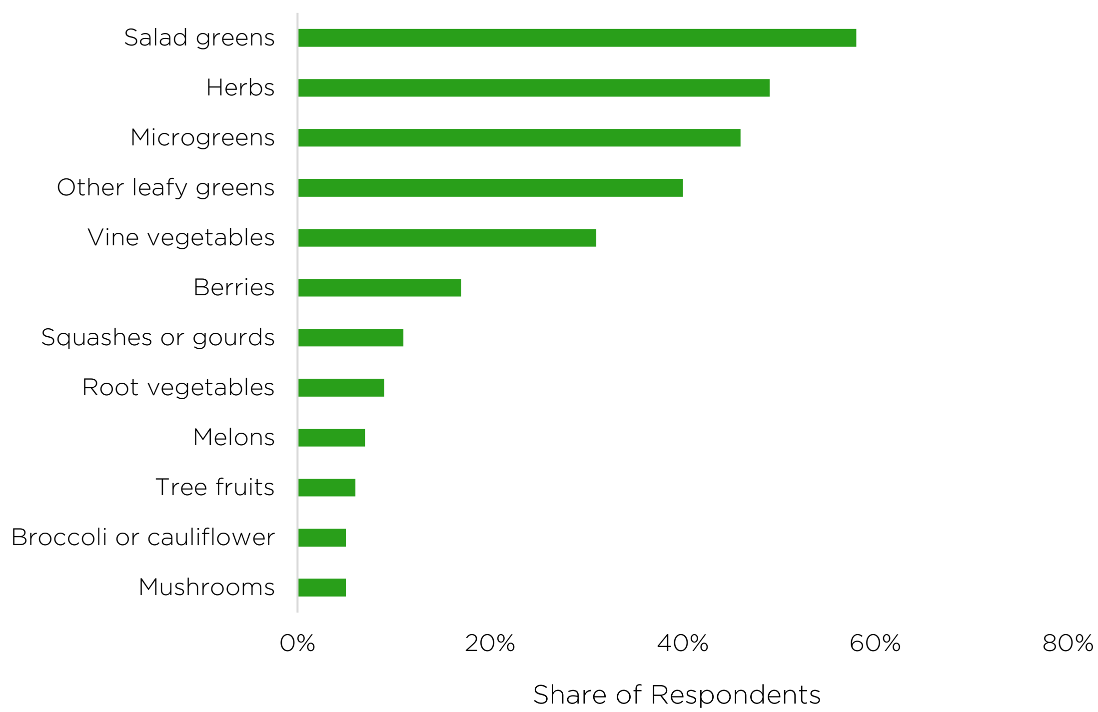
When vertical farms began experimenting with crop production, leafy produce — greens, herbs and microgreens — originally captured the focus. Still today, vertical operations commonly include greens in the product mixes that they market to consumers.

Data from the 2021 Global Controlled-Environment Census administered by WayBeyond and Agritecture Consulting provide an overview of products commonly grown by controlled-environment facilities. Note, the controlled-environment category is broader than vertical production alone. The data can indicate directions toward raising certain crops in controlled-environment settings. Of the facilities responding to the census, 44% said they grew in greenhouses, and 38% had indoor vertical farms (waybeyond.io/census).

The products highlighted in Exhibit 2.6 are those that the greatest share of controlled-environment facilities said they produced. Note, this list doesn't capture all products but the 12 products most frequently named by respondents. Leafy products topped the list. More than half of facilities said they grow salad greens, and roughly half grew herbs. Microgreens were named by 46% of respondents, and 40% of facilities produced other leafy greens, which include chard, kale and cabbage. Vine vegetables, such as tomatoes, cucumbers and peppers, ranked fifth in terms of share of facilities producing those products, and berries ranked sixth (waybeyond.io/census).

Producing leafy greens may stem from a business strategy decision to turn as many harvests as possible. These short-maturity crops support a facility with increasing its throughput. More harvests signal more frequent opportunities to capture a return that can offset a facility's costs (cobank.com/knowledge-exchange/specialty-crops/vertical-farms-must-trim-costs-hone-business-models-to-achieve-profitability).

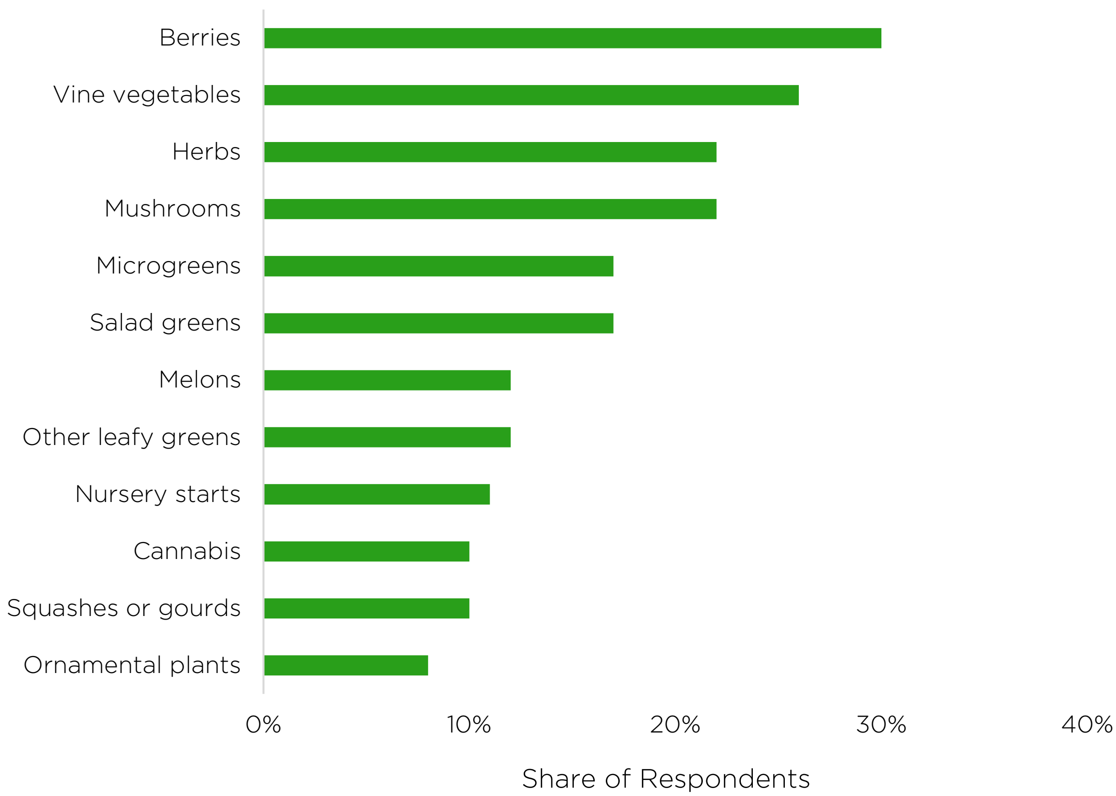
Exhibit 2.6. Top 12 Most Frequently Cited Products Produced by Controlled-Environment Facilities



Source: WayBeyond and Agritecture Consulting (waybeyond.io/census)

The 2021 Global Controlled-Environment Agriculture Census also asked respondents to indicate the crops they would consider producing in the next 12 months. Exhibit 2.7 shares this outlook. Respondents most frequently selected berries and vine vegetables, such as tomatoes, cucumbers and peppers. Just more than one-fifth of respondents said they would consider mushroom or herb production (waybeyond.io/census).

Exhibit 2.7. Top 12 Most Frequently Cited Products Being Considered by Controlled-Environment Facilities



Source: WayBeyond and Agritecture Consulting (waybeyond.io/census)

Note, many products frequently produced by today's controlled-environment agriculture facilities predominantly reach a fresh market. For example, these businesses sell salad greens, microgreens and other leafy greens in bags, clamshells or other packaging designed to deliver fresh product to consumers. However, for indoor farms or other growing facilities configured to produce ingredients used in other foods, locating near final product manufacturing facilities may hold an opportunity, according to an AgFunderNews interview with Erika Summers, a controlled-environment agriculture expert. As an example, Summers mentioned how a pesto manufacturing facility and a controlled-environment basil facility may co-locate (agfundernews.com/meet-the-founder-cea-engineer-advisor-erika-summers-on-why-vertical-farming-isnt-a-get-rich-quick-industry).

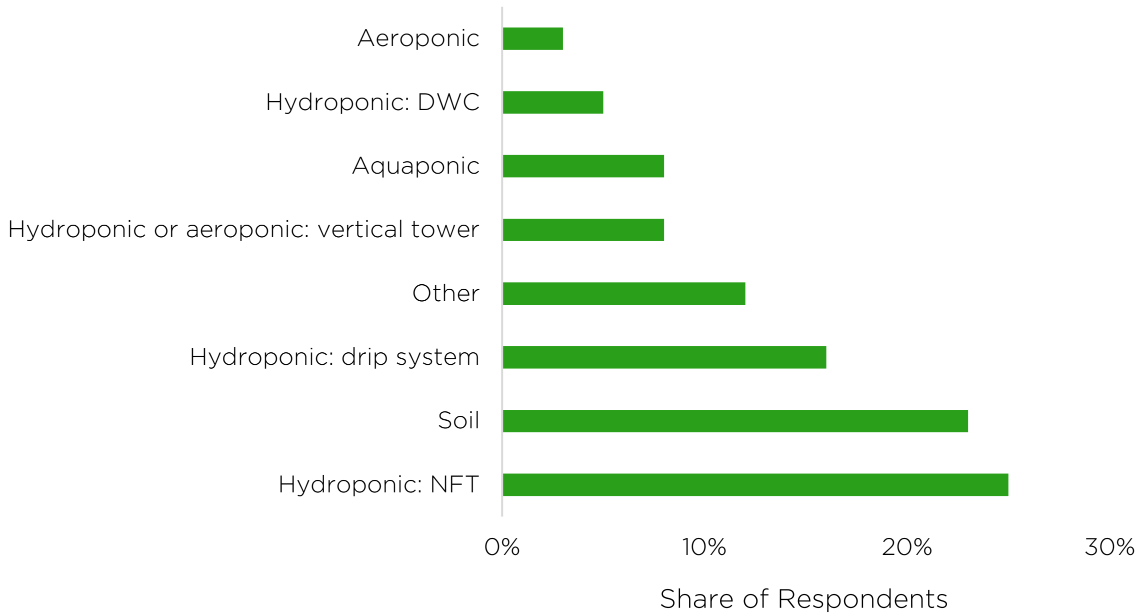
Exhibit 2.8 pinpoints Missouri manufacturers that process, package or sell spices, including herbs. Areas near these businesses may support an appropriately sized growing facility to provide freshly harvested herbs that can be processed into value-added products.

Exhibit 2.8. Locations of Missouri Spice Manufacturers

Production Method

To produce food in a controlled environment, facilities may choose from several growing methods. Facilities responding to the 2021 Global CEA Census Report from WayBeyond and Agritecture Consulting indicated the primary growing method they use to produce their goods. Exhibit 2.9 illustrates that the greatest share — roughly half — use some type of hydroponic system: nutrient film technique, drip system, vertical tower or deep water culture. Nearly one-quarter said they use soil. Fewer have adopted an aquaponic or aeroponic system (waybeyond.io/census).

Exhibit 2.9. Primary Growing Method Used by Respondents to 2021 Global Controlled-Environment Agriculture Census



Source: WayBeyond and Agritecture Consulting (waybeyond.io/census)

The following summaries describe typical production practices in hydroponic, aquaponic and aeroponic systems.

Hydroponics
In a hydroponics-based production model, plant roots have contact with a nutrient- and mineral-rich water solution. This form of soil-less food production may use an growing medium, such as peat mixes, rockwool, perlite, gravel or coconut husk, to anchor plants, or the roots may only have exposure to a nutrient solution (essential minerals dissolved in water) (vertical-farming.net/glossary-vertical-farming/#1507273262862-77ad5ec6-a74b).

In an NFT system, the plants are placed on plastic gutters, and a thin film of nutrient solution soaks the plants' roots. The gutters are positioned at a 1% to 2% slope. Water pumped from the reservoir trickles on one end of the over the gutter, and the excess drains on the other end into the reservoir. An ebb and flow model works similarly, but it periodically floods the tray with water rather than facilitate a constant trickle, and the plants are in pots with growing media. Unused water drains into the reservoir and is held there until trays are flooded again. A wick model grows plants in a soil-less media, and a wick or string transports water from the reservoir to the growing media (boweryfarming.com/hydroponics). The wick model may be difficult to scale.

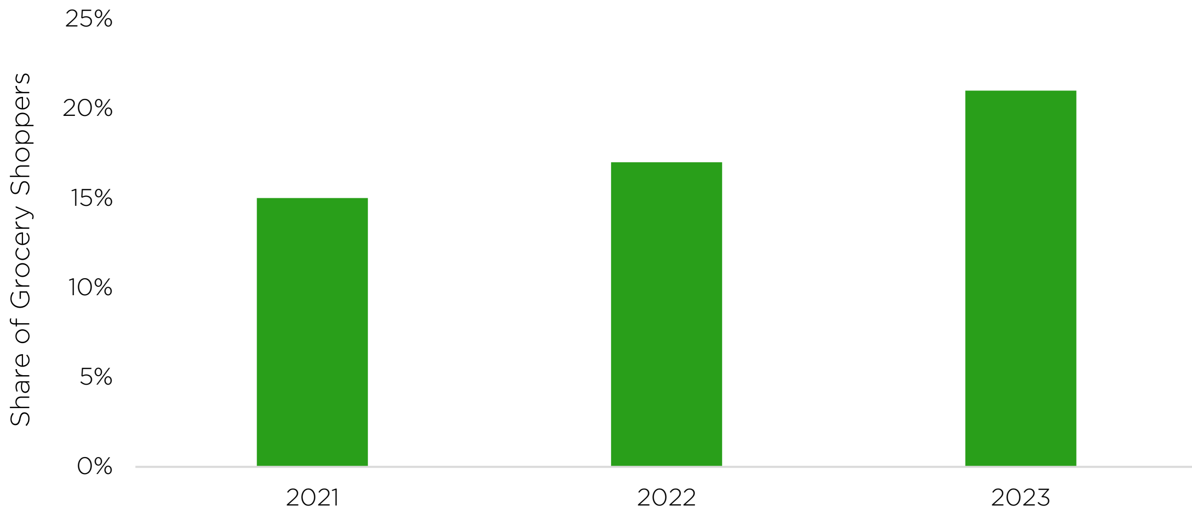
Vertical farms frequently choose to grow plants in hydroponic systems (attra.ncat.org/publication/vertical-farming). Bowery and NW Farms are examples of vertical farms producing food in this model. The following summaries describe their businesses in early 2023.

- **Bowery** operates hydroponic vertical facilities in New Jersey, Pennsylvania and Maryland (boweryfarming.com). Its facilities resemble warehouses with stacked trays of growing plants to make use of vertical space. Bowery has developed its own operating system called BoweryOS, which manages facility functions such as lighting and tracking plants from the seed-starting stage to harvest (boweryfarming.com/vertical-farming). The company's production system enables Bowery to produce crops without pesticides, herbicides and fertilizer runoff. As a result, the company produces "purer food," which the company says is one of the most significant advantages of its chosen production model (boweryfarming.com/hydroponics).

- **NW Farms** grows food hydroponically without pesticides, herbicides or other chemicals. The production system involves no soil, but the farm starts its seeds in peat moss. NW Farms operates a commercial facility and an R&D site in Washington. It has also indicated it will operate a facility in Portland, Oregon. In its facilities, NW Farms has produced crops such as berries, herbs, leafy greens, wet hops and tomatoes (nw.farm/wp-content/uploads/2021/03/NW-Farms-Presentation-Deck.pdf). Herb product packaging mentions that the product is grown hydroponically (nw.farm).

In its 2023 Power of Produce research report, FMI-The Food Industry Association evaluated whether consumers hold a preference for hydroponically grown produce. Of all respondents, 46% indicated they had no preference for whether fruits and vegetables had been grown hydroponically indoors or grown outdoors. Smaller shares of respondents stated a preference for hydroponically indoor grown (26%) products or traditionally outdoor grown products (28%). The 2023 Power of Produce survey did capture slight increases in the share of participating shoppers who said they want to see more hydroponic or greenhouse-grown produce where they shop. In 2021, 15% said they would like to see more hydroponic or greenhouse-grown produce options. That share increased to 21% in 2023; see Exhibit 2.10 (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023).

Exhibit 2.10. Share of Shoppers Who Would Like More Hydroponic or Greenhouse-Grown Fresh Fruit and Vegetable Options Where They Shop



Source: FMI (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023)

Aquaponics

An extension of hydroponic production, aquaponics replaces the reservoir that holds nutrient-rich water with a pond to house aquatic organisms such as fish. Therefore, these systems produce two products: a crop and fish. Wastewater from the fish tank moves to a filtration complex of clarifiers and biofilters and then to the plants' growing area. Oftentimes, fertilizers are added to the nutrient solution to ensure the plants' nutritional needs are met. Plants absorb the nutrients, and the clean water recirculates to the fish tank (attra.ncat.org/publication/vertical-farming). The following summaries highlights business activities of businesses using aquaponics in early 2023.

- **Upward Farms**, which is based in Brooklyn, New York, combine vertical farming and aquaponic production practices. The hybrid striped bass raised in this production system produce waste that the microgreens use to grow and develop (upwardfarms.com/our-story). The farm markets two microgreen mixes. One features a kale, broccoli and kohlrabi blend, and a spicy mix lists mustard, radish and kohlrabi as ingredients. On-pack labels describe that the microgreens are raised in a coconut coir growing medium. The products also have USDA organic certification and a pesticide-free label. Bass raised in the facility are described as "grown free of antibiotics, hormones and mercury" (upwardfarms.com/products). Upward Farms has completed the Best Aquaculture Practices certification (upwardfarms.com/our-story). In March 2023, Upward Farms announced it had stopped operating (verticalfarmdaily.com/article/9517119/us-ny-upward-farms-ceases-all-vertical-farming-operations).

- **Balance Farms** operates an aquaponics system in a Toledo fast casual restaurant. The 8,600-square-foot farm aligns with Balance Grille, which is a restaurant focused on vegetable dishes. Plus, the farm markets fresh vegetables and herbs it produces to other area buyers. Instead of raising food fish, Balance Farms produces ornamental fish that it sells. Compost is the business' third revenue stream (balancefarms.com).

Aeroponics
Through aeroponic production, facilities grow food without soil. They also require little water because plants will at the most be misted rather than grow in water reservoirs. Compared with efficient hydroponic systems, aeroponic operations can reduce water use by as much as 90%. Some research also suggests that mineral and vitamin uptake improve in aeroponic systems (attra.ncat.org/publication/vertical-farming).

Vertical farms less commonly use aeroponics compared with other production methods (attra.ncat.org/publication/vertical-farming). However, AeroFarms and OnePointOne are two examples that have adopted this method. The following summaries describe their operations in early 2023.

- **AeroFarms** first opened a commercial farm in Ithaca, New York. Commercial facilities in Newark, New Jersey, and Danville, Virginia then followed. The company grows greens — microgreens and baby greens — using aeroponics. Facilities mist roots of growing plants with nutrients, water and oxygen. They grow greens using a cloth medium, which has patent protection. Through aeroponics, AeroFarms requires less water and fertilizer than facilities that use other growing models. AeroFarms distributes its products through channels including Whole Foods Market, Walmart, FreshDirect and Amazon Fresh (aerofarms.com). Note, in June 2023, AeroFarms filed for Chapter 11 bankruptcy (producebluebook.com/2023/06/08/aerofarms-files-for-chapter-11-bankruptcy-protection).

- **OnePointOne** got its start in Silicon Valley, and it later opened a 12,000-square-foot aeroponics facility in Avondale, Arizona. The facility features columns with growboards. The plants positioned in those growboards only have exposure to air and mist containing nutrients. They receive little water and no pesticides, herbicides or fungicides. The site produces greens, such as kale, arugula and spinach; basil and dill; and strawberries. The facility sells its product directly to consumers through Willo Farm (cronkitenews.azpbs.org/2023/01/09/onepointone-newest-sustainable-vertical-farm-arizona). On its website, OnePointOne markets its Opollo vertical farm system to full automate aeroponic production (onepointone.com). The firm says its production model leads to better yields than those achieved with other technologies (cronkitenews.azpbs.org/2023/01/09/onepointone-newest-sustainable-vertical-farm-arizona).

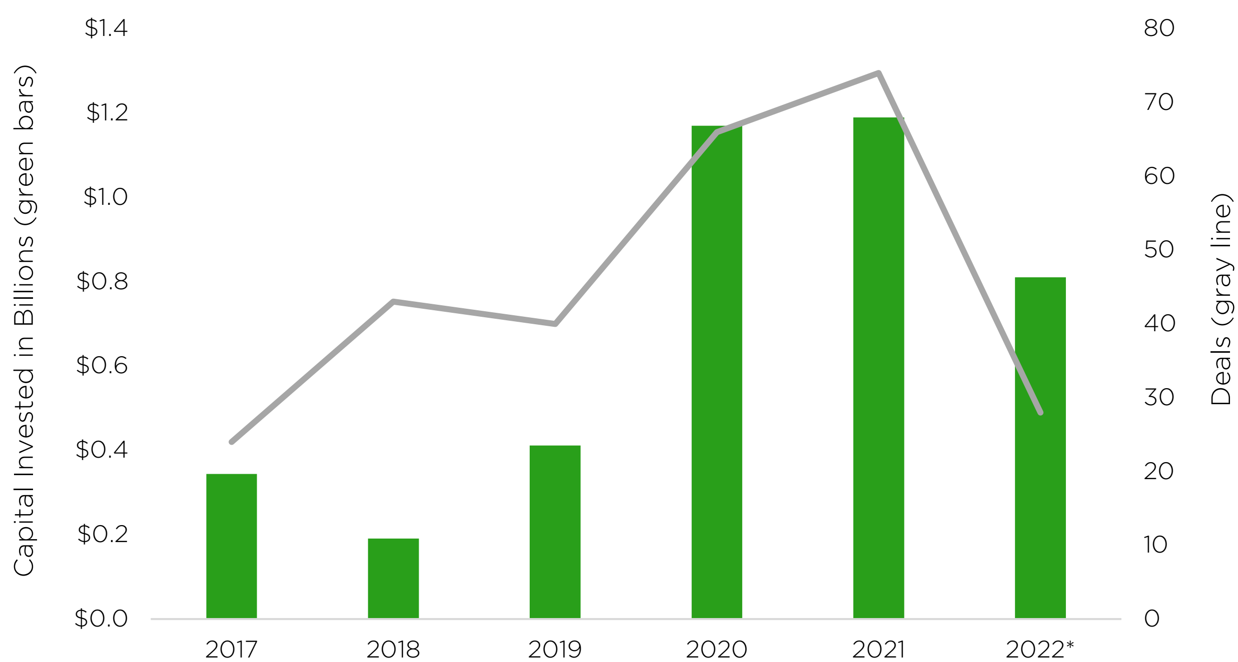
Investment

In many cases, vertical farms rely on external financing. That's because many have not achieved profitability on their own, according to a CoBank analysis (cobank.com/knowledge-exchange/specialty-crops/vertical-farms-must-trim-costs-hone-business-models-to-achieve-profitability). Therefore, capital infusions are necessary for operations to continue. The following discussion describes trends in financing vertical farming businesses.

Venture capital

Private sources of financing have contributed significantly to vertical farming businesses. On a global scale, PitchBook tracks venture capital deals in the indoor farming space. In 2021 — the most recent year with a full year's data available — 74 deals raised $1.19 billion. For 2022, PitchBook presented data through June 1. These data suggest that the number of deals were declining compared with 2021, but capital investment continued to post strong numbers. Exhibit 2.11 shares the annual trend in deals and capital invested since 2017 (pitchbook.com/news/articles/vc-investment-agtech-indoor-farming-food-supply-crisis).

Exhibit 2.11. Trend in Global Venture Capital's Indoor Farming Investments



Source: PitchBook (pitchbook.com/news/articles/vc-investment-agtech-indoor-farming-food-supply-crisis)

Agritecture published an analysis in December 2022 that further describes global controlled-environment agriculture investments. For the analysis, the firm used its own data and data from Crunchbase. It found nearly 50 firms had secured private investments of at least $10 million. Of those, 60% operated farms. One-fifth developed technology and equipment for controlled-environment production, and one-fifth had a dual focus on farming and technology or equipment development. U.S. firms were the primary recipients — 60% of companies receiving funding and 79% of funds raised (agritecture.com/blog/2022/12/5/the-influx-of-cea-investment-where-has-the-money-gone).

According to the analysis, of the $7.1 billion in funding secured, farm operators captured 86%. Slightly more than half (55%) of funds raised by farms supported those involved in vertical production. Hybrid operators — those that blend vertical and greenhouse systems — captured 8% of funding, and greenhouses raised the other 37%. Farms raising leafy greens and herbs captured most of the funding (agritecture.com/blog/2022/12/5/the-influx-of-cea-investment-where-has-the-money-gone).

Public markets

Some controlled-environment operations have raised capital by becoming publicly traded businesses — for example, AppHarvest, Local Bounti, Kalera and urban-gro. To go public, they issued an initial public offering or merged with special purpose acquisition companies. Most have had declining stock prices since their market debut (foodinstitute.com/focus/column-why-vertical-farming-stocks-are-struggling).

Strategic partner financing

Entities upstream or downstream in a value chain represent potential funding partners. Oftentimes, downstream firms may view an investment in a vertical production facility as a step to accessing an adequate product supply. That is, a well-capitalized facility is more likely to consistently provide a regular source of food products. For upstream firms, an investment may create a market for a product or a technology.

Plenty, a producer of vertically grown produce, states "always be partnering" as part of its mission. In recent years, it has received funding from upstream and downstream value chain partners. The following summaries describe Plenty partnership examples through early 2023.

- Driscoll's was part of a Series D funding round for Plenty in fall 2020. The $140 million round intended to support strawberry cultivation research and development (agfundernews.com/plenty-scoops-up-

140m-in-series-d-round-led-by-driscolls-and-softbank). In September 2022, Plenty announced that it would open a Driscoll's berry farm in Virginia in one area of a 120-acre vertical farming campus. The firm set winter 2023-24 as the Driscoll's facility's completion date (thepacker.com/news/packer-tech/driscolls-heads-virginia-grow-strawberries-worlds-largest-indoor-vertical-farm). No other indoor vertical facility worldwide has produced strawberries at scale. The Driscoll's facility annually would produce an estimated 4 million pounds, which would be directed to Northeast markets. Later, Plenty plans to construct other facilities at the Virginia campus. Those facilities would grow diverse crops, including leafy greens and tomatoes (growingproduce.com/production/protected-agriculture/huge-vertical-farm-venture-will-raise-strawberries-to-a-new-level).

- **Walmart** partnered with **Plenty** in January 2022 as part of a $400 million Series E funding round. The investment marked the first time a significant retailer pushed into vertical food production. Because of its role as an investor, Walmart would have representation on Plenty's board (businesswire.com/news/home/20220125005272/en). Walmart also agreed to stock Plenty leafy greens products in its California stores. For several reasons, it viewed the investment into Plenty favorably. One reason is the strength of Plenty's yields. From 2020 to 2022, leafy greens yields recorded by the company improved 700%. Other reasons include the ability of Plenty's technology to adapt and support at-scale production of other crops, such as strawberries and cherry tomatoes (reuters.com/business/us-indoor-vertical-farm-plenty-gets-big-injection-cash-walmart-deal-2022-01-25).

Collective action

In a cooperative or collective action model, member-investors capitalize the business after they feel comfortable with the market opportunity and business plan. They have the option to buy shares, which are priced at an approachable level. Each share represents a stake in the business. This model enables a business to pool resources from multiple investors.

A board, which includes member-investor representation, assists with structuring the strategic plan and overseeing managers. Board members ultimately must act on the membership's behalf. Paid a salary, the managers take responsibility for implementing the business' strategic plan. They make the day-to-day business decisions and communicate updates to members.

In conventional agriculture, the cooperative model has had longstanding use. The following two instances illustrate how two farm co-ops through early 2023 initiated investments in operations producing crops indoors.

- **Alabama Farmer's Cooperative** invested in **Bonnie Plants** during 1975. Today, Bonnie Plants functions as a joint venture for the cooperative, and it has more than 70 locations with operating greenhouses. The facilities produce vegetable and herb plants sold at U.S. retail stores (alafarm.com/p/other/joint-ventures/bonnie-plants-inc). In 2016, Alabama Farmer's Cooperative sold a minority stake of Bonnie Plants to Scotts Miracle-Gro (dispatch.com/story/business/2016/02/02/scotts-miracle-gro-discloses-investment/23425457007).

- **CORE Electric Cooperative**, which distributes power throughout a 5,000-square-mile area in Colorado, partnered with **FarmBox Foods** in November 2022. Also based in Colorado, FarmBox Foods manufactures climate-controlled farm facilities. The partnership involves CORE purchasing a vertical hydroponic farm — a refitted shipping container — to grow blue spruces and ponderosa pines that ultimately will be planted as part of the co-op's forest rehabilitation initiative. FarmBox Foods will assume responsibility for facility operations. At the facility, FarmBox Foods will also research topics such as drought resistance, nutrient dosing and lighting (news-journal.com/colo-electric-co-op-farmbox-foods-announce-partnership-to-grow-trees-for-reforestation/article_5556f275-e361-59dc-9369-35dbdbdb1c1c.html).

Debt financing
For most startups, equity financing represents the most viable pathway to begin raising funds. At this stage, indoor farms lack the cash flow that banks want to see before they lend funds. They also haven't reached a scale that would support fulfilling take-or-pay contracts or purchase agreements, which would provide more certainty about realistic sales volumes and prices (freshproduce.com/resources/technology/takes-on-tech-podcast/tackling-indoor-ag). Both variables are imperative to know — at least as rough estimates — when projecting revenue potential. Additionally, lenders may have difficulties with arriving at a salvage value, which affects a facility's valuation when it no longer needs a given asset.

Some controlled-environment agriculture operations have secured debt financing. The following list provides three examples through early 2023.

- **AppHarvest** grows tomatoes, strawberries, cucumbers and leafy greens in four Kentucky indoor facilities. The company has sought multiple types of financing, including funding from equity investors. Additionally, Rabo AgriFinance provided a $75 million credit facility to AppHarvest in 2021 (just-food.com/news/appharvest-to-raise-40m-via-share-offer-for-indoor-farming-capital).

- **Local Bounti** has also sought financing from multiple sources. In 2021, it prepared to become a publicly traded company. It also has sourced financing using private investments in public equity from Cargill and the CEO of a Thailand-based energy and infrastructure firm. To further support the business, Cargill offered $200 million in debt. The funding would enable Local Bounti to expand its footprint more quickly into western U.S. markets (producebluebook.com/2021/06/18/vertical-farm-merger-valued-at-1-1-billion).

- **Freight Farms**, which grows food vertically and hydroponically in shipping containers, secured $12 million in debt financing from Cambridge Trust Company. Announced in July 2022, the funding would support product line expansion and overall business growth (cambridgetrust.com/insights/news-updates/cambridge-trust-provides-$12-million-debt-facility).

Challenges

Despite the opportunity for vertical farms, the industry faces multiple challenges that threaten these businesses' long-term viability. The following discussion highlights several of the most impactful challenges.

High capital costs

To start up a facility, vertical farms tend to incur high capital costs. In an analysis, CoBank indicated that industry estimates suggest construction costs for a vertical facility may exceed $100 million (cobank.com/knowledge-exchange/specialty-crops/vertical-farms-must-trim-costs-hone-business-models-to-achieve-profitability). Operations may choose from varying types of facilities. Buildings — those repurposed from existing structures or those newly constructed — represent one option. Shipping containers refitted into farms also work as vertical growing environments. In a 40-foot shipping container, growers will add shelves, lighting and drip irrigation systems to support vertical crop production (attra.ncat.org/publication/vertical-farming). For comparison purposes, Freight Farms priced its Greenery S — the newest iteration of the shipping container farm the firm had available in April 2023 — at $149,000. Shipping and installation would add to this baseline cost (dtnpf.com/agriculture/web/ag/news/business-inputs/article/2023/04/25/vertical-farming-thinking-inside-box).

Depending on the farm, facilities may need to invest in other capital to enable them to begin operations. Those other capital costs include lights, computer systems, cameras, artificial intelligence technology and robotics. Some of these costs have the potential to ease as the technology further develops. For example, LED lighting costs may decrease (cobank.com/knowledge-exchange/specialty-crops/vertical-farms-must-trim-costs-hone-business-models-to-achieve-profitability). Technology costs add substantially to the capital investment requirement for a vertical farming operation, particularly when companies choose to develop their own technologies as a pathway to differentiate their businesses. Many firms in this industry develop their own technologies for maintaining temperature, controlling humidity, lighting facilities and so forth. Although the motivation behind this work is often focused on lowering costs, the research and development adds expense while the technology is being designed (fastcompany.com/90824702/vertical-farming-failing-profitable-appharvest-aerofarms-bowery).

The property itself for a vertical farm facility also adds costs. Rural properties where outdoor-grown crops are raised carry a smaller price tag. To situate themselves near population centers that demand their products, vertical farms often locate in urban areas. From a cost perspective, urban sites require a greater investment because they have more potential competing uses.

Inefficient energy consumption
For an average vertical farm, Barclay's estimates energy costs to capture a 50% to 70% share of cost of goods sold. The energy requirements do vary according to crop produced, however. For example, energy demands for a fruiting crop would exceed those for leafy greens or herbs (cobank.com/knowledge-exchange/specialty-crops/vertical-farms-must-trim-costs-hone-business-models-to-achieve-profitability). For a February 2023 story published in *Fast Company*, the lead at the Center of Excellence for Indoor Agriculture roughly quantifies the energy expense for a vertical facility. When just considering lighting, $100,000 to $200,000 may be needed to cover a 10,000-square-foot facility's needs. Other equipment, including HVAC systems, would demand further energy and add expense (fastcompany.com/90824702/vertical-farming-failing-profitable-appharvest-aerofarms-bowery).

Vertical farms have an opportunity to use renewable energy. However, the space needed to install renewable energy systems can be extensive. Assuming that generating 1 megawatt of electricity per month would require 3 acres to 4 acres of land for solar panels, a farm would require 1.5 acres of solar panels if it targets monthly produce production at 25,000 pounds (cobank.com/knowledge-exchange/specialty-crops/vertical-farms-must-trim-costs-hone-business-models-to-achieve-profitability).

Local Bounti has adopted a production model that blends vertical farming and greenhouse farming to capture power use efficiencies. The operation vertically raises seedlings. It then moves those seedlings into a greenhouse, where the seedlings reach their maturity. Local Bounti has said this approach allows it to achieve production typical of vertical growing environments but use power at a rate similar to that of greenhouse production (localbounti.com/wp-content/uploads/2021/12/localbounti-lca-overview.pdf).

Lack of access to skilled labor

Not unlike other roles in production agriculture, vertical farm operators must have diverse skills to succeed. In a blog post, Agritecture broke down the needed competencies into these categories: plant science, plant nutrition, integrated pest management, machinery, mechanics and engineering. Plus, employees in managerial roles will need familiarity with leading people, understanding finance and communicating with stakeholders (agritecture.com/blog/2022/1/27/tips-for-a-career-in-vertical-farming-1). The knowledge and skills required from each of these categories may vary depending on the production model a facility uses, too. For example, skills involved in running a hydroponics operation will have some differences from skills demanded by an aquaponics production system. Also, vertical farm employees will need an appreciation for how farm operations vary according to different facility sizes (verticalfarmdaily.com/article/9458579/the-future-of-indoor-ag-and-education).

Given the breadth of these required skills, vertical farms may struggle to find skilled candidates who immediately can contribute in each needed skill area. A combination of hands-on learning and educational programming informed by industry will develop to create a skilled labor force that's prepared to work in indoor farm facilities. One industry stakeholder has said "micro-credentials" may become the standard. Each micro-credential would direct attention to developing one skillset during a relatively short time. As an alternative to more formal education, these micro-credentials could be stacked, so employees have flexibility to learn about topics particularly relevant to them and their professional networks (verticalfarmdaily.com/article/9458579/the-future-of-indoor-ag-and-education).

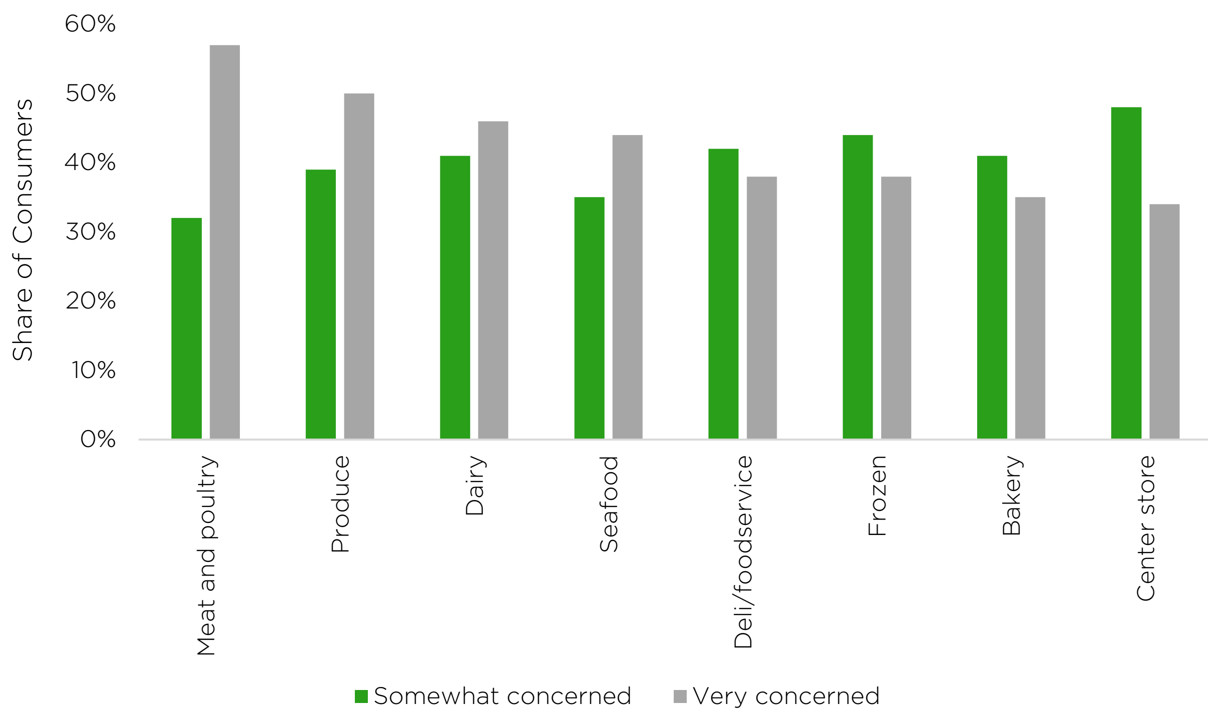
Educational programs will require instructors who have knowledge to share with students. Because indoor farming is a relatively new production system, training programs may find themselves recruiting from a small pool to place enough experienced educators (verticalfarmdaily.com/article/9458579/the-future-of-indoor-ag-and-education).

Intense product price competition

The 2023 Power of Produce research from FMI-The Food Industry Association asked participating consumers to identify the extent to which several factors affect their fresh fruit and vegetable purchase decisions. The greatest share — one-quarter of respondents — chose price as the factor that most influenced their product selection and purchase decisions. Appearance, health benefits and ripeness followed as the second, third and fourth most influential factors. Fewer respondents selected nutrient content, shelf life, convenience and production claims as factors that affect their product selection and purchase decisions (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023).

Exhibit 2.12 illustrates that produce ranked second behind meat and poultry for the share of consumers reporting they were very concerned about product prices, according to the 2023 Power of Produce report. Half of participating consumers said they felt very concerned about produce prices — just behind the 57% of consumers who indicated that sentiment for meat and poultry prices. In total, 89% of participating consumers said they were somewhat or very concerned about produce product prices (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023).

Exhibit 2.12. Share of Consumers Expressing They Were Somewhat Concerned or Very Concerned about Food Product Prices by Product Category



Source: FMI (fmi.org/forms/store/ProductFormPublic/power-of-produce-2023)

As described earlier, vertical farms have significant costs, so they may feel financial pressure to set a premium price that positions them to recoup those costs. However, the sentiment shared by consumers participating in the Power of Produce 2023 research indicates that consumers may feel more inclined to consider low-price alternatives, which allow them to better control their grocery spending.

III. Siting Vertical Farming Facilities

A siting analysis provides a macro perspective into whether a vertical farming operation would likely succeed in a given locale. More specifically, this project's analysis considers how well Missouri counties offer market access and production resources needed for a vertical farm to operate viably.

The analysis involved scoring counties for their performance on eight market factors and 10 production factors. Based on the data collected and weights applied to each factor — the weights suggest the relative importance of factors included in the model — the analysis produced a composite score for each county. Those composite scores communicate the extent to which counties deliver comprehensively on market access and production resource factors. Ultimately, they suggest the extent to which a county may be a suitable target for a vertical farming facility.

The following discussion summarizes the factors included in the analysis. It also presents the composite scores by county, highlights the methodology used to generate those scores and explains the implications for firms considering vertical farming in Missouri.

Market Factors

Food producers require markets for their products. Otherwise, they lack the opportunity to capture value from the goods they have produced. The siting analysis considers eight market factors, which Exhibit 3.1 lists. These factors account for the size of markets, food need, infrastructure required to move food from production location to buyers and buyer capacity to pay premiums for higher-value products.

Exhibit 3.1. Market Factors Considered in Vertical Farm Siting Analysis

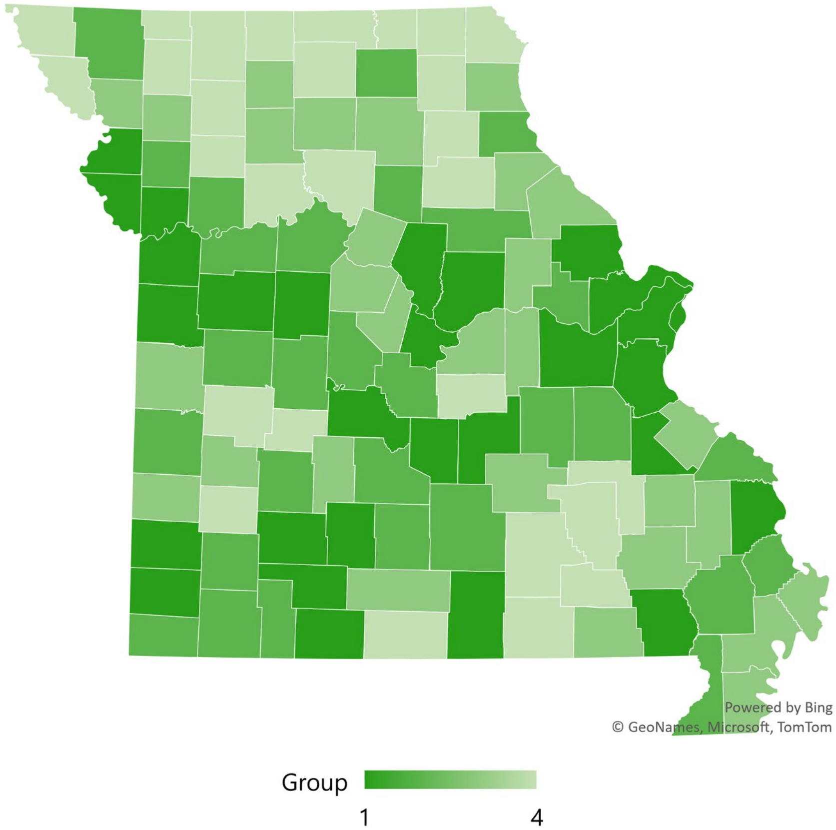
Population

For a couple of reasons, population represents an important market-related criterion. First, population centers will require more food to meet residents' needs. Therefore, they represent an opportunity for vertical farms to move more product. Second, highly populated areas often have high population densities. This means homes and commercial and industrial developments use more nearby land, and less area is available for local food production. Vertical farms represent a solution as they can embed themselves within or near populated areas.

A brief from the World Economic Forum reinforces population's importance to a vertical farm site selection decision. It explains how Singapore's large, highly dense population has valued vertical farming as a source of domestically produced fresh food that would not be as readily available without the vertical infrastructure (weforum.org/agenda/2015/05/how-vertical-farming-can-make-you-a-better-eater).

To account for population levels by county, the siting analysis includes population estimates released by the U.S. Census Bureau. The organization conducts a decennial census, but it also releases annual population estimates. The analysis uses July 1, 2021, estimates. Exhibit 3.2 illustrates counties assigned into four groups based on population. Shaded in the darkest green, the counties where the largest population centers are positioned represent the largest markets for goods produced by vertical farms.

Exhibit 3.2. Missouri Counties Grouped by Population*



* 1 denotes the largest population centers

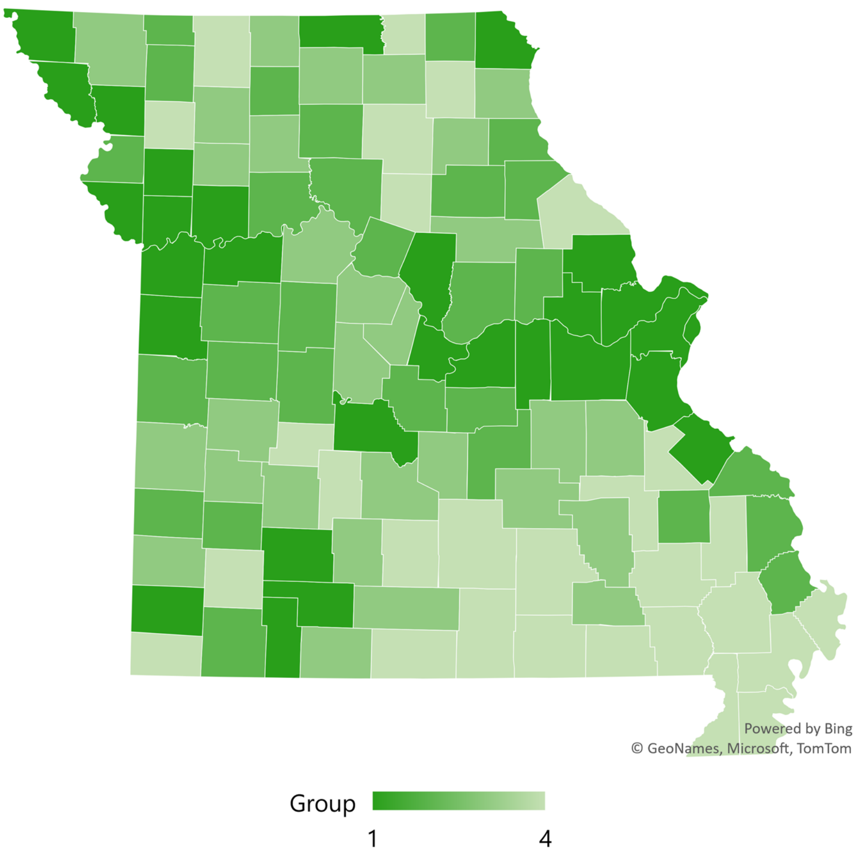
Per capita income

To grow food vertically, operations incur higher costs for some inputs. For example, L.E.K. Consulting estimated in a 2020 report that capital expenditures for a vertical facility top $10 million per acre — multiple times the cost required to build a greenhouse. Vertical production also carries higher operational costs in some cases. For example, lighting needed in a vertical facility adds to energy expenses (lek.com/insights/ei/controlled-environment-agriculture-futuristic-fix-food-system). An analysis published by AgFunderNews communicates the extent to which such expenses affect unit production costs. For greens, vertical farm costs were 4.7 times greater than conventional outdoor production costs and 32% greater than hydroponic greenhouse production costs (agfundernews.com/the-economics-of-local-vertical-and-greenhouse-farming-are-getting-competitive).

Vertical farms have the potential to reduce their costs as they optimize their technology and production methods. However, until then, most will need to set premium prices for their products to recoup their costs. Additionally, depending on their production practices, vertical facilities may produce goods that have certain valued attributes — for example, produced without chemicals or produced with fewer chemicals — that attract consumers willing to pay a premium for those attributes.

Not all consumers will accept price premiums, however. Per capita income suggests whether buyers have the purchasing power to choose a higher-priced product. This analysis incorporates 2020 inflation-adjusted per capita income estimates reported by the U.S. Census Bureau to serve as a proxy for whether markets would pay the higher prices. Exhibit 3.3. shares the income data by county. The counties shaded in the darkest green had the highest per capita income, which suggests greater purchasing power.

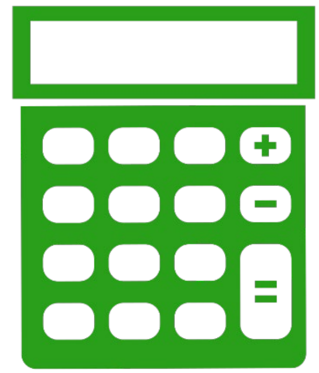
Exhibit 3.3. Missouri Counties Grouped by Per Capita Income*



* 1 denotes the highest per capita income

Per capita demand estimates

A critical business activity, estimating demand, enables a farm to determine the mix of enterprises it should consider, how many units it could sell and the logistical systems it needs to reach buyers. The current study estimates demand for producing items well-suited to vertical growing environments. Demand represents the total product quantity typically purchased within a given period for a given area. For a given product, estimated demand equals population multiplied by per capita consumption.



This analysis assesses the viability of businesses growing bulk horticultural products in a climate-controlled facility and distributing them to retail establishments — known as wholesale marketing. We assume the grower receives a wholesale price, which is generally less than the price charged for products sold directly to consumers. The wholesale price accounts for possible retail-level product defects and spoilage. Retailers bear the full costs of these issues. Therefore, the estimates are gross demand, not net demand consumed, because they do not assume production quantity adjustments for returned products (i.e., estimates assume no food loss at the wholesale level).

The demand estimates produced for this study reflect regional averages. Per capita consumption does vary by individual consumer. However, for most food products, the cost-benefit ratio is too high to identify consumption behavior, quantity and location for each consumer. Regional averages sufficiently suggest per capita consumption — and consequently, total estimated demand — needed for scenario analysis and business planning.

The estimates adjust for regional consumption differences that arise due to eating habitat variations. Multiple factors shape habits that vary by region: consumer socioeconomic standing; demographics; and climate, product knowledge and historical consumption that differ by locale. For most foods, the relationship between consumption and eating habits has continuity over time. Using historical causes (e.g., factors affecting eating habits) and effects (product consumption) is generally accepted.[2] This analysis looks at how food habit causes affect per capita consumption county-level patterns.

[2] For the current study, none of the products represented were susceptible to an abrupt change in consumption due to a significant shift in preference. If we would have been aware of a significant change in a particular causation factor leading to a significant change in consumption, then we would have adjusted this relationship accordingly. The following hypothetical example summarizes how a cause-effect change may arise: *A past study found a particular ethnicity has a hereditary trait that causes higher rates of cancer when consumers of that ethnicity eat a particular food (i.e., cause), and consumers of that ethnicity now eat less of that food (i.e., effect).*

Because population and per capita consumption drive a product's estimated demand, both represent key assumptions for demand modeling. Estimated population of an area is well-known, and the data are easily accessible through the Bureau of Labor Statistics census estimates. The locations of retail establishments, which serve as markets that growers often use to reach consumers, can be determined with relatively low human search costs.

With respect to per capita consumption, this analysis used the national average per capita availability level that USDA reported for 2020 as the starting value for each product. Per capita consumption could be approximated by adjusting availability for losses in the supply chain. For the current study, per capita availability was used because our interest is in the levels of product transferred between production and retail, institutional or wholesale buyer. Then, the starting values had marginal adjustments made to ensure that the per capita consumption levels reflected typical product consumption in a region. This step is necessary because consumers in particular geographic areas can have more or less affinity for a particular food product than the national average would suggest.

To estimate demand for a product, we applied marginal adjustments by region to national per capita consumption. We used findings from Lin et al. (2003) to approximate the cause-effect relationship between consumption and eating habitat traits.[3] The reference study conducted a national survey of U.S. households and reported average and standard deviation values to indicate how multiple factors affect food product consumption. Along with the cause-effect relationships from the reference study, we used the consumption-informing factor averages as the reference level of each factor. The factors considered in the reference study included food knowledge, eating out preference, age, employment status, race, ethnicity, household size, income and educational attainment. Models were specified for at-home and away-from-home consumption.[4]

Note, knowing how much product is consumed at home (e.g., purchased at a grocery store for consumption at home) or away from home (e.g., consumed at a restaurant or hospital) has value for businesses that must determine delivery routes. For our study and because produce is generally delivered fresh to buyers, the product form (i.e., fresh) will not differ between retail and away-from-home purchasers (e.g., restaurants, hospitals) for the wholesale market. Quantifying the proportion of product consumed at home or away from home is helpful for disaggregating marketing channels.

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[3] Food and Agricultural Commodity Consumption in the United States: Looking Ahead to 2020
[4] Some of the consumption-informing factors were recorded as binary (0 or 1), meaning either the individual responding indicated "yes = 1" to the factor or "no = 0" to the factor. An example is race; an individual of Asian descent would indicate "yes" to being of Asian descent.

We next gathered county-level data for each consumption-informing factor. We adjusted consumption in an additive two-step process for each factor: 1) find the marginal difference between reported average in the reference level and actual county-level representation and 2) multiply this marginal difference by the relationship coefficient reported in the reference study.

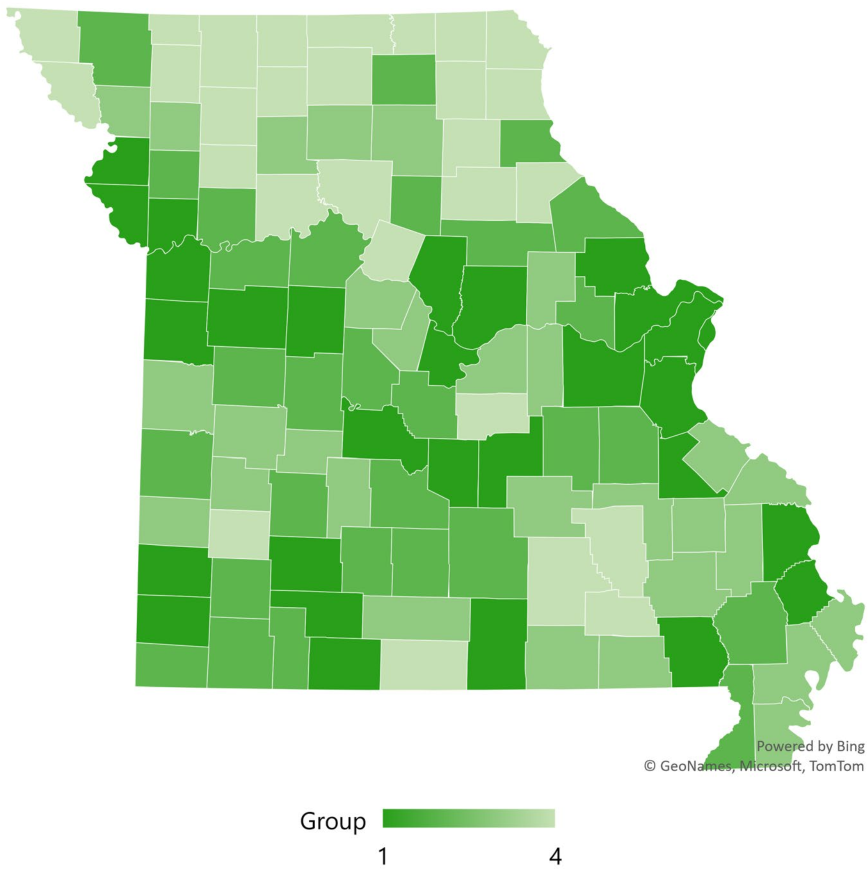
The following employment-consumption example explains how the model will adjust to a region based on data from the refence study. Assume a vegetable's national average per capita consumption totals 23.6 lb. per year. The reference study indicates the average employed person from the national study is 93% employed. From the reference study, assume the relationship factor between being employed and consuming vegetables is 0.1. This relationship infers that for each 1 percentage point increase in average employment level, an individual is likely to increase per capita consumption of vegetables by 0.1 lb. per year. A given county recorded a 96% employment rate. The employment rate difference between the county of interest and the reference study's national average is 3 percentage points. To adjust the 23.6-lb. vegetable consumption per year average and make it specific to the particular county, add 0.3 lb. to reach 23.9 lb. per year. This estimate approximates the county's per capita vegetable consumption after adjusting for employment rate (23.9 lb. = 23.6 lb. + [0.1 x 3]). We repeated this process for every adjustment factor considered in the reference study, so a county-level estimate reflects the sum of marginal differences.

These adjustment steps were completed for each product considered in the current study. Because the reference study reported cause-effect relationships for at-home and away-from-home consumption, we used a similar methodology to arrive at estimated at-home and away-from-home per capita consumption by county. Adding these values gives total per capita consumption. Multiplying at-home, away-from-home or total consumption per capita by an area's population yields the demand estimates for that area.

The reference study did not offer cause-effect relationships for each product considered in the current study. It did provide the cause-effect relationship for per capita vegetable consumption, which we used as an approximation for most products included in the current study. To account for differences between the general vegetable category and a specific vegetable, we scaled each consumption-informing factor by the difference in the specific vegetable's per capita consumption and the reference study's reported average for vegetable per capita consumption.

By county, Exhibit 3.4 presents the extent to which estimated demand varies for the following crops well-suited to vertical growing environments: spinach, kale, romaine lettuce, mustard greens, turnip greens, onion, okra, lima beans, cucumbers and tomato. Using demand index values, the map categorizes counties into four groups. Those highlighted in the darkest green have the greatest index values, which communicates consumers in these counties have greater demand for the selected foods relative to consumers in other counties and they have stronger total demand for the selected food products.

Exhibit 3.4. Missouri Counties Grouped by Per Capita Demand Estimates*



* 1 denotes the highest demand index values

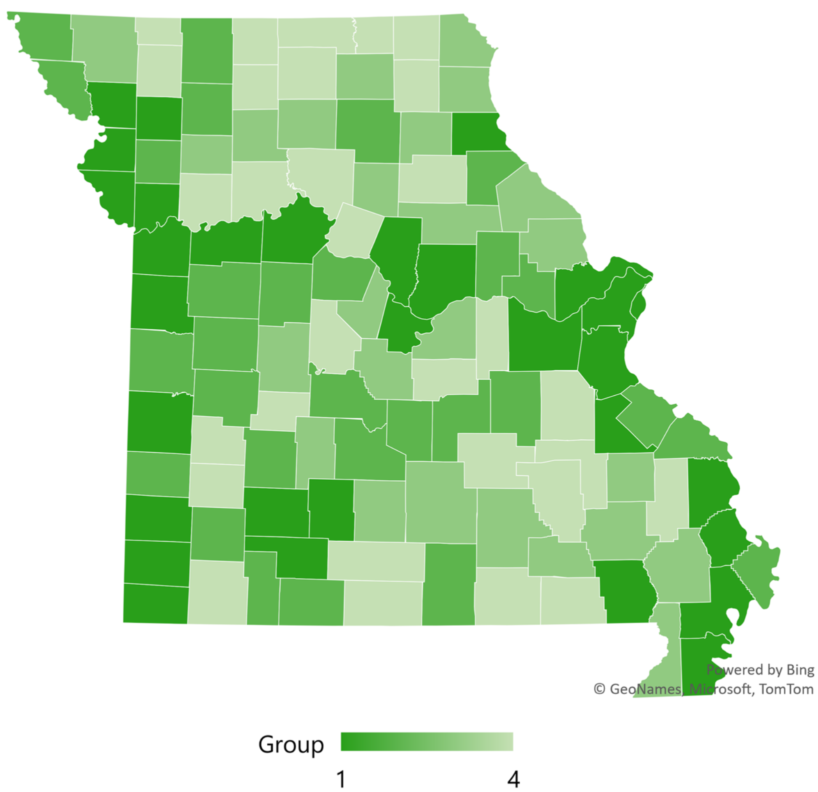
Highway access

Infrastructure plays a critical role in moving products to markets. Additionally, it connects businesses to input suppliers and labor. Emphasizing the importance of roadway infrastructure, a logistics industry leader interviewed for a 2013 story from Area Development, a trade publication focused on site selection and relocation, highlighted a "5 to 55" principle. It guides decision-makers to locate facilities within five minutes of a roadway that allows 55 mph travel (areadevelopment.com/logisticsinfrastructure/q4-2013/highway-access-site-selection-factors-36282652.shtml).

For food businesses producing and handling perishable products, good infrastructure and logistics systems have particular importance. If shipments are delayed, then the product may spoil or degrade in quality before it reaches the market (foodlogistics.com/transportation/cold-chain/article/12332506/logistics-gets-fresh).

This study accounts for infrastructure by examining proximity to highways. The analysis considers the count of interstates, other freeways and expressways and other principal arterial roadways — categories the Missouri Department of Transportation uses in its functional classification maps — passing through counties. Then, weights were applied to those counts to suggest the value of one classification relative to another. Interstates had the highest weight. Other principal arterial roadways had the lowest weight. Applying these weights to the count of roadways produced a highway access score for each county. Exhibit 3.5 shades counties into four groups based on their scores. Those in the darkest green had the highest scores, which signal in-county access to major roadways or in-county access to multiple roadways.

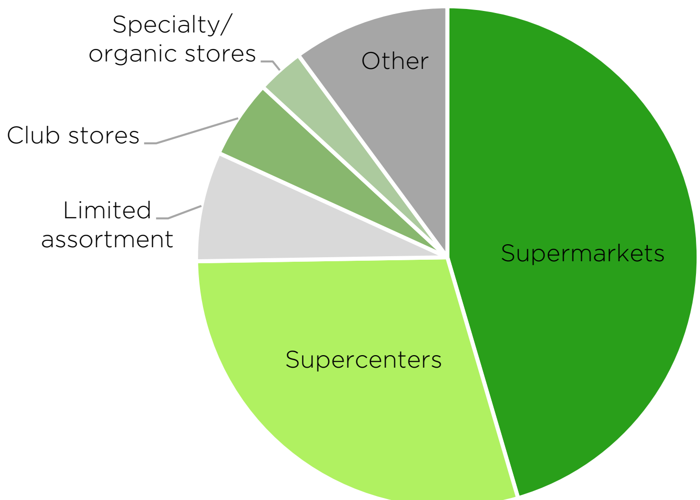
Exhibit 3.5. Missouri Counties Grouped by Highway Access Scores*



* 1 denotes the highest highway score values

Supermarkets and other grocery stores, except convenience stores
Supermarkets and other grocery stores represent important market channels for consumers to access food that is prepared and consumed at home. Most consumers — 89% — buy fresh produce from the retail outlets they visit to buy a majority of their groceries, according to "The Power of Produce 2022" report from the Food Industry Association (FMI). The FMI research found supermarkets ranked first as the primary store where consumers shop. See Exhibit 3.6. In 2022, 45% of shoppers identified supermarkets as their primary store. Supercenters followed at 29% of consumers (fmi.org/forms/store/ProductFormPublic/power-of-produce-2022).

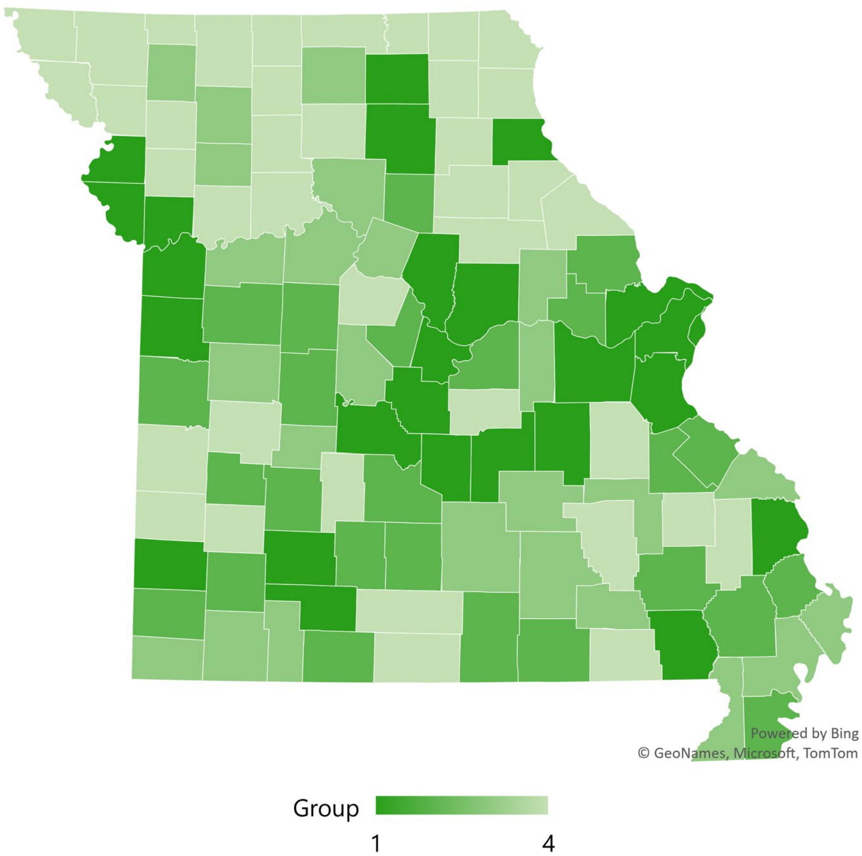
Exhibit 3.6. Consumers' Primary Grocery Store, 2022



Source: FMI (fmi.org/forms/store/ProductFormPublic/power-of-produce-2022)

Operating near supermarkets and other grocery retailers gives vertical farms an opportunity to develop local markets and reduce transportation costs. By county, this project's siting analysis considers two datasets related to supermarkets and other grocery stores, except convenience stores. First, the count of supermarkets and other grocery stores in 2020 suggests the number of potential customers in a county. Second, the number of employees working in these retailers during 2020 suggests the size of the retailers operating. Both metrics — establishments and employees — originate from the U.S. Census Bureau's County Business Patterns dataset. Exhibit 3.7 presents these two metrics in a single map. The counties shaded in darker green have the greater combined establishments and employee count — suggesting they offer better access to supermarkets and other grocery retailers.

Exhibit 3.7. Missouri Counties Grouped by Supermarket and Other Grocery Store Access and Approximated Size*



* 1 denotes the greatest composite number of establishments and average employee count

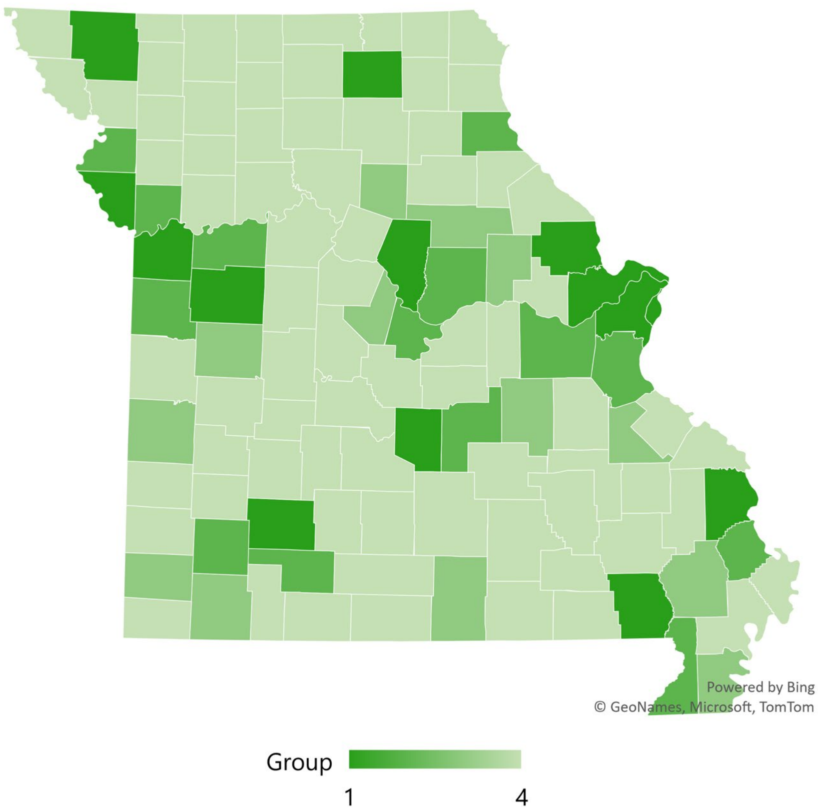
Food service contractors

Businesses listed as food service contractors manage the food service operations — for example, cafeterias, restaurants and concession stands — at institutions, government agencies or commercial and industrial sites. In total, the food service sector captures a sizable share of fresh produce sales. In an April 2020 story from Bloomberg Law, a representative with United Fresh estimated that U.S. fresh produce growers direct two-fifths of their production to commercial food service buyers (news.bloomberglaw.com/environment-and-energy/with-restaurants-reeling-produce-farmers-seek-reason-to-harvest). The COVID-19 pandemic limited consumer purchases in food service settings. However, as behaviors readjust post-pandemic, the food service sector may regain its share of fresh produce purchasing.

For counties with data reported, the siting analysis reflects the number of food service contractors and the size of their workforce in 2020. The U.S.

Census Bureau publishes these data in its County Business Patterns dataset. Exhibit 3.8 presents the two metrics in a single map. Counties shaded in darker green have the greater combined establishments and employee count — suggesting they offer better access to food service contractors.

Exhibit 3.8. Missouri Counties Grouped by Food Service Contractor Access and Approximated Size*



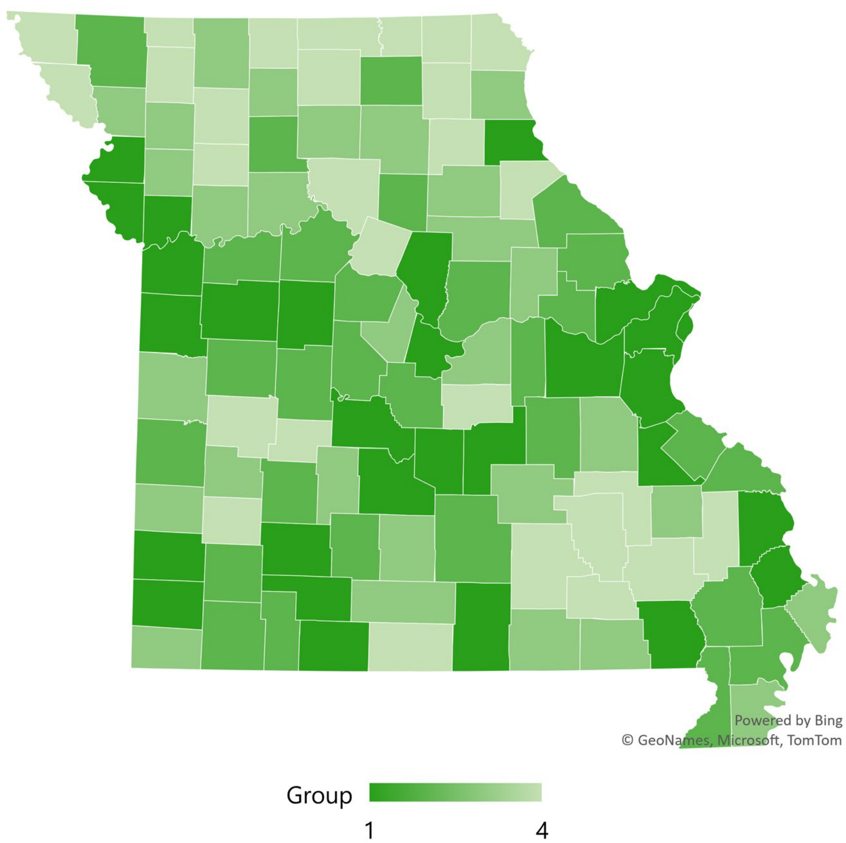
* 1 denotes the greatest composite number of establishments and average employee count

Restaurants and other eating places

Published in November 2019, the National Restaurant Association's "Restaurant Industry 2030" report named more fresh produce options as one of the most likely developments to unfold by 2030 (restaurant.org/nra/media/restaurant-2030/restaurant2030.pdf). As another trend relevant to vertical farms, some restaurants also prioritize local sourcing to satisfy consumer demand. Research conducted for the "2022 State of the Restaurant Industry" — a National Restaurant Association publication — found nearly two in five adult consumers preferred eating at a restaurant that sources local food (restaurant.org/education-and-resources/resource-library/state-of-the-industry-sustainability-is-back-on-the-menu).

To account for restaurant demand, the siting analysis includes two metrics tied to restaurants and other eating places. First, it considers the count of establishments by county during 2020. This number suggests potential buyers. Second, the analysis includes the number of employees working in restaurants and other eating places during 2020. A greater number of employees suggests greater activity and sales. The U.S. Census Bureau reports both variables in its County Business Patterns dataset. In Exhibit 3.9, counties shaded in darkest green ranked highest for combined establishments and average number of employees tied to restaurants and other eating places.

Exhibit 3.9. Missouri Counties Grouped by Restaurant and Other Eating Place Access and Approximated Size*



* 1 denotes the greatest composite number of establishments and average employee count

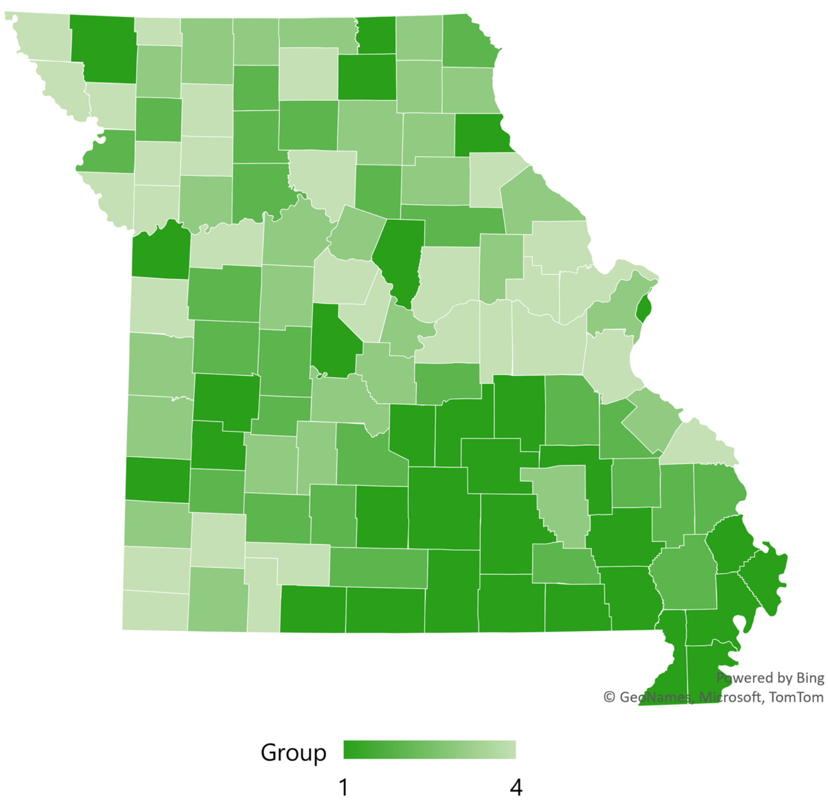
Food security

Measures of food insecurity communicate whether residents in an area have access to enough food. A July 2022 story from the American Planning Association describes how digital urban agriculture, such as vertical farms, may ease food insecurity (planning.org/planning/2022/summer/ag-tech-

could-help-solve-food-insecurity-and-supply-chain-issues). Research conducted by faculty from Penn State University, the University of Missouri and Bartin University concluded that production models such as vertical farms can supply part of the nutrition consumers require. However, communities would also rely on farms farther away to produce foods that meet all nutrient needs of their residents, particularly if foods don't have added nutritional fortification (psu.edu/news/research/story/urban-agriculture-can-help-not-solve-city-food-security-problems).

The siting analysis includes food insecurity as a variable. The data, sourced from the Missouri Hunger Atlas, indicate food insecurity levels by county in 2019. The University of Missouri's Interdisciplinary Center for Food Security periodically updates the atlas to understand changes in food insecurity levels. Exhibit 3.10 groups counties according to the extent to which they exhibit food insecurity in the Missouri Hunger Atlas. Darker shading indicates greater levels of food insecurity. In these communities, locally situated vertical farms may have an opportunity to close the food access gap.

Exhibit 3.10. Missouri Counties Grouped by Food Insecurity Level*



* 1 denotes highest food insecurity

Production Factors

Several production factors influence whether a particular site would likely support operating a vertical facility to grow food. Exhibit 3.11 highlights the 10 production factors considered in this project’s site selection analysis. The following sections then describe those factors in more detail.

Exhibit 3.11. Production Factors Considered in Vertical Farm Siting Analysis

Temperature **Water Rates**
Broadband Availability **Dew Point**
Unemployment Rate **Electric Rates**
Quality of Life
Renewable Energy Capacity
Power Plants **Ethanol Plants**

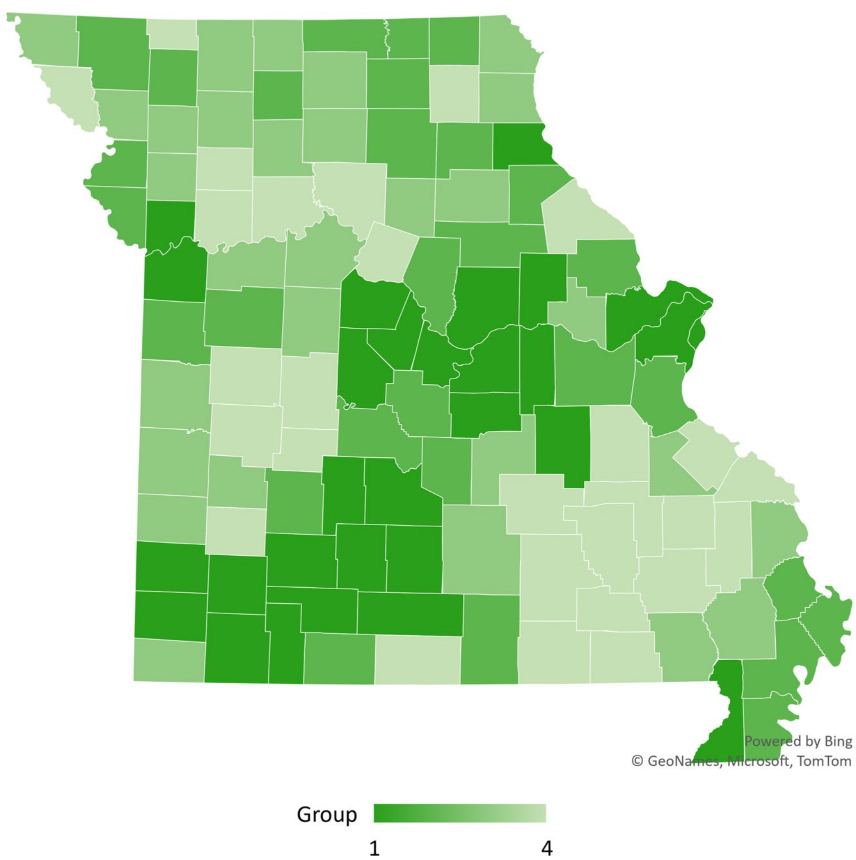
Broadband availability

To grow food vertically, farms require a relatively significant investment in technology. A whitepaper from Infosys, a digital services and consulting business, described the internet of things (IoT) as a potential “backbone of vertical farming.” An IoT system features wireless sensors recording data about plant growth, light exposure, temperature, pH, carbon dioxide, moisture levels, machinery condition and other variables. IoT technology then delivers these data to the appropriate places, and the data can be analyzed and used to make decisions about how to better control the growing environment (infosys.com/industries/agriculture/insights/documents/vertical-farming-information-communication.pdf). A broadband connection plays an important role in facilitating communication within an IoT system. Therefore, access to broadband represents a consideration for vertical farming site selection.

An indoor farm located in Rochelle, Illinois, Mighty Vine serves as a case study into an internet connection’s value to indoor food production. Mighty Vine produces tomatoes hydroponically in greenhouses that provide nearly 30 acres of growing space. The farm has an automated monitoring system to track plant health and environmental factors, and it relies on a broadband connection to achieve this automation. Rochelle, Illinois, has the needed broadband infrastructure to support this type of activity (planning.org/planning/2022/summer/ag-tech-could-help-solve-food-insecurity-and-supply-chain-issues).

This project's site selection analysis uses December 2019 broadband deployment data from the Federal Communications Commission. Sourced from Form 477, these data indicate broadband availability at the census block level. Those data were then aggregated to the county level. Exhibit 3.12 breaks Missouri counties into four groups based on their broadband availability. Shaded in darkest green, the counties with highest levels of broadband availability offer the most widespread access to broadband infrastructure, which vertical farms may use to run parts of their operations.

Exhibit 3.12. Missouri Counties Grouped by Broadband Availability*



* 1 denotes highest level of broadband availability

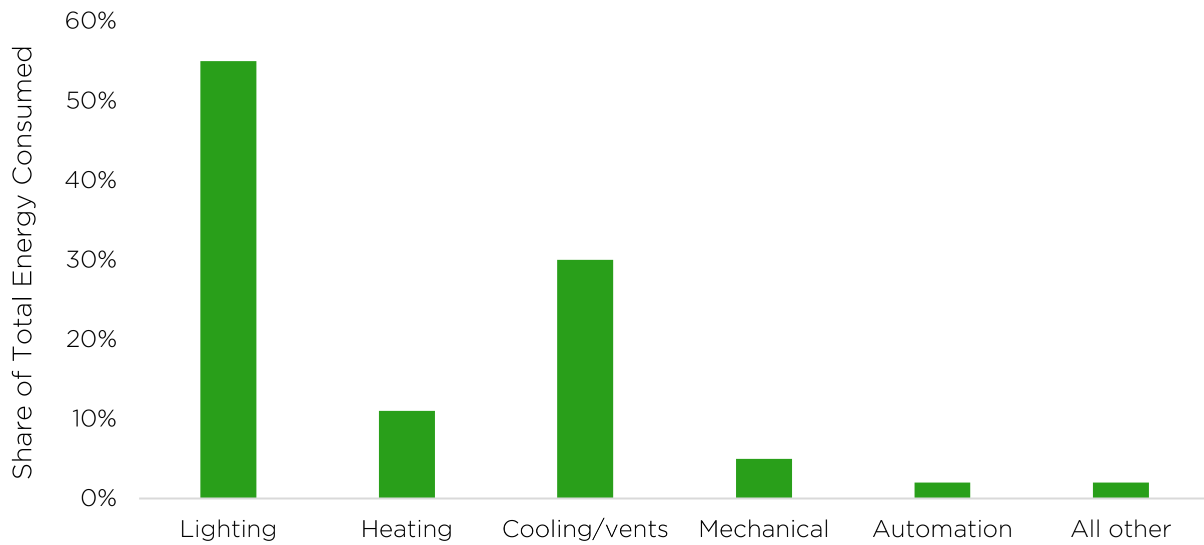
Electric rates

Energy represents an important and costly input for vertical farms. Barclay's estimates that energy captures a 50% to 70% share of a vertical farm's cost of goods sold, according to a CoBank brief (cobank.com/documents/7714906/7715347/VerticalFarming-Nov2022.pdf/97557b2e-1df4-2293-9895-bd8dd03b0963?t=1667424716228).

A 2021 Global Controlled-Environment Agriculture Census Report from WayBeyond and Agritecture Consulting assessed energy use among types of controlled-environment agriculture facilities. Among all vertical farms responding, their energy use was slightly more than seven times greater than energy use among all greenhouses responding. WayBeyond and Agritecture Consulting further explored whether the same relationship was true for facilities growing the same crops, and they found a similar relationship (engage.farmroad.io/hubfs/2021%20Global%20CEA%20Census%20Report.pdf).

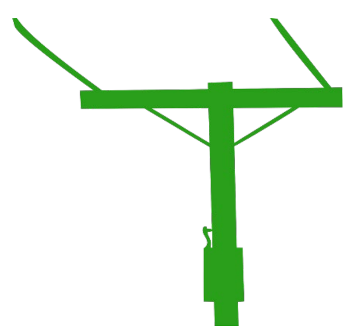
Using the census data collected, WayBeyond and Agritecture Consulting also roughly estimated the share of energy use tied to various vertical farm facility functions. Exhibit 3.13 shows that 55% of all vertical farm energy use stemmed from lighting. Cooling and venting ranked second as a driver of energy use (engage.farmroad.io/hubfs/2021%20Global%20CEA%20Census%20Report.pdf).

Exhibit 3.13. Energy Use Breakdown Among Vertical Farms*



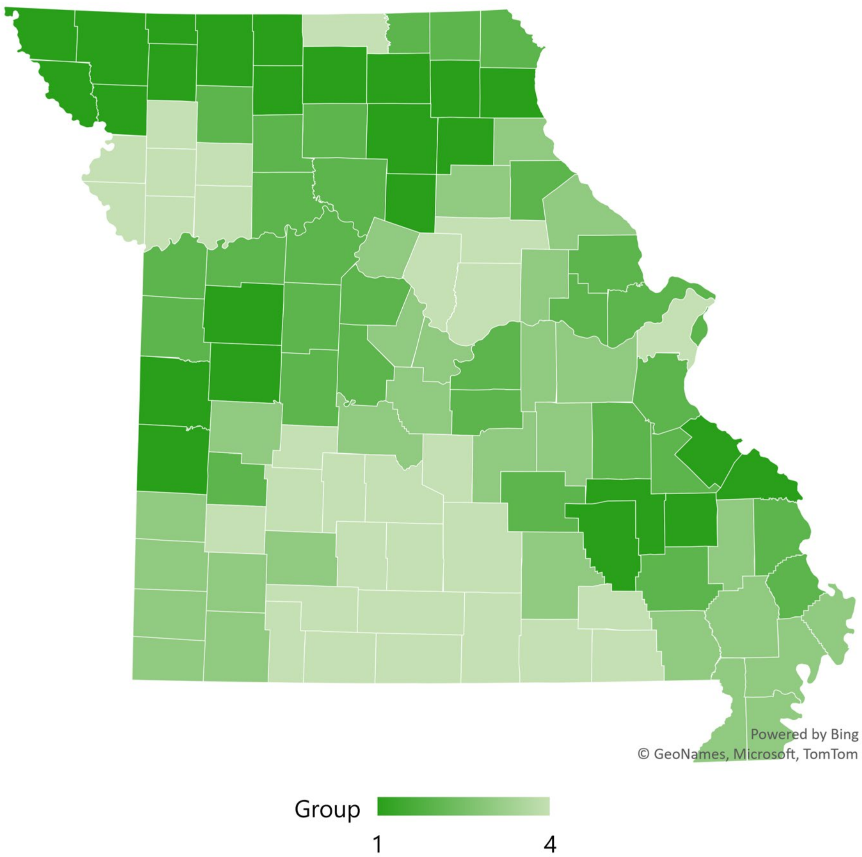
* Source noted thin data and possible respondent misinterpretation of categories, but the analysis intended to create a baseline.
Source: WayBeyond and Agritecture Consulting
(engage.farmroad.io/hubfs/2021%20Global%20CEA%20Census%20Report.pdf)

This project's siting analysis uses data from the U.S. Energy Information Administration to estimate an average industrial electric rate charged by county in 2020. A county's average reflects data for all utilities reporting data to the administration. In one instance, a county didn't have data reported, so the project team sourced a rate from an in-county electric utility. Exhibit 3.14 visualizes industrial electric rates by county. Those highlighted in darkest green had the least expensive



industrial electricity rates; therefore, they represent an opportunity for vertical farming facilities to control their electric-related input costs.

Exhibit 3.14. Missouri Counties Grouped by Industrial Electric Rates*



* 1 denotes least expensive industrial electric rates

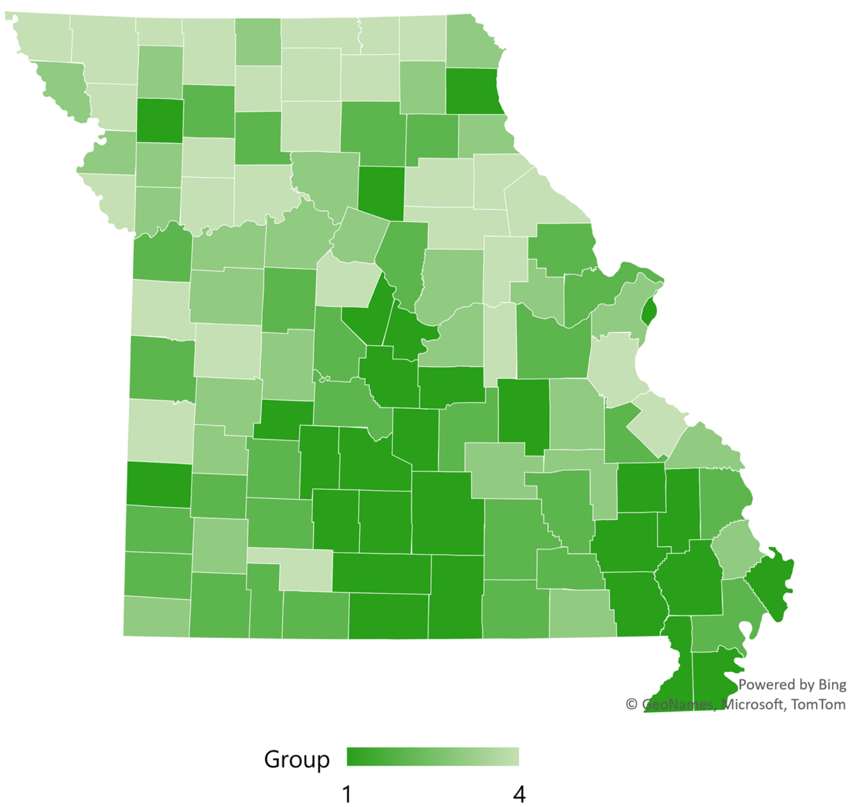
Water rates

Estimates often suggest controlled-environment facilities use as much as 90% to 95% less water than traditional agriculture. In the 2021 Global Controlled-Environment Agriculture Census Report from WayBeyond and Agritecture Consulting, two-thirds of respondents said their facilities used at least 90% less water than field-grown production, which was assumed to demand 250 liters per kilogram of product. Roughly one-quarter quantified the water reduction at 50% to 89%. Respondents noted leafy greens required less water than vining crops and berry crops. Greenhouse facilities reported more water use than vertical farms — 51.5 liters per kilogram of product compared with 20.4 liters per kilogram. Factors motivating the differences include the crops grown in these facilities. Also, a vertical facility may repurpose moisture using an HVAC system designed to capture and reuse transpired water (engage.farmroad.io/hubfs/2021%20Global%20CEA%20Census%20Report.pdf).

The production model — aeroponics, hydroponics or aquaponics — a facility chooses will also affect water requirements. Aeroponics growers use little water — as much as 90% less water than hydroponic systems that operate efficiently. Roots of plants grown hydroponically sit in a nutrient solution, and aquaponics systems feature indoor ponds that provide enough space for growing plants and fish (attra.ncat.org/publication/vertical-farming).

In instances where vertical farms rely on water from a utility, the rates charged for water represents a factor to consider when choosing a facility site. To approximate water rates for a county, this project's analysis involved estimating a mock water bill based on rates charged by the municipality serving the county seat. In instances where the county seat's water utility didn't post rates online, then the analysis reflects data from another in-county water utility. If no in-county water utilities posted rates online, then the analysis involved averaging rates charged in surrounding counties. Exhibit 3.15 groups counties into categories based on the water bill approximated for a sample vertical farm facility. Those highlighted in the darkest green have the lowest approximated water bill; therefore, they present an opportunity to control water-related input costs.

Exhibit 3.15. Missouri Counties Grouped by Approximated Water Bill*



* 1 denotes least expensive approximated water bill

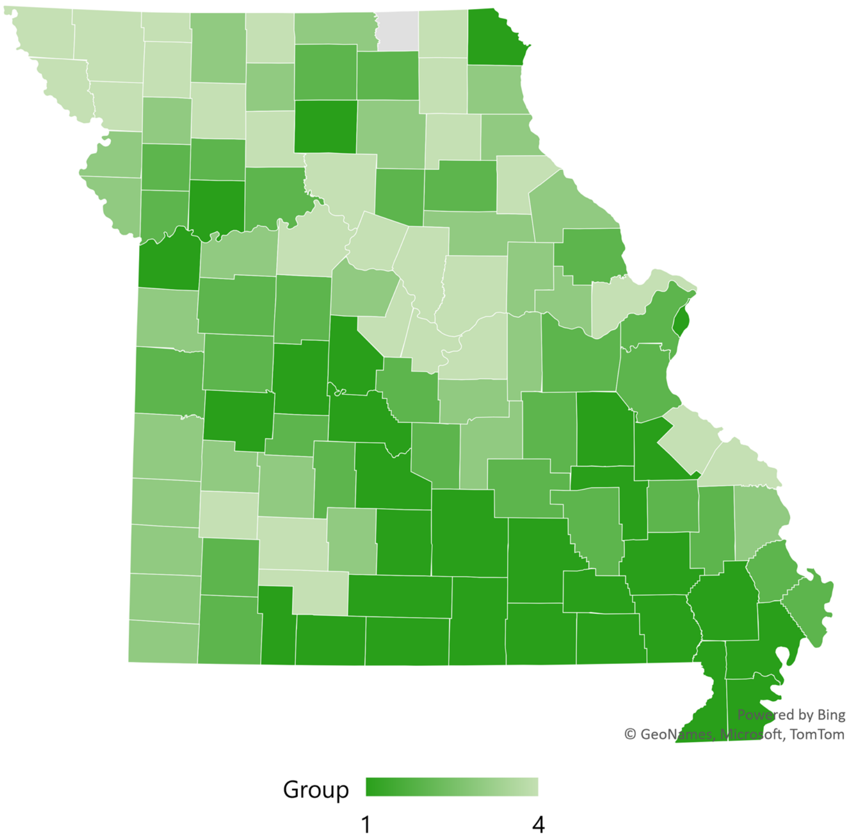
Unemployment rate

Although technology enables vertical farms to automate some tasks, these operations need employees to oversee the technology and take responsibility for managerial functions. Therefore, vertical farms must cultivate a skilled workforce that understands plant production, technology and innovation. Researchers from Cornell University and The Ohio State University conducted research in 2018 and 2019 to understand controlled-environment workforce needs. This information would then support developing curriculum (urbanagnews.com/blog/news/research-for-workforce-development-in-controlled-environment-ag-what-makes-a-successful-indoor-farm-manager). The research summary lists typical duties and tasks for vertical farm managers. Examples include managing crop production and labor, overseeing distribution and facility maintenance, implementing a product safety plan and maintaining stakeholder relationships. It also describes knowledge, skills and behaviors associated with vertical farming jobs, and it names tools, equipment, supplies and materials with which vertical farm managers should be familiar (blogs.cornell.edu/urbancea/files/2020/02/Indoor-Farm-Operations-Manager-DACUM-Chart.pdf).

To approximate local labor availability, this project's analysis considers the unemployment rate reported by the U.S. Bureau of Labor Statistics. A five-year average reflective of 2017 to 2021 provides a "smooth" representation of recent employment levels. Counties with higher unemployment have a greater proportion of their population that may consider working at a vertical farm. Counties with lower unemployment have a greater proportion of their residents already employed, which means they may not have as ready access to a labor force. Note, the unemployment rate represents only one labor-related factor. The extent to which available labor has the skills and knowledge demanded by a vertical farm managerial position should also be considered.

To see the analysis' results, refer to Exhibit 3.16. It shades counties according to their unemployment rate average from 2017 to 2021. Those shaded in the darkest green had the highest average unemployment rate. This signifies the local area more readily has a potential workforce that could be recruited and trained to work in a vertical farming facility.

Exhibit 3.16. Missouri Counties Grouped by Unemployment Rate Average, 2017-21*



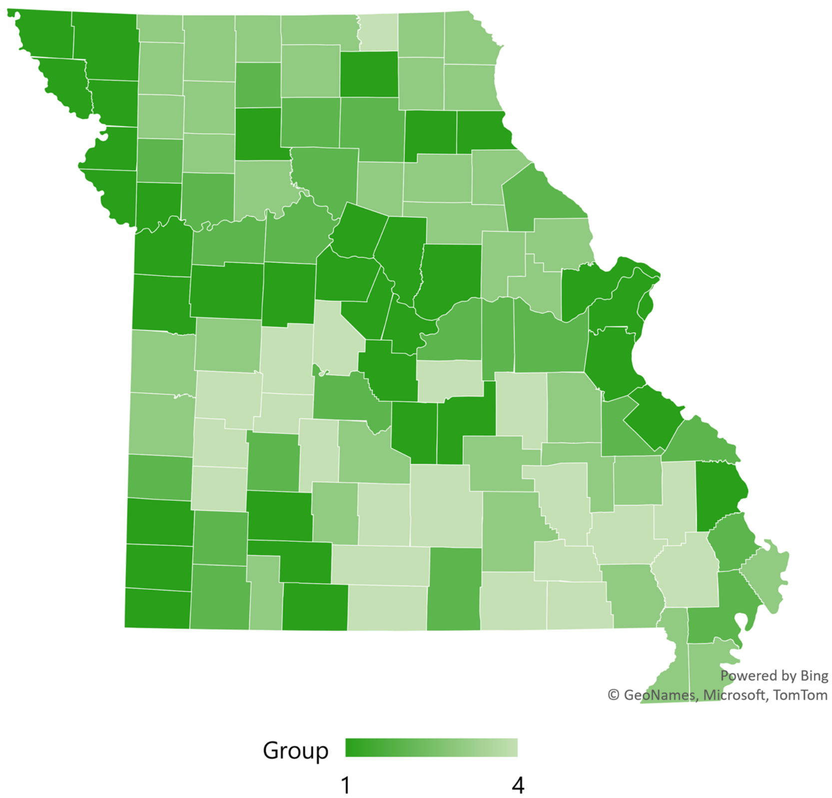
* 1 denotes highest unemployment rate

Quality of life

A multifaceted site selection dimension, quality of life refers to whether a site meets a particular workforce's expectations. In a December/January 2010 article, Area Development listed multiple criteria that could be included in a quality of life assessment: schools, affordable housing, public transportation, commute time, crime rate, health care access, weather and recreation opportunities (areadevelopment.com/siteSelection/dec09/quality-of-life-location-factors010.shtml). These subfactors' importance varies based on the target audience a business has a need to attract. For example, a new workforce entrant who recently completed a college degree may view quality of life differently from a professional who has young children (areadevelopment.com/Print/laboreducation/dec06/qualityoflife.shtml). However, the amenities available from a site should also support employee retention, so anticipating how a workforce's needs and expectations may change over time is also important (areadevelopment.com/corporate-site-selection-factors/q4-2016/quality-of-life-site-selection-factor.shtml).

Niche, an online service that aggregates reviews and profiles for communities, schools and workplaces, published a "Best Counties to Live in Missouri" list in 2022. It graded counties based on criteria such as cost of living, job opportunities and local amenities. The siting analysis considers these county-by-county grades as a proxy for quality of life. Counties ranked higher in the list — those categorized in the group with the darkest shading in Exhibit 3.17 — may have better potential to attract and retain residents and a workforce that value the variables included in the grading criteria.

Exhibit 3.17. Missouri Counties Grouped by Quality of Life Rating*



* 1 denotes highest quality of life rating

Environmental conditions

Vertical farming is often associated with a climate-controlled environment. Environmental conditions outside the optimal production range lead to plant stress and lower production. A six-point scale communicates the extent to which building operators control indoor conditions. It ranges from a level 1 uncontrolled facility to level 6 climate-controlled facility. To stabilize the environment, a level 6 facility involves special HVAC and humidity control with precision monitoring systems. Level 6 climate control is not financially viable currently in climate-controlled indoor farming. More often, indoor farming occurs in level 5 controlled environments, which feature HVAC systems and some humidity control. This level of control is sometimes described as climate control with seasonal drift in levels of both temperature and humidity (archives.gov/preservation/storage/climate-control-table.html).

Energy represents the highest expense for vertical farms. Facilities use energy for lighting, temperature control, airflow, water pumping and filtration, humidity control and smart computer system operation. When the outside climate varies drastically from ideal growing conditions, optimizing the environment's temperature and humidity can lead to high energy costs and lost productivity. Thus, vertical farms may consider locating in climates that minimize variation between outdoor and indoor optimal climate in all seasons. The following sections share more about temperature and dew point control.

Temperature

Because climate-controlled vertical farming is most financially feasible in a climate control with seasonal drift setup, the relationship between the outside temperature and a crop's desirable temperature are important to consider. Maintaining optimal soil temperature is the goal. Depending on the plant species, optimal plant growth and productivity occur within a certain temperature range. Exhibit 3.18 lists optimal temperature for crops commonly produced in vertical facilities. Anytime the outside air temperature deviates from the optimal range, the interior HVAC system is used to maintain the indoor air temperature. The further the outdoor air temperature deviates from the optimal range, the more energy the HVAC system requires and the higher the risk of the indoor air temperature falling outside the optimal range.

Exhibit 3.18. Optimal Temperature Ranges for Crops Grown in Vertical Systems

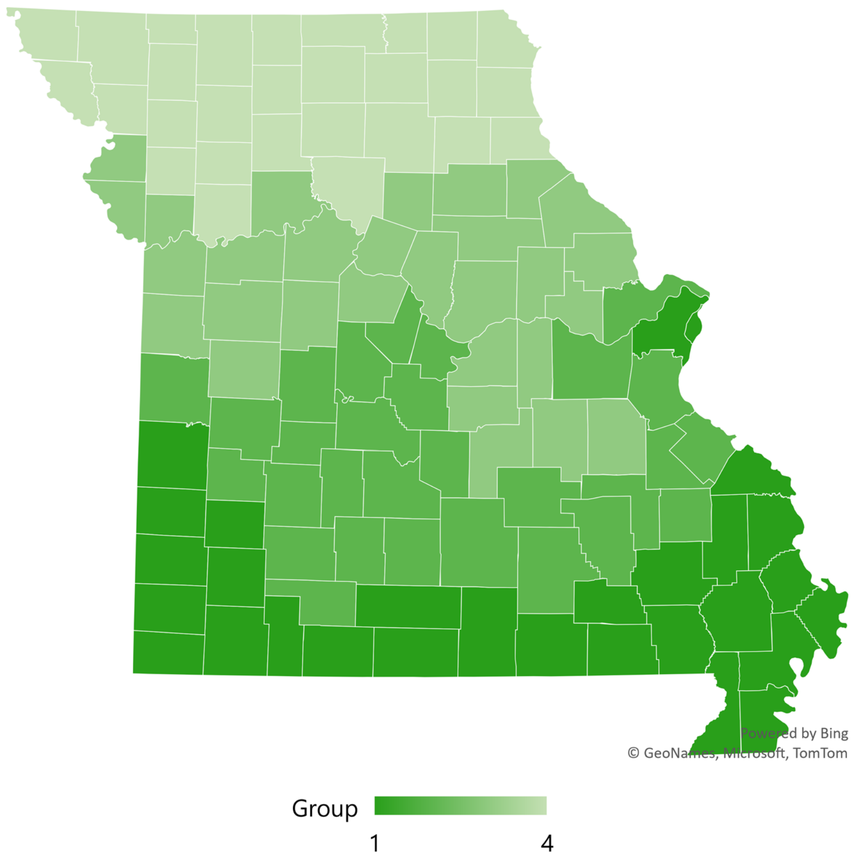
Item	Cool/Warm Season	Day
Tomatoes	Warm	70–79°F
Cucumber	Warm	60–78°F
Lima beans	Warm	65–80°F
Okra	Warm	>85°F
Onions	Cool	55–75°F
Turnip greens	Cool	55–65°F
Mustard greens	Cool	55–65°F
Romain & leaf lettuce	Cool	60–65°F
Kale	Cool	60–75°F
Spinach	Cool	50–60°F

* Typically, nighttime temperature will reduce by around 5°-10°F.

To include temperature as a variable in the siting analysis, the project team collected annual mean temperature data by county. Sourced from the PRISM

Climate Group at Oregon State University, the data are based on 30-year normals calculated from 1991 to 2020. Using the annual averages, counties were assigned into one of four groups. Exhibit 3.19 visualizes these assignments. Counties shaded in the darkest green had the warmer average annual temperatures.

Exhibit 3.19. Missouri Counties Grouped by Mean Annual Temperature, 1991 to 2020*



* 1 denotes warmest annual mean temperature

Dew point

Because climate-controlled vertical farming is most financially feasible with a setup of climate control with seasonal drift, the outside humidity (or dew point) level and its variation are important for optimizing humidity within the controlled environment. Depending on the plant species, optimal plant growth and productivity occur within a certain humidity range.

Exhibit 3.20 presents the optimal humidity ranges for multiple crops commonly grown in vertical production facilities. Anytime the outside air humidity deviates from the optimal range, the interior humidifier-dehumidifier system must maintain the indoor air humidity. The further the outdoor air humidity deviates from the optimal range, the more energy is required to operate the humidity system and the higher the risk of the indoor humidity falling outside the optimal range.

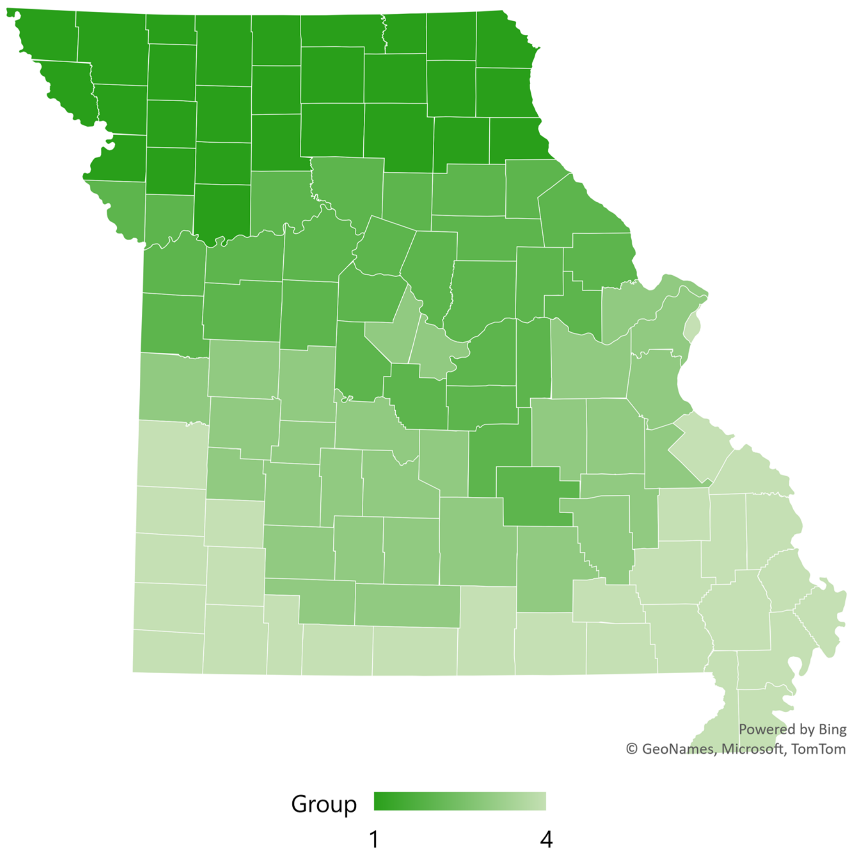
Exhibit 3.20. Optimal Humidity Ranges for Crops Grown in Vertical Systems

Item	Cool/Warm Season	Day
Tomatoes	Warm	80–90%
Cucumber	Warm	60–70%
Lima beans	Warm	95%
Okra	Warm	90–95%
Onions	Cool	30–50%
Turnip greens	Cool	>90%
Mustard greens	Cool	>90%
Romain & leaf lettuce	Cool	50–70%
Kale	Cool	55–65 %
Spinach	Cool	Wide range

* Typically, nighttime humidity will be lower.

The PRISM Climate Group at Oregon State University also reports dew point data in its 30-year normals. Exhibit 3.21 creates four groups for counties based on their annual mean dew point from 1991 to 2020. Counties shaded in the darkest green represent those with the lowest annual mean dew point levels. Therefore, they offer an external environment that contributes less to a high-humidity environment that would need to be controlled.

Exhibit 3.21. Missouri Counties Grouped by Mean Annual Dew Point, 1991 to 2020*

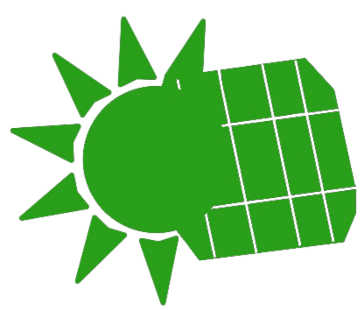


* 1 denotes lowest annual mean dew point

Note, facility operators also must manage vapor pressure deficit — the difference between the amount of moisture in the air and the maximum amount of moisture the air can hold when saturated. This measure influences plant transpiration and, therefore, affects the plant's water use, nutrient uptake and risk of foliar diseases. For a particular facility, the targeted vapor pressure deficit can vary by the crop produced, its growth stage and environmental conditions. Indoor farmers often use sensors and automated systems to monitor and control vapor pressure deficit levels.

Proposed renewable energy capacity

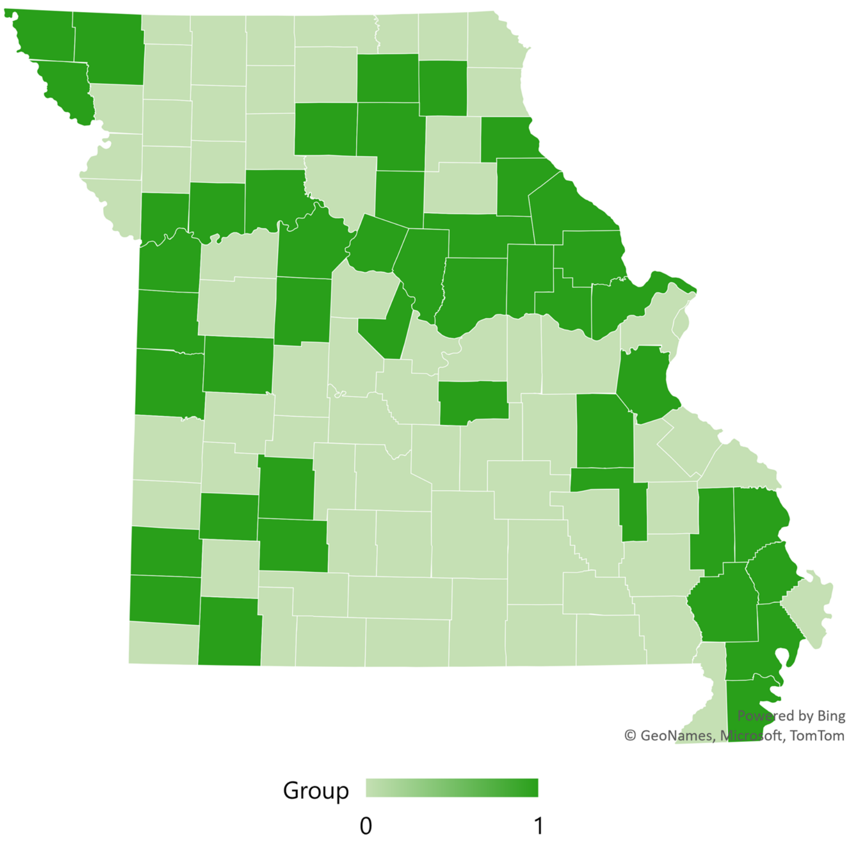
Some food providers have identified an opportunity to label their products as sustainably produced to meet consumer preferences. Energy represents the largest cost to vertically farming in climate-controlled spaces. The opportunity to co-locate or tie into power generated through renewable clean energy sources could allow vertical climate-



controlled facilities to offer products they can market as those that have been produced using clean energy.

This project's siting analysis includes whether a county has a proposed renewable energy project as a criterion to consider when choosing a vertical farm facility location. The analysis focused on identifying proposed projects that would be powered by solar, wind, battery, hydro or a combination of these technologies. Exhibit 3.22 color-codes counties according to whether they had a proposed project listed. Counties highlighted in the darker green had at least one proposed renewable energy project listed. Note, a proposed project doesn't necessarily indicate a project ultimately will go online. Developers often submit multiple planning requests as they work to determine the site best suited to their needs.

Exhibit 3.22. Missouri Counties with Proposed Renewable Energy Project*

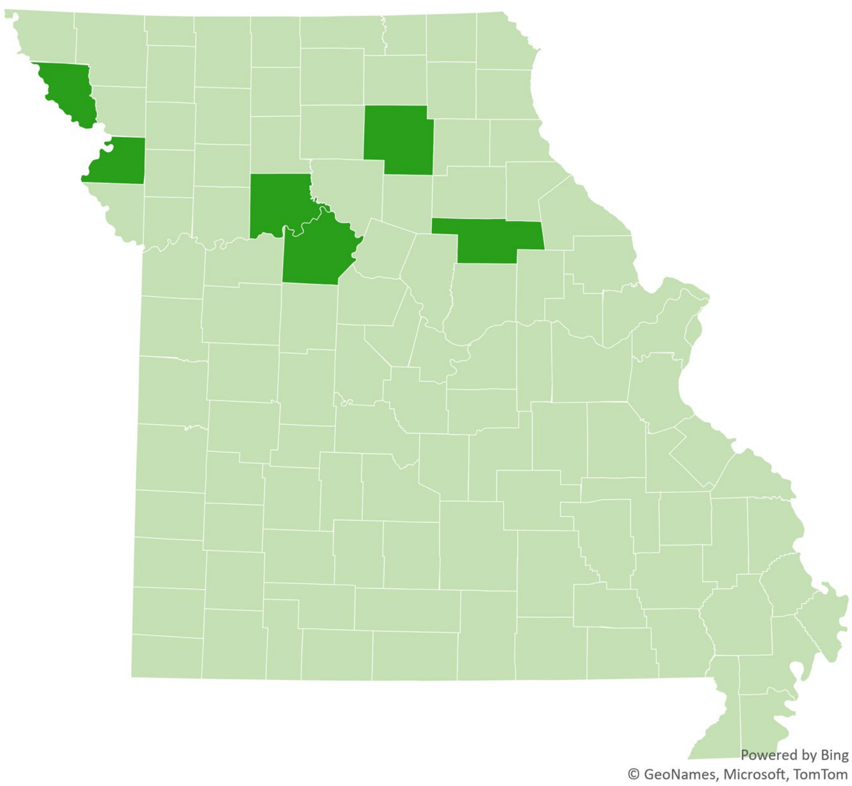


* 1 denotes county had at least one proposed renewable energy project

Ethanol plants

Ethanol plants generate a substantial amount of heat in the corn-to-ethanol conversion process. When efficiently captured, this heat could support the HVAC system in maintaining the optimal temperature within climate-controlled facilities. Capturing heat from ethanol production and transferring it to an enclosed growing chamber are not costless. Upfront (sunk) costs are involved, but the operating costs of pumping warm water through a heat exchanger will be less than the costs incurred to generate heat through conventional HVAC systems powered by gas or electricity. Exhibit 3.23 shades Missouri counties based on whether they have an ethanol facility. Counties with the dark green shading had at least one facility.

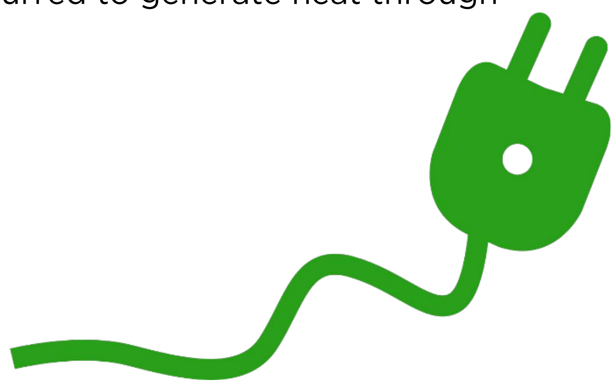
Exhibit 3.23. Missouri Counties with Ethanol Facility*



* 1 denotes county had at least one ethanol facility

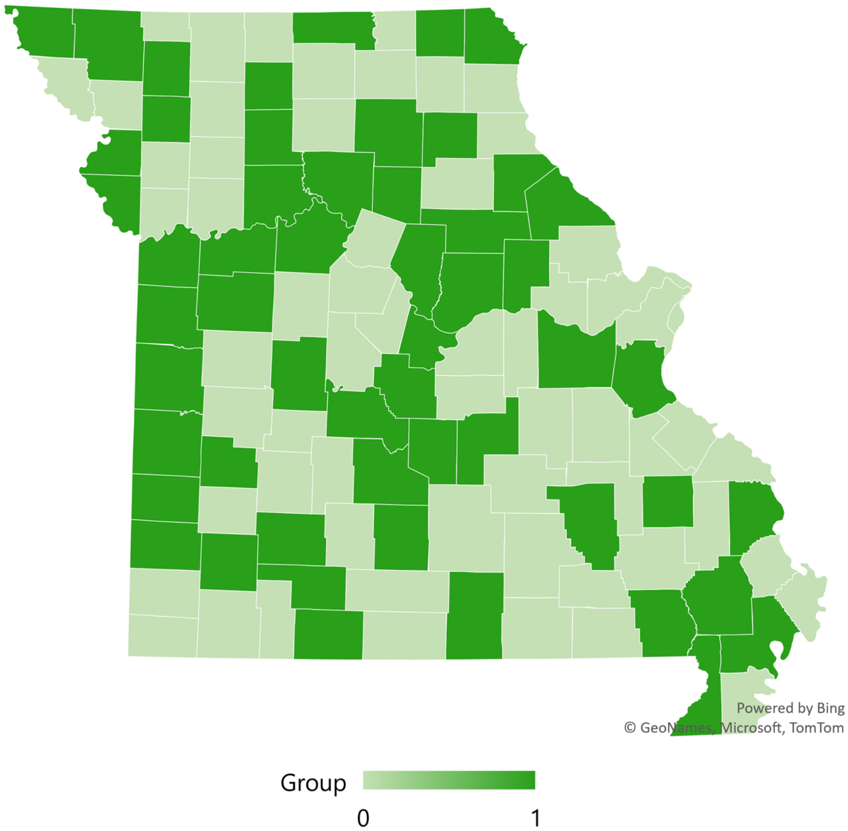
Power plants

Power plants generate two co-products — heat and carbon dioxide — that can be used in climate-controlled horticultural production to enhance plants' growth activity. American Ag Energy is co-locating greenhouses with power plants (igrownews.com/american-ag-energy-to-build-two-greenhouses-in-new-england). Capturing heat from power plant facilities and transferring it to an enclosed growing chamber are not costless activities. Upfront (sunk) costs are involved, but the operating costs of pumping warm water through a heat exchanger will be less than the costs incurred to generate heat through conventional HVAC systems powered by gas or electricity. Elevated levels of carbon dioxide enhance a plant's photosynthesis process, which leads to thicker leaves, faster growth and more production. Also, a vertical farming operation could add a carbon footprint measure to its marketing program to communicate how much carbon release is saved.



The U.S. Energy Information Administration provides an inventory of operating generators on its website. Exhibit 3.24 highlights counties according to whether they had at least one operating generator listed in October 2022. Darker green indicates counties with an operating generator.

Exhibit 3.24. Missouri Counties Grouped by Presence of Operating Generator*



* 1 denotes county had at least one operating generator

Composite Scores

A siting analysis combines location selection variables into a single metric that allows for side-by-side site evaluation. The analysis conducted for this project produced respective market- and production-side composite scores and an overall composite to suggest suitable site locations. The following discussion highlights the methodology and the siting analysis results.

Market analysis

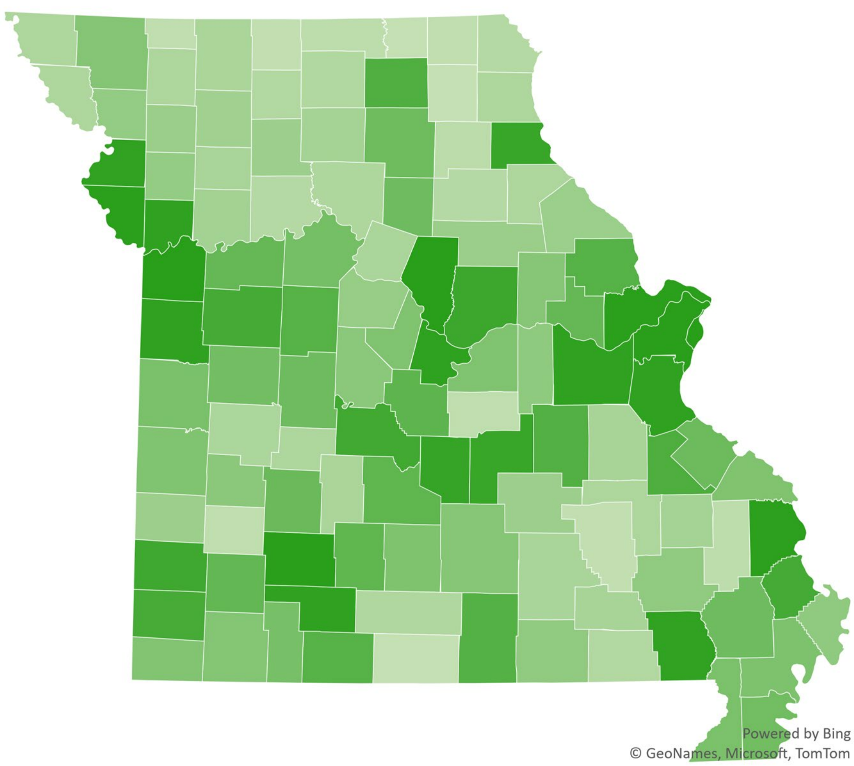
The market factors included in the siting analysis suggest the extent to which a county provides access to final and intermediary buyers with the purchasing behavior and potential to use products from a locally situated vertical farm. The siting analysis packages these factors in one metric by first assigning a weight to each factor and then applying the weight to the group values generated for each county. For the weights applied, see Exhibit 3.25.

Exhibit 3.25. Market Factors Considered in Vertical Farm Siting Analysis

Factor	Weight
Supermarkets and other grocery	34%
Restaurants and other eating places	20%
Highway access	15%
Food service contractors	10%
Food product consumption	10%
Population	5%
Per capita income	5%
Food insecurity	1%

Summing the weight-adjusted values produces the composite market scores for each county. Exhibit 3.26 maps Missouri counties by score. Here, the darker shading indicates that a county offers more conducive market access and, therefore, represents a better potential target from a market perspective.

Exhibit 3.26. Market Analysis Scoring by County*



* Darker colors represent counties scoring best from a market access perspective

The following counties ranked strongest from a market perspective.

- Boone
- Jackson
- St. Louis city
- Greene

- St. Louis County
- Platte
- St. Charles
- Cape Girardeau
- Cole
- Cass
- Christian
- Clay
- Franklin
- Jefferson

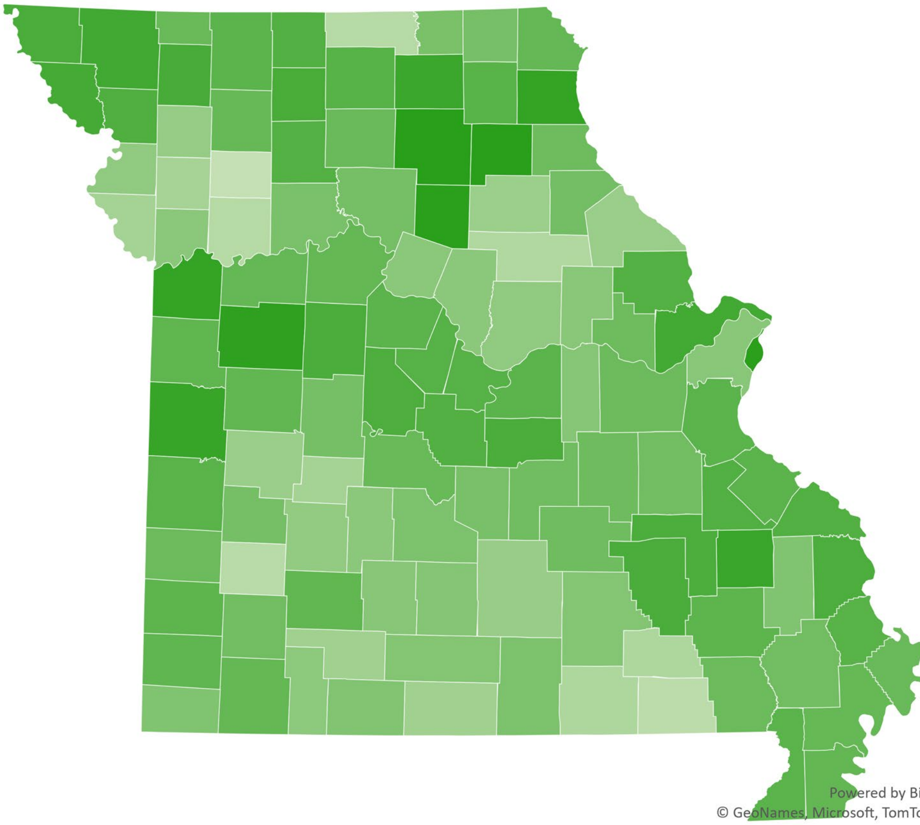
Production analysis
To assess how well a county offers a well-suited production environment, the siting analysis combines the 10 production factors listed in Exhibit 3.27 into a single metric. Collectively, these factors represent input cost variables, opportunities to align with co-products generated by other industries, workforce considerations and environmental criteria. The analysis aggregates these factors in one metric by first assigning a weight to each factor and then applying the weight to the group values generated for each county. Exhibit 3.25 lists the weights used in the analysis.

Exhibit 3.27. Production Factors Considered in Vertical Farm Siting Analysis

Factor	Weight
Electric rates	40%
Water rates	16%
Quality of life	10%
Broadband availability	10%
Unemployment rate	5%
Mean dew point	5%
Mean temperature	5%
Proposed renewable energy projects	3%
Ethanol plant access	3%
Power plant access	3%

Summing the weight-adjusted values produces the composite production scores for each county. Exhibit 3.28 maps Missouri counties by score. Here, the darker shading indicates that a county offers more conducive production environment for a vertical farm facility. Thus, these counties represent better potential targets from a production perspective.

Exhibit 3.28. Production Analysis Scoring



* Darker colors represent counties scoring best from a production resources perspective

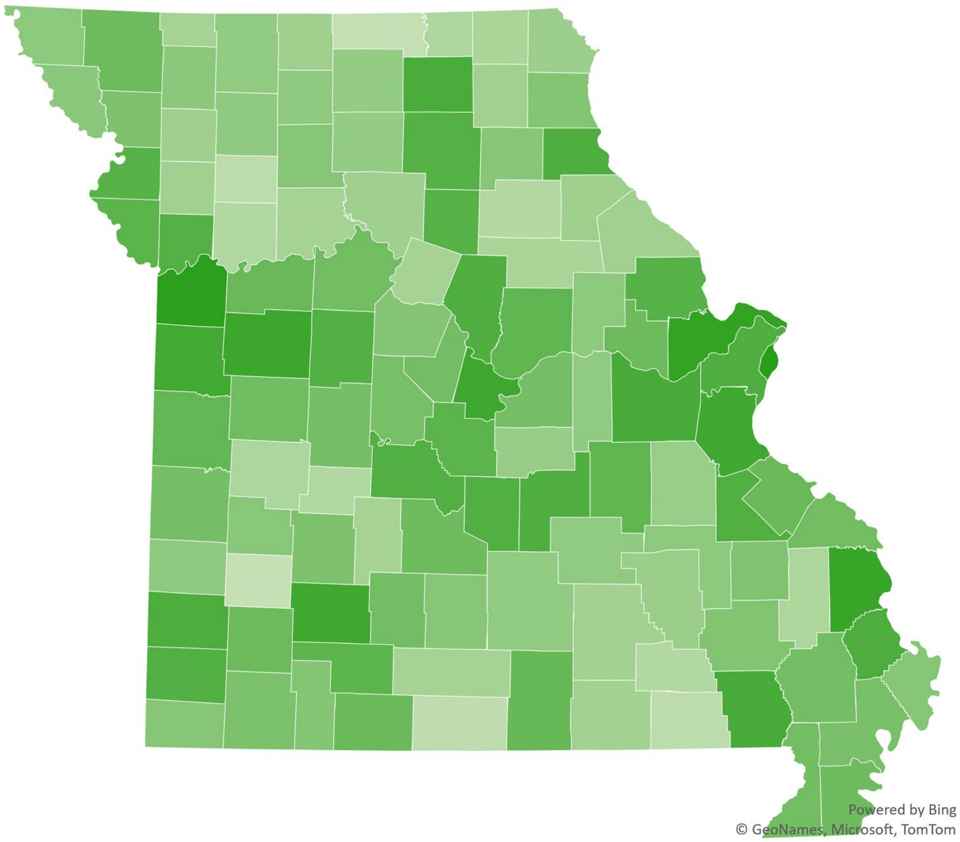
The following counties ranked strongest from a production perspective.

- Macon
- Shelby
- Randolph
- St. Louis city
- Johnson
- Lewis
- Jackson
- Bates
- Madison
- Adair

Overall composite

When a vertical farm operator considers a site, it will want to weigh the market and production factors simultaneously to identify a site that delivers on both supply- and demand-side characteristics. To do this, the analysis applied a 50% weight to the composite market score and a 50% weight to the composite production score. Exhibit 3.29 shares the results equally weighing the market analysis and production analysis composite scores.

Exhibit 3.29. Overall Composite Analysis Scoring



* Darker colors represent counties scoring best overall

The following counties ranked strongest in the overall composite analysis.

- St. Louis city
- Jackson
- St. Charles
- Cape Girardeau
- Johnson
- Cole
- Greene
- Jefferson
- Cass
- Franklin

Limitations

The siting analysis shared here does have limitations. For one, it narrowly focuses on evaluating Missouri counties for their fit with vertical farm market needs and production expectations. Therefore, the analysis used to group counties into categories only stems from in-state comparisons, not comparisons of Missouri locations relative to other locations in the U.S. or a particular region. Therefore, the findings from this analysis are most useful for a business or investor focused on exploring facility options in Missouri.

The analysis also focuses on a core set of location considerations — market- and production-side variables — but it may not capture all factors relevant in a siting decision. For example, real estate cost and availability will affect a facility's viability in a certain locale. However, this consideration wasn't included in the model due to 1) facilities having the choice to use existing infrastructure or build new and 2) incomplete data outlining county-by-county commercial real estate costs.

IV. Indoor Farming Supply Chain Optimization Model: St. Louis Case Study

Due to an interest in developing scale-appropriate vertical farms in the U.S. and because of the opportunity to focus on local production, this section broadens its scope of analysis to various indoor farming supply chains. Alternative size, and scope, of operation is considered. Small-scale production systems target niche opportunities in a localized market, and they are less capital-intensive. Although the economies of size of large-scale vertical farms offer promise to provide products into low-margin supply chains, high-margin supply chains offer more persons the opportunity to enter the market.

Case Study Data Request
The input data used for this case study are available upon request. Users may refer to these baseline values and adjust them as needed to fit their particular indoor farming projects. To request the input data, send a message via email to lihait@umsl.edu.

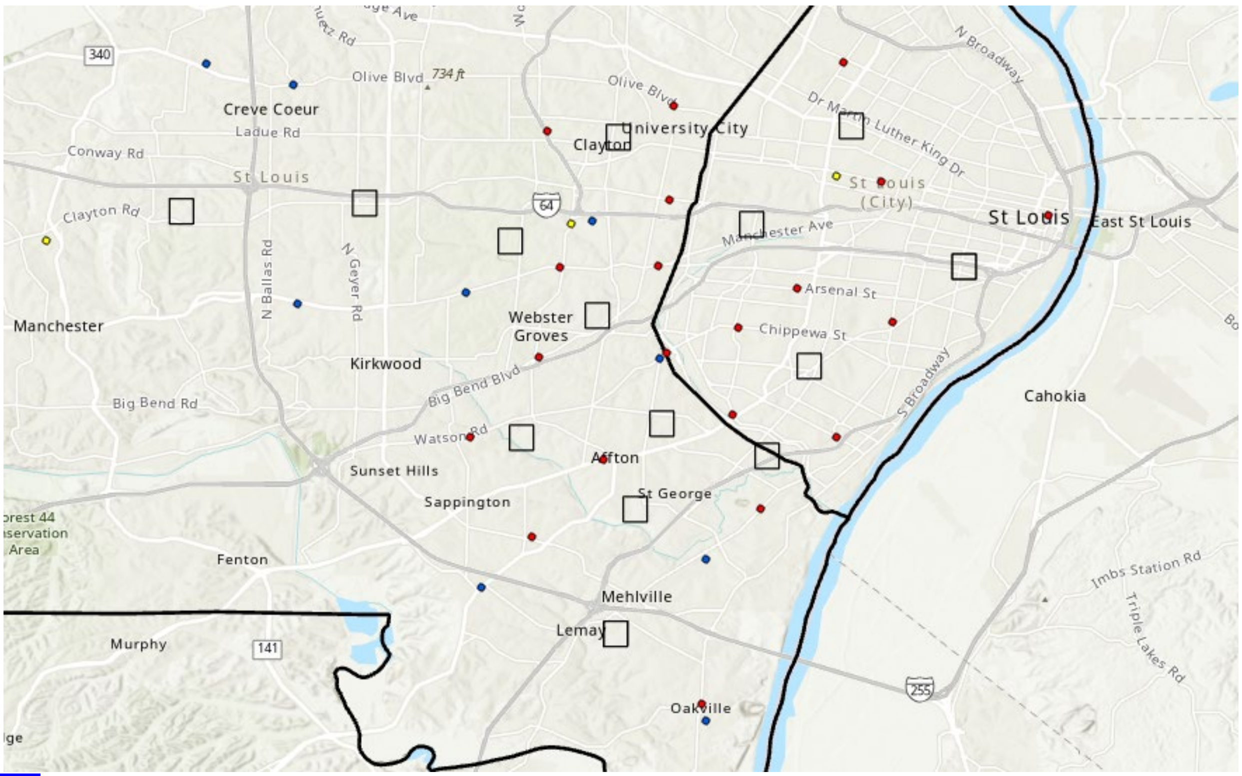
An indoor farming supply chain optimization model developed in this project provides data-driven decision-support for locating and configuring indoor farming facilities. It also informs the crop portfolio decision (i.e., what to grow and how much to grow) to meet a region's market demand. The model's objective is to maximize total net profit, measured as total revenue less costs for the fixed facility, variable operating expenses and transportation. The model can be updated and adjusted for different regions, crop portfolios and consumption patterns. The model considers and satisfies the following requirements:

- A candidate location can be selected to build an indoor farming facility, and if so, then the facility can be built with one configuration among multiple options that differ in size or capacity, fixed facility cost and variable operating cost.
- At the location where an indoor farming facility is built, the total available space to grow all types of produce cannot exceed the space allowed by a particular configuration.
- Each type of produce shipped out of a facility cannot exceed the quantity produced at the facility.
- The demand of each type of produce at each customer or retail store must be satisfied. For the produce being considered, the assumption of a sole-source supplier is common.

Overview of the Case Study

This case study focuses on an indoor farm named ABC Produce Farms, a start-up indoor farming operation in St. Louis. The farm states the following as its mission: We will produce and distribute fresh produce year-round to serve the local St. Louis community. As a start-up, ABC Produce Farms needs to strategically design its supply chain network to serve customers. Exhibit 4.1 shows 14 candidate locations for indoor farming facilities and 32 grocery stores (e.g., Dierbergs, Whole Food Markets, Schnucks) to be served.

Exhibit 4.1. Candidate Indoor Farm and Grocery Store Locations, Greater St. Louis



Blue: Dierbergs

Yellow: Whole Foods Market

Red: Schnucks

☐ Candidate Indoor Farming Locations

The CEO of ABC Produce Farms would like answers to these questions:

- How many farms are necessary to meet local demand, and where should they be located?
- What configurations (e.g., size and technology) should the farms have?
- What types of produce should be grown, and how much produce should each farm grow?
- What are the fixed and variable costs incurred to operate a farm and grow produce there?
- Would the farms break even and ideally generate a profit?

Input Data

The following data support the base scenario of the indoor farming supply chain optimization model.

Market demand

This study considers demand for produce well-suited to vertical farming: tomatoes, cucumbers, lima beans, okra, onions, turnip greens, romaine and leaf lettuce, kale and spinach. Demand represents total product quantity typically purchased within a given period for a given area. A product's demand is estimated to be the population multiplied by per capita consumption.

To derive per capita consumption, this analysis used average national per capita availability that USDA reported for 2020 as the starting value for each product. Per capita consumption could be approximated by adjusting availability for losses in the supply chain. For the current study, per capita availability was used because our interest is in levels of product transferred between producers and retail, institutional or wholesale buyers. Then, the starting values had marginal adjustments made to ensure the per capita consumption levels reflected typical product consumption in a region. This step is necessary because consumers in particular areas can have more or less affinity for a particular food product than the national average would suggest.

Exhibit 4.2 shows average per capita consumption values used. These values reflect the regional averages. Per capita consumption varies by individual consumer. However, for most foods, the cost-benefit ratio is too high to identify consumption behavior, quantity and location for each consumer. Regional averages sufficiently suggest per capita consumption and total estimated demand needed for scenario analysis and business planning.

Exhibit 4.2. Per Capita Produce Consumption Used in the Case Study

Produce Type	Per Capita Consumption (Pounds/Person/Year)
Tomatoes	30.00
Cucumbers	6.46
Lima Beans	0.21
Okra	0.51
Onions	17.60
Turnip Greens	0.25
Mustard Greens	0.35
Romaine And Leaf	11.96
Kale	0.78
Spinach	1.54

The demand at each retail store can be estimated as follows: average per capita consumption * 300,000 (population of St. Louis) * 0.01 (market share to represent reaching 1% of the population) / 32 (spread evenly among the retail stores considered in the case study).

Market prices

Based on the 2018 data from the USDA Economic Research Service, produce market prices considered in this case study are provided in Exhibit 4.3.

Exhibit 4.3. Produce Market Prices Considered in Case Study

Produce	Price ($/pound)
Tomatoes	1.98
Cucumbers	0.47
Lima Beans	0.47
Okra	2.42
Onions	0.57
Turnip Greens	0.97
Mustard Greens	1.36
Romaine And Leaf	3.60
Kale	1.48
Spinach	5.99

Source: USDA Economic Research Service (ers.usda.gov/data-products/fruit-and-vegetable-prices)

Facility types and configurations

Based on interviews with subject matter experts, the case study considered several types of farming facilities and their corresponding configurations in terms of size, technology, building cost per square foot and annual operating expenses. The operating expenses include insurance costs, legal services, professional services and office expenses. Exhibit 4.4 summarizes these facility options. To compute a facility's cost, multiply the cost per square foot by the facility's square footage. The Dutch bucket indoor plant factory or container farm model would use vertical production practices.

Exhibit 4.4. Candidate Types of Farming Facilities and Their Configurations

Facility Type	Square Footage	Building Cost ($/sq. ft.)	Operating Cost ($)	Technology
Greenhouse	10,000	28	61,951	Dutch Bucket Kit
Greenhouse	50,000	28	309,756	Dutch Bucket Kit
Greenhouse	100,000	28	619,513	Dutch Bucket Kit
Indoor Farming Facility	200	375	1,239	Dutch Bucket Kit
Greenhouse	10,000	37	61,951	Nutrient Film Technique (NFT)
Greenhouse	50,000	37	309,756	Nutrient Film Technique (NFT)
Greenhouse	100,000	37	619,513	Nutrient Film Technique (NFT)
Indoor Farming Facility	200	93	1,239	Nutrient Film Technique (NFT)
Container Farm	320	492	1,983	Nutrient Film Technique (NFT)
Greenhouse	10,000	38	61,951	Deep Water Culture (DWC)
Greenhouse	50,000	38	309,756	Deep Water Culture (DWC)
Greenhouse	100,000	38	619,512	Deep Water Culture (DWC)
Indoor Farming Facility	200	88	1,239	Deep Water Culture (DWC)

The model considers the annualized interest payments reported in Exhibit 4.5.

Exhibit 4.5. Annualized Interest by Facility Configuration

Facility Type	Annualized Interest
Indoor Plant Factory - Dutch Bucket	$168.98
Greenhouse 10,000 sq. ft. - Dutch Bucket	$8,448.90
Greenhouse 50,000 sq. ft. - Dutch Bucket	$42,244.49
Greenhouse 100,000 sq. ft. - Dutch Bucket	$84,488.98
Container Farm – NFT	$1,892.55
Indoor Plant Factory – NFT	$168.98
Greenhouse 10,000 sq. ft. - NFT	$8,448.90
Greenhouse 50,000 sq. ft. - NFT	$42,244.49
Greenhouse 100,000 sq. ft. - NFT	$84,488.98
Indoor Plant Factory - DWC	$168.98
Greenhouse 10,000 sq. ft. - DWC	$8,448.90
Greenhouse 50,000 sq. ft. - DWC	$42,244.49
Greenhouse 100,000 sq. ft. - DWC	$84,488.98

For indoor farms, water and energy are the two main variable cost factors. With respect to water, the cost is estimated to be $0.0087 per gallon in the case study. Usage has been approximated based on the values in Exhibit 4.6.

Exhibit 4.6. Water Consumption by Farm Facility Configuration

Facility Type	Water Consumption (Gal./Sq. Ft./Year)
NFT[5]	11.89
Dutch Bucket – Greenhouse[5]	24.57
Dutch Bucket – Indoor Plant Factory/Container Farm[5]	14.27
DWC	34.65

Energy cost is estimated to be $0.12 per kWH. Exhibit 4.7 reports estimated energy consumption per year. The following assumptions were used to approximate energy usage. The NFT and DWC scenario assumes energy use totals 11,000 kJ per kilogram per year, based on lettuce as the model crop. Yields are estimated at 41 kg per sq. meter per year. The Dutch bucket models assume energy is needed for fluorescent lighting, heating and cooling. The greenhouse model also requires energy for air fans, and the indoor plant factory or container operations use additional energy for ventilation. Note, water pumps are not required in Dutch bucket configurations.

Exhibit 4.7. Energy Consumption by Farm Facility Configuration

Facility Type	Energy Consumption (Kwh/Sq. Ft./Year)
NFT or DWC*[6]	11.64
Dutch Bucket – Greenhouse	31.97
Dutch Bucket – Indoor Plant Factory or Container Farm	424.30

* Assumes lettuce as a model crop

The study also accounts for labor expenses. The annual labor cost is estimated to be $12.09 per square foot.

[5] researchgate.net/publication/47866259_Water_use_efficiency_of_tomatoes_-_in_greenhouses_and_hydroponics; onlinelibrary.wiley.com/doi/full/10.1111/jwas.12819; researchgate.net/profile/Mithilesh-Singh-18/publication/361275103_Hydroponic_Agriculture_System_a_Potential_Solution_to_the_World's_Food_Shortage_A_Review/links/62a81b0a55273755ebeb33ac/Hydroponic-Agriculture-System-a-Potential-Solution-to-the-Worlds-Food-Shortage-A-Review.pdf; journals.sagepub.com/doi/full/10.1177/1178622121995819

[6] ncbi.nlm.nih.gov/pmc/articles/PMC4483736/#:~:text=Specifically%2C%20hydroponic%20lettuce%20production%20had,%2Fy%20(Figure%202).&text=Modeled%20annual%20water%20use%20in,southwestern%20Arizona%20using%20hydroponic%20vs

Yields

The yield estimates are based on subject matter expert input and other sources[7]. Yields in NFT systems are assumed to be four times greater than yields in DWC systems because usually four vertical racks are available in NFT. Exhibit 4.8 shows estimated yields for crops considered in this case study. N/A indicates a crop is usually not grown in a particular configuration.

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[7] canr.msu.edu/uploads/files/Table%204.pdf

Exhibit 4.8. Estimated Crop Yields (lb./sq. ft./year)

	Tomatoes	Cucumbers	Lima Beans	Okra	Onions	Turnip Greens	Mustard Greens	Romaine & Leaf	Kale	Spinach
Dutch Bucket										
Indoor Plant Factory	20	10	0.5	2.7	N/A	N/A	N/A	N/A	N/A	N/A
Greenhouse, 10,000 Sq. Ft.	20	10	0.5	2.7	N/A	N/A	N/A	N/A	N/A	N/A
Greenhouse, 50,000 Sq. Ft.	20	10	0.5	2.7	N/A	N/A	N/A	N/A	N/A	N/A
Greenhouse 100,000 Sq. Ft.	20	10	0.5	2.7	N/A	N/A	N/A	N/A	N/A	N/A
Nutrient Film Technique										
Container Farm	N/A	N/A	N/A	N/A	36.8	116	116	72.6	116	116
Indoor Plant Factory	N/A	N/A	N/A	N/A	36.8	116	116	72.6	116	116
Greenhouse, 10,000 Sq. Ft.	N/A	N/A	N/A	N/A	36.8	116	116	72.6	116	116
Greenhouse, 50,000 Sq. Ft.	N/A	N/A	N/A	N/A	36.8	116	116	72.6	116	116
Greenhouse, 100,000 Sq. Ft.	N/A	N/A	N/A	N/A	36.8	116	116	72.6	116	116
Deep Water Culture										
Indoor Plant Factory	N/A	N/A	N/A	N/A	9.2	29	29	18.15	29	29
Greenhouse, 10,000 Sq. Ft.	N/A	N/A	N/A	N/A	9.2	29	29	18.15	29	29
Greenhouse, 50,000 Sq. Ft.	N/A	N/A	N/A	N/A	9.2	29	29	18.15	29	29
Greenhouse, 100,000 Sq. Ft.	N/A	N/A	N/A	N/A	9.2	29	29	18.15	29	29

Demand fulfillment costs
Distributing produce from farms to markets is considered at the strategic level, assuming all produce ships using refrigerated trucks — known as reefers — with no more than 40,000 lb. per truckload. In the Midwest, reefer costs are about $4.03 per mile[8]. Note that operational-level route planning and fleet scheduling decisions are not considered. Thus, the indoor farming supply chain optimization model conservatively estimates the transportation costs.

Base Scenario Results
The optimal supply chain of the base scenario consists of one 10,000-sq.-ft. greenhouse with the Dutch bucket kit technology, one indoor farming facility with DWC and 10 indoor farming facilities with NFT — in total, 12 facilities.

Exhibit 4.9 shows the economic performance of the supply chain. Annual revenue totals $384,130, and costs total $391,742, resulting in a loss of $7,612.

Exhibit 4.9. Economic Performance of the Optimal Supply Chain

Total Revenue	$384,130.24
Fixed Facility Costs	$124,435.31
Operating Costs	$119,454.40
Labor Costs	$147,498.00
Transportation Costs	$354.78
Total Costs	$391,172.49
Total Profit	-$7,612.25

As mentioned earlier, the optimization approach is data-driven, so the model used for this case study could be customized for other unique case studies. To customize the model, a user would simply replace the input data to generate a corresponding solution and insights.

What-if Analysis Results
According to the base scenario results, ABC Produce Farms is close to break-even. The CEO would like to know whether there is any opportunity to improve it. Thus, she asks the following questions:

- What if the company reduces the fixed facility cost or the labor cost?
- What if market prices for produce increase?
- What if the company would like to scale its operation by increasing its market share (i.e., demand quantity)?

A sensitivity analysis — or what-if analysis — can address these questions and generate insights regarding how changing input data (i.e., fixed facility cost,

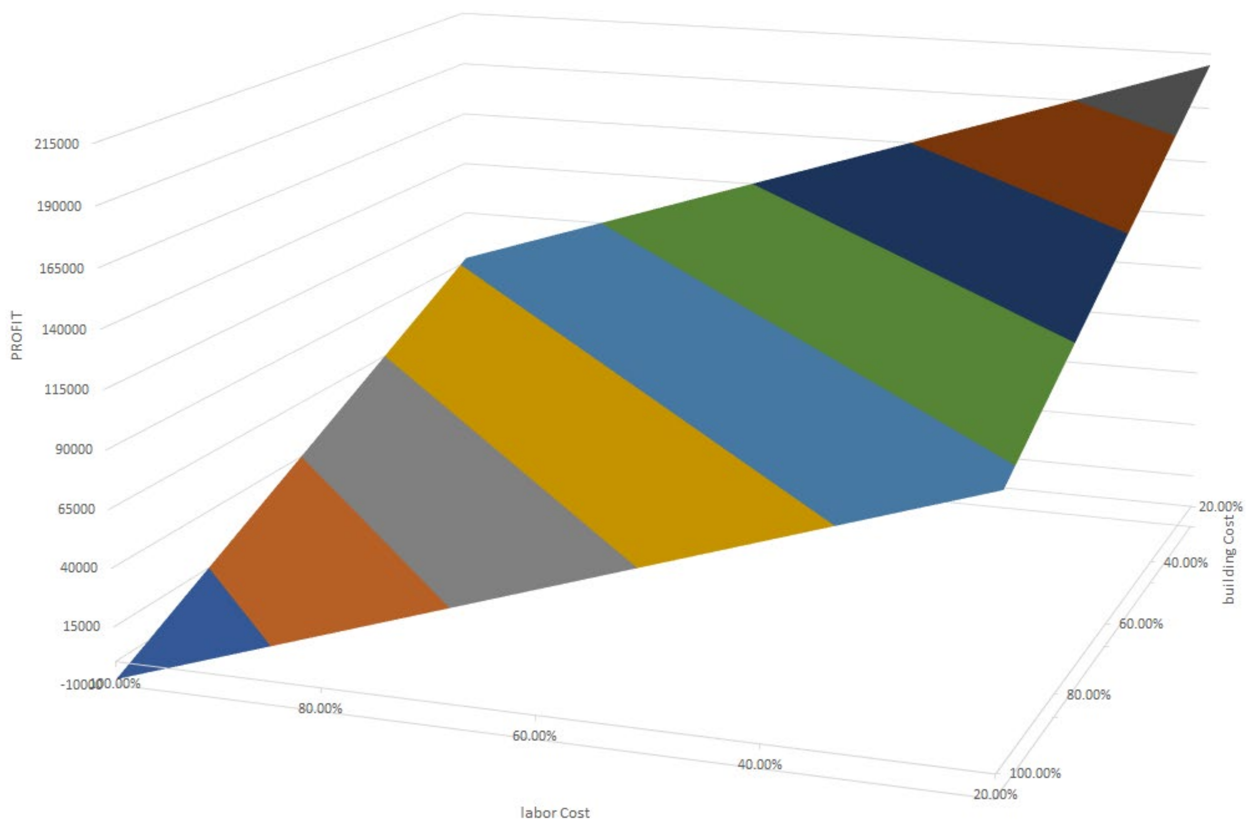
[8] Based on DAT Freight & Analytics: tcicapital.com/tci-insights/current-freight-trends

labor cost, market prices and market demand) affects the optimal solution and objective function value.

Effect of costs

Exhibit 4.10 shows how total profit changes when fixed facility cost and variable operating cost vary. Total profit increases at a constant rate with respect to the percentage of reduction in either fixed facility cost or variable operating cost. The company reaches about $110,000 in profit if it can reduce both costs by half.

Exhibit 4.10. Effect of Fixed Facility and Labor Costs on Optimal Total Profit



Effect of market price

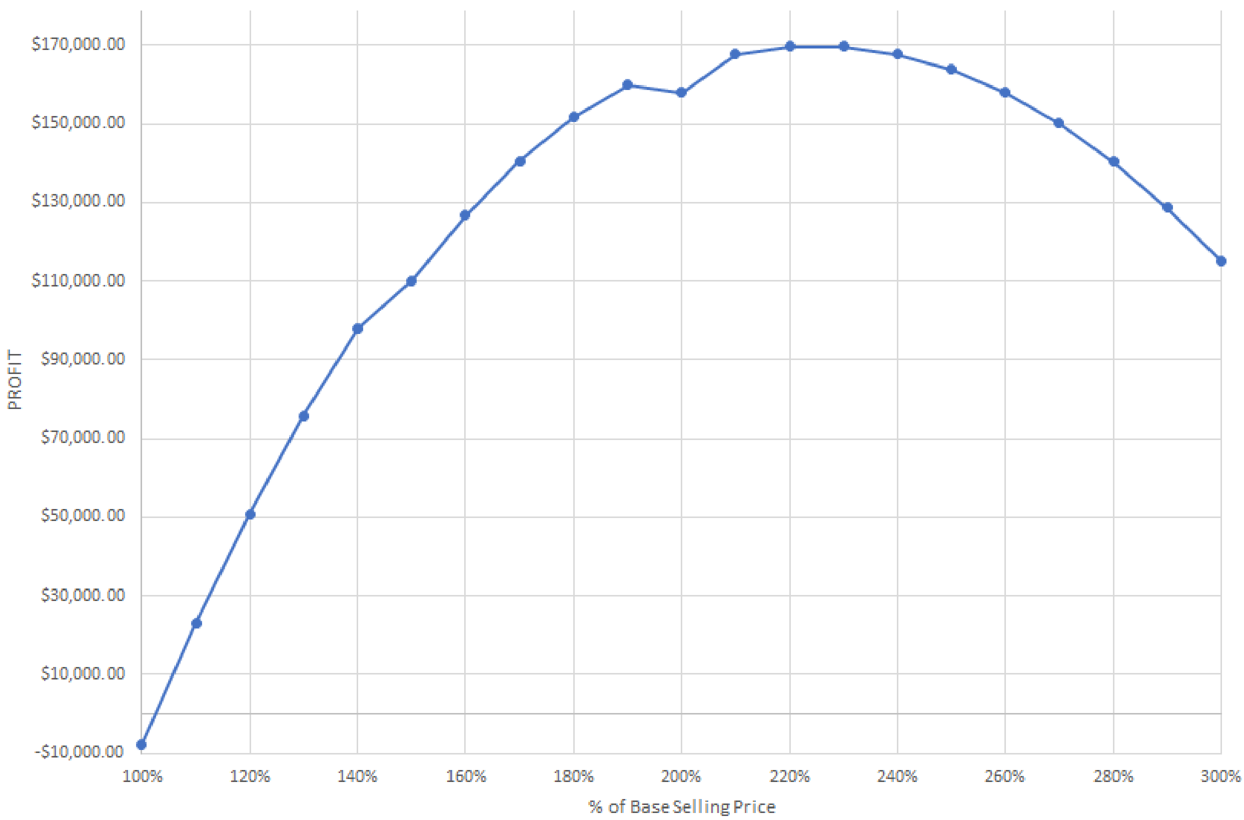
To analyze the effect of market price, we first obtain estimates of the price elasticity of demand as shown in Exhibit 4.11, which measures the percentage of change in demand given a 1% change in price.

Exhibit 4.11. Price Elasticity of Demand for Produce

Produce Type	Price Elasticity of Demand
Tomatoes	-0.28
Cucumbers	-1.00
Lima Beans	-0.15
Okra	-0.91
Onions	-0.99
Turnip Greens	-0.422
Mustard Greens	-0.422
Romaine & Leaf Lettuce	-0.28
Kale	-0.422
Spinach	-0.35

As shown in Exhibit 4.12, optimal total profit increases with the market price of all produce at a decreasing rate (diminishing return). For instance, a slight price increase of about 4% will enable the company to break even. A 50% price increase will result in a profit of $110,000. Then, due to diminishing returns of market price on total profit (i.e., decreased demand in response to price increase) further increasing price may reduce the total profit if an excessively high price leads to demand shrinking significantly.

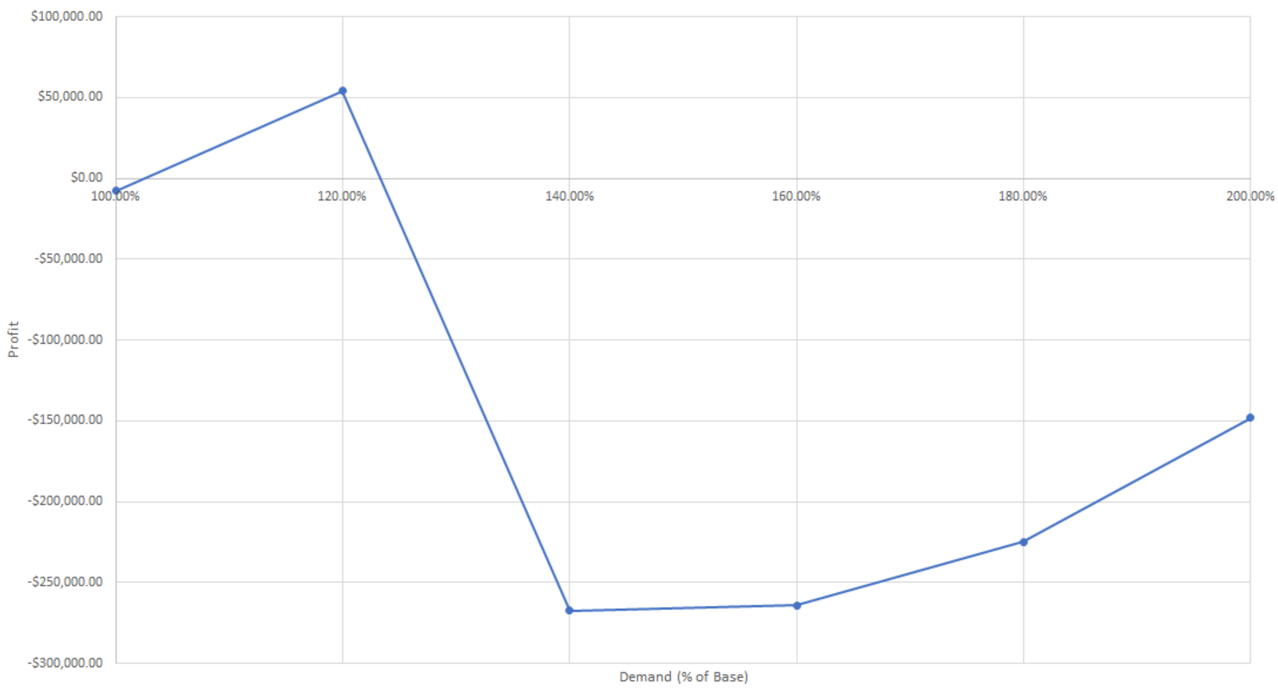
Exhibit 4.12. Effect of Market Price on Optimal Total Profit



Effect of market demand

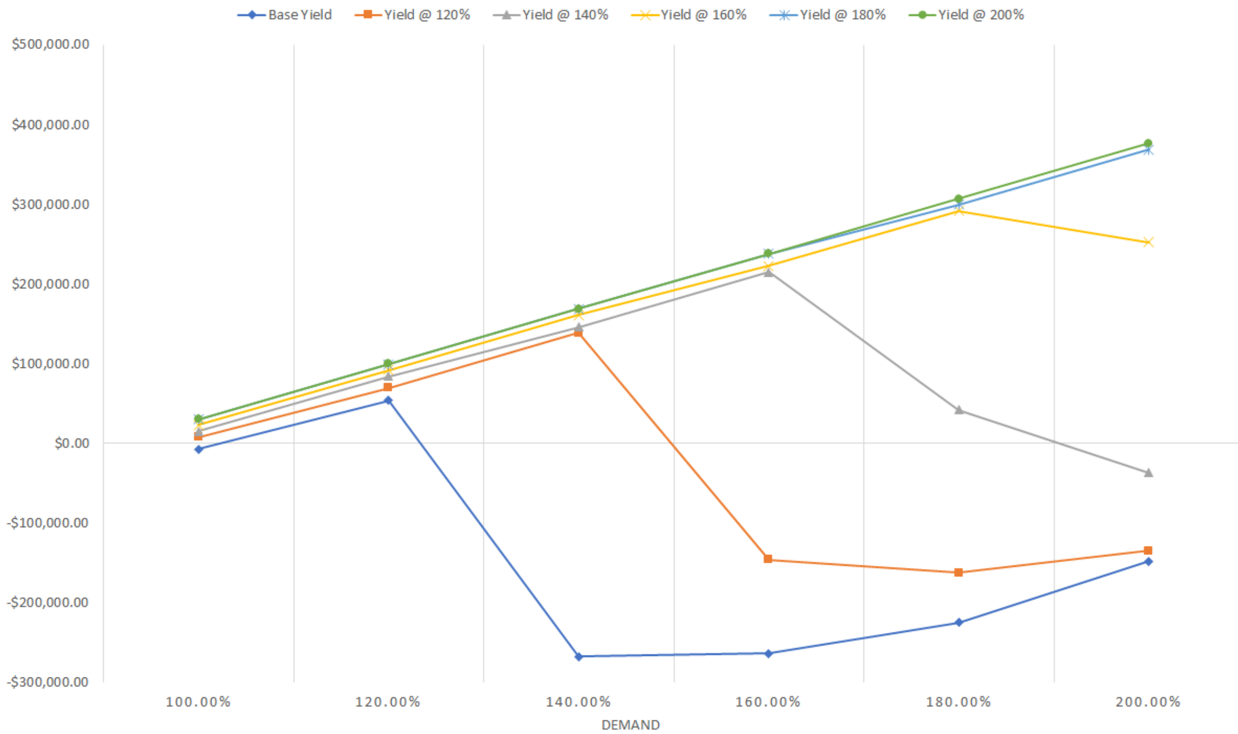
Exhibit 4.13 shows the effect of market demand on optimal total profit, assuming the price stays the same. Note that total profit does not always increase with market demand, though an initial demand increase of about 3% will enable the company to break even. A 20% increase of demand will achieve a total profit of $50,000. Further increasing demand by 40%, however, leads to significant profit drop and a loss of more than $250,000. This is due to the significant fixed building cost and annual operating cost needed for scaling. In order to meet more demand, the company needs to build or establish more facilities, which add to fixed facility and operating costs and may outweigh the gain in total revenue made possible by producing and selling more. In our scenario, though an additional demand increase can reduce the loss, the company will fall far from break even — even if the production and sales double.

Exhibit 4.13. Effect of Market Demand on Optimal Total Profit



Given that increasing market demand alone does not necessarily improve total profit, how can ABC Produce Farms successfully scale? To answer this question, we vary market demand and yield simultaneously in another sensitivity analysis. Exhibit 4.14 shows the results. Note that when yields of all crops increase by 20%, the company will be to meet a 40% demand increase and gain profit. When the yields increase by 40% or 60%, more demand can be supported and enable the business to increase profit. Further yield increases will facilitate successful, smooth scale of operations.

Exhibit 4.14. Effect of Market Demand and Yield on Optimal Total Profit



Case Study Summary

The indoor farming supply chain optimization model provides data-driven decision support for indoor farming start-ups to plan their supply chain networks and product portfolios and maximize net profit. It considers crop yields; farm-level costs, including fixed facility cost and variable operating costs such as labor and energy; distribution cost; and market factors including demand and price. These factors are used as input data to the model.

The data-driven model is applicable for any start-up in any region or any operating and market scenario with customized input data. The suite of sensitivity analysis (what-if analysis) provides a playbook for start-ups to obtain analytical solutions to optimize supply chain and production decisions and understand the impacts of varied key input data on the optimal solution.

The case study and sensitivity analysis demonstrate the scope and capability of the indoor farming supply chain optimization model. The findings offer the following insights for practitioners:

- *Reducing the fixed facility cost and variable operating cost* (e.g., labor, energy) is an effective means to improve profitability. This can be achieved by proper facility-level production and resource planning.
- *Increasing market prices may benefit profitability but with diminishing returns*. This motivates firms to improve reputation and competitiveness

in the market, though the benefit of these marketing activities will decline when the price reaches a high level.

- *Growing demand or market share does not necessarily improve profitability*, which may feel counterintuitive. Without improving other operational aspects such as reducing costs, increasing prices or boosting yield, attempting to meet more demand might significantly reduce profit or even trigger a loss because satisfying more demand increases facility and operating costs. This partially explains why most indoor farming start-ups face challenges as they scale. The analysis shows that if crop yields improve simultaneously with demand, then profitability can increase as demand — and market share — strengthen.

Limitations of Case Study

The current indoor farming supply chain optimization model has several limitations. First, indoor farming technologies are considered at a high level without addressing implementation of various technologies at the operational level (e.g., lighting, layout schemes) and their effects on yield and cost. Second, in the current model, the production side is static in nature, which does not capture the problem's dynamic features (e.g., growing cycles, demand and price seasonality). Third, produce distribution or transportation is considered at a high level without addressing different types of truckloads and number of trips needed. Moreover, the current model assumes all input data are deterministic using their point estimates (means or averages), which does not account for the impact of uncertainty prior to obtaining solutions.

From the modeling perspective, the indoor farming supply chain optimization model can be improved and extended in the following ways:

- Consider innovative controlled-environment agriculture technologies and practices with their effects and tradeoffs on yield and cost.

- Consider growing and harvest planning decisions in a multiperiod setting, which also captures variation in market conditions.

- The environmental impact of different growing methods and operations (e.g., carbon emission) can be considered.

- The deterministic model and method can be extended to explicitly account for uncertainty of yield, demand and price, using various methodologies in stochastic optimization.

From the application perspective, there is a need to develop a data-driven decision-support tool that integrates the data environment in an easy-to-understand graphic user interface. The indoor farming supply chain optimization model would serve as the backend engine of the tool. We would also like to reach out to potential tool users and ask them to test it.

V. Potential Economic Impact of Missouri Vertical Farming Industry

As an industry, controlled-environment agriculture has the potential to trigger positive economic impact in multiple ways, such as:

- Produce food year-round in enclosed facilities,
- Lead to higher yields than alternatively grown crops could achieve and
- Have the potential to capture higher retail prices for products.

This report chapter estimates a St. Louis-region indoor, controlled-environment farming operation's potential economic impact to Missouri.

Economic Impact of an Optimized Indoor Farming Operation

This project modeled two similar but different outcomes. The results of this economic impact analysis reflect a different set of outcomes than those presented in the case study section. For convenience, both the case study and economic impact analysis focused on the St. Louis region.

This analysis assumes a controlled-environment farm business would consist of one 10,000-sq.-ft. greenhouse, two 320-sq.-ft. container farms and seven 200-sq.-ft. indoor plant factories. To construct these 10 facilities, which would provide 12,040 sq. ft. of space, an initial investment of $361,200 is estimated to be required. It is assumed this investment is financed over a seven-year period through business loans. This investment includes building construction and equipment purchases required to produce fruits and vegetables.

The business would employ 2.5 individuals — likely part- and full-time staff including the proprietor — at a cost of $145,563 annually. Annual input costs of $228,306 for materials, services, utilities and other items would be required. The indoor farming business is assumed to generate $384,104 in annual sales.

Expected gains in jobs, income and other measures would primarily benefit St. Louis City and St. Louis County; however, the ripple effects would extend beyond these borders to benefit surrounding communities. To illustrate these impacts, Exhibit 5.1 highlights the expected economic benefits to St. Louis City and St. Louis County and the rest of Missouri. The table also presents totals for both areas.

Exhibit 5.1. Economic Impact Summary

St. Louis Region (City and County combined)

Impact	Jobs	Labor Income	GDP	Output
Direct	2.5	$145,563	$155,824	$384,130
Intermediate	1.2	$74,156	$133,933	$247,247
Induced	0.8	$49,636	$85,217	$142,224
Totals	**4.5**	**$269,355**	**$374,974**	**$773,602**

Rest of Missouri

Impact	Jobs	Labor Income	GDP	Output
Intermediate	0.1	$2,608	$4,500	$11,040
Induced	0.2	$10,072	$18,558	$33,961
Totals	**0.3**	**$12,680**	**$23,058**	**$45,001**

Total Missouri

Impact	Jobs	Labor Income	GDP	Output
Direct	2.5	$145,563	$155,824	$384,130
Intermediate	1.3	$76,764	$138,433	$258,287
Induced	1.0	$59,709	$103,775	$176,185
Totals	**4.8**	**$282,036**	**$398,032**	**$818,602**

Note: All money figures in 2023 dollars to adjust for inflation

For every $100,000 in sales, the indoor farming business would create 1.25 jobs, $73,422 in labor income and $103,619 in GDP when indirect effects are considered.

For every *$100,000* in Missouri sales:

1.25 jobs are created.

$73,422 is generated in labor income.

$103,619 is contributed to GDP.

Direct effects represent the annual operation of the indoor farming business, which requires labor, supplies and loan repayments from initial start-up investments. These direct activities will support 2.5 jobs and $145,563 in labor income in St. Louis City and St. Louis County. Annual sales of $384,130, in 2023 dollars, is expected to generate $155,824 in new local gross domestic product (GDP).

Intermediate effects estimate the impacts to supply chains needed to provide materials, equipment and services. Analysis shows supply-chain ripple effects would largely be felt in the St. Louis region — with only 0.1 of the 1.3 total jobs indirectly supported beyond its border. Missouri supply-chain jobs are found in hundreds of industries such as real estate, wholesale goods, transportation and other services. Exhibit 5.2 highlights the top industries for supply-chain jobs in Missouri.

Exhibit 5.2. Top 10 Intermediate Industries, by Job Supported

IMPLAN Industry	Jobs
Other real estate	0.4
Support activities for agriculture and forestry	0.3
Commercial and industrial machinery and equipment rental and leasing	0.08
Full-service restaurants	0.07
Hospitals	0.07
Limited-service restaurants	0.06
Greenhouse, nursery and floriculture production	0.06
Wholesale - Other nondurable goods merchant wholesalers	0.05
Services to buildings	0.05
Employment services	0.05

In the St. Louis region, the top supply-chain jobs are expected in other real estate services (e.g., property financing, rental and leasing); support activities for agriculture and forestry; and machinery and equipment rental and leasing. Outside of St. Louis, top supply-chain jobs were in greenhouse, nursery and floriculture production; limited- and full-service restaurants; and hospitals.

Induced effects measure household spending from workers at the indoor farming operation and its supply-chain businesses. A total of one Missouri job — a sum of partial employment in multiple industries due to worker spending — is supported primarily in the St. Louis region.

As with supply-chain industries, jobs supported by worker household spending are found in many industries. Exhibit 5.3 highlights the top-employing industries supported by this additional household spending. Both within the St. Louis region and beyond, the top induced jobs are expected in hospitals, restaurants and individual and family services.

Exhibit 5.3. Top 10 Missouri Household Spending (Induced) Industries, by Job Supported

IMPLAN Industry	Jobs
Hospitals	0.18
Limited-service restaurants	0.14
Full-service restaurants	0.13
Individual and family services	0.1
Offices of physicians	0.08
Other real estate	0.07
Retail - General merchandise stores	0.07
All other food and drinking places	0.06
Retail - Food and beverage stores	0.06
Junior colleges, colleges, universities and professional schools	0.06

Tax Benefits of Indoor Farming Activities

In addition to positive economic impacts associated with indoor farming, county, city and state taxes benefit as well. Tax benefits include additional income, sales, property and other taxes collected by local and state governments. The IMPLAN economic model estimates taxes[9] using U.S. Census Bureau and Bureau of Economic Analysis data.

Exhibit 5.4 shows the expected annual fiscal benefits of the proposed facilities. Combined county and city tax benefits of roughly $12,000 are expected for communities in St. Louis City and St. Louis County. Other local communities within Missouri would gain $1,304 in tax revenues, and $11,113 in new state tax revenue would also be expected.

Exhibit 5.4. Tax Benefits

Area	County/City Taxes	State Taxes
St. Louis area	$11,973	$10,008
Rest of Missouri	$1,304	$1,105
Total Missouri	$13,277	$11,113

Note: Figures in 2023 dollars to adjust for inflation.

Methodology

The economic impact analysis used estimates from an input-output economic model, called IMPLAN, that the project team modified based on data collected from research partners. IMPLAN data are updated annually from

[9] Tax estimates are primarily based on U.S. Census Bureau state-level data on sales, income, property and other taxes that are allocated to counties using a variety of factors. Due to this tax allocation process, IMPLAN figures should be considered a broad estimate that does not include specific local taxing district figures or potential fiscal expenditures associated with an economic activity that can decrease tax benefits.

three main sources: the U.S. Bureau of Labor Statistics, Bureau of Economic Analysis and Census Bureau.

Economic models track the flow of spending that moves around an economy through primary relationships between businesses and consumers. Models consider what companies typically purchase to produce goods or services, where those companies are located and how workers spend the income they earn from making consumer products and services. The models follow these spending patterns to understand the larger economic impacts that circulate within a region and to what extent income leaks out due to imports.

Regional Spending Effects
Spending effects describe how a business' final sales (direct effect) cause money to flow to regional supply chains and consumer-oriented firms (indirect effects) to support additional jobs, wages, profits, taxes and so forth. These spending impacts can be broken out by direct, indirect and total effects.

Direct effects include the revenue, wages and jobs that come from selling a product or service for consumption. For an indoor farming operation, this includes the sales of packaged produce such as lettuce. To make these sales, the business owners invest in buildings, equipment and technology; buy supplies and services; and employ full- and part-time workers. Direct effects drive the other indirect effects in a region's economy.

Indirect effects are the ripple impacts of spending in a region that have two parts:

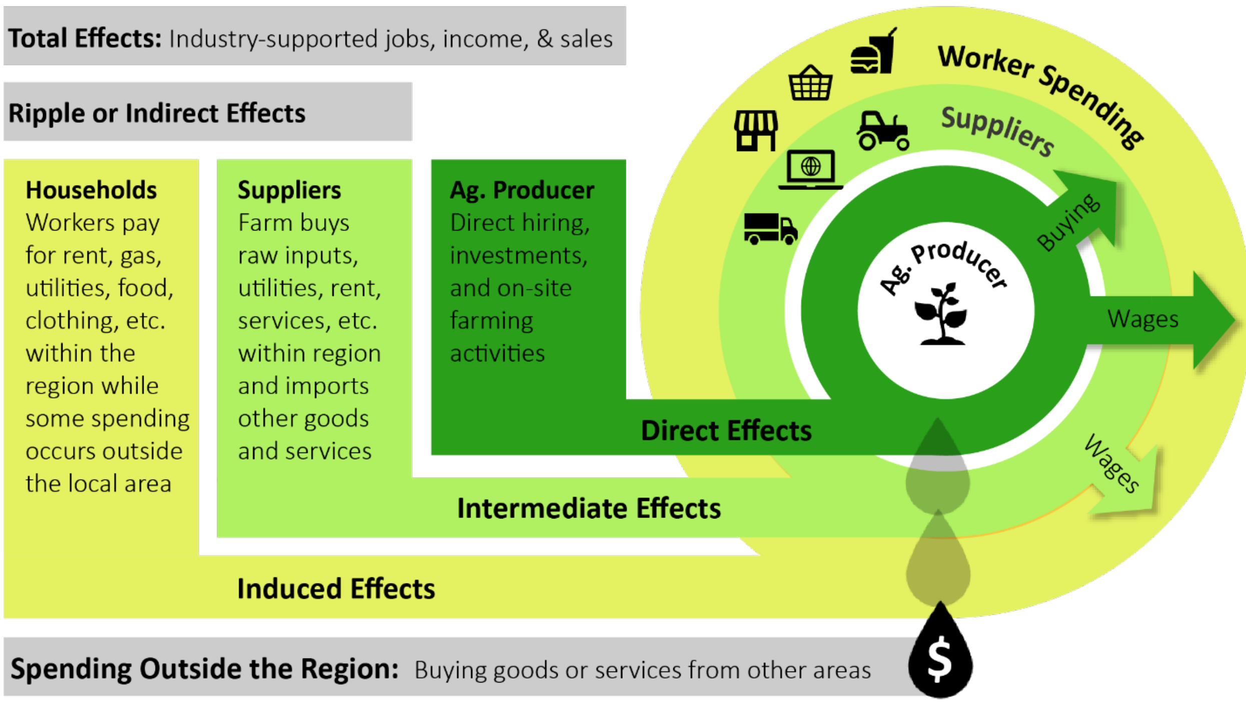
- **Intermediate effects** are impacts from supply-chain purchases. For example, an indoor farming operator buys fertilizer from a wholesaler, which purchased the refined materials from a processor that purchased raw materials from a mine and so on. At each step in the supply chain, some purchases are made outside the region, state or country for specialized inputs or price considerations. That spending leaks out of the region during each cycle of purchasing.

- **Induced effects** capture the household spending of individuals who own and work for an indoor farm or its suppliers. For example, the owners purchase groceries and clothing in the local economy. Just like suppliers, workers spend some of their income outside the region for goods and services such as travel, online purchases and specialized goods.

Total effects combine the direct effect of jobs and income from a business or industry with the indirect effects of supplier and household spending within the region; these effects support additional employment and wealth.

The diagram of spending flows in Exhibit 5.5 further illustrates the regional spending ripple effect that input-output models describe.

Exhibit 5.5. Economic Input-Output Model of Spending Flows: Controlled-Environment Agriculture Example



Economic Analysis Terms

The IMPLAN model shows how direct spending can have monetary and labor ripple effects that benefit businesses and workers in a community. Key spending effect figures include:

- **Gross output** (or **total sales**) estimates the total value of all sales, including the input cost of making a good or service along with the money received when that product is sold for final use.
- The **value-added** part of total sales (or **final sales**) is comparable to GDP. Value-added deducts the cost of goods and services from total sales to show what new money is left to pay wages, profits, rents, interests and taxes.
- **Labor income**, which captures wages, benefits and owner pay, is a part of the value-added impact. It represents all spending, including health,

retirement and other benefits, directed to workers and income earned by proprietors.

- Jobs estimates annual average full- or part-time jobs needed for business operations.

Economic Model Limitations

Although IMPLAN is an excellent tool for understanding spending impacts, input-output models have some underlying limitations, including these:

- No supply constraints: The model assumes no supply constraints on products, services or labor that would alter inputs needed by an industry. Although the model can be adjusted if specific constraints are known, rarely will such detailed industry information be available, and those constraints can change periodically depending on broader economic conditions.

- Static input structure: The model is based on national survey information and assumes that the type and ratio of inputs needed by an industry are fixed. The model also assumes a constant return to scale and technology use.

- Backward-linked structure: The model considers an industry's input supply chain effects and does not account for forward-linkage effects such as sales cannibalization from existing businesses.

Economic Model Adjustments for this Study

Several steps allowed for adjusting the input-output model used in this study. Model adjustments, which were based on research and consultation with subject-matter experts, included the following:

- Create an "indoor farming" industry by adjusting IMPLAN's "greenhouse, nursery, and floriculture production" industry using assumptions from industry and subject-matter experts. IMPLAN contains 546 industries that largely correspond with North American Industrial Classification System (NAICS) codes but does not list a category for indoor, vertical or controlled-environment agriculture.

- Modify job, sales and input information for IMPLAN's "greenhouse, nursery and floriculture production" industry based on input provided by Juan Cabrera-Garcia, Ryan Milhollin and other project team members.

- Model supply-chain inputs and labor income impacts separately, so information could be customized to reflect the impact of indoor farming in the St. Louis area. This was necessary to produce more accurate modeling as information including indoor farming operations' income and input costs as a share of gross sales differed from the baseline values reported for the standard "greenhouse, nursery and floriculture production" industry found in the model. For example, indoor farming facilities typically utilize half the water and seven times the electricity of a traditional greenhouse.

Exhibit 5.6 highlights the "greenhouse, nursery and floriculture production" industry inputs that the project team modified in IMPLAN to better reflect the indoor farming industry.

Exhibit 5.6. Industry Spending Pattern Input Adjustments

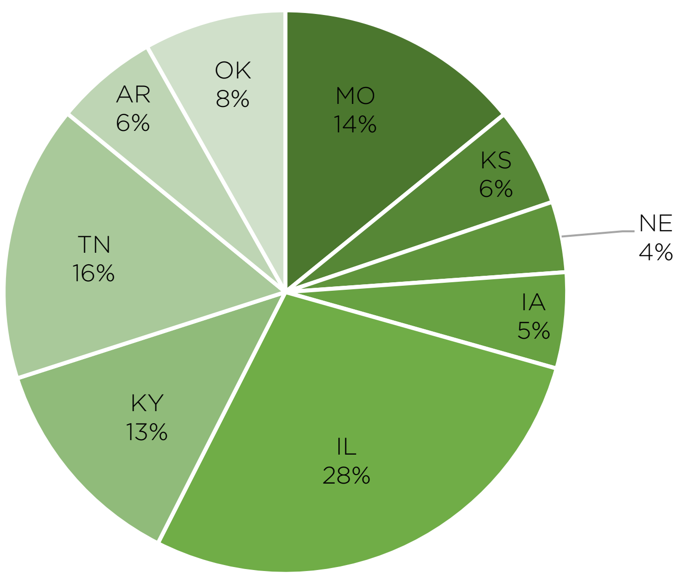
Commodity	Greenhouse, nursery and floriculture production *IMPLAN model inputs (Not adjusted)*	Indoor farming production *IMPLAN model inputs (Adjusted)*
Support activities for agriculture and forestry	12.14%	18.29%
Electricity transmission and distribution	0.30%	2.18%
Natural gas distribution	2.56%	0.00%
Water, sewage and other systems	0.32%	0.13%
Maintained and repaired nonresidential structures	0.70%	1.82%
Other basic inorganic chemicals	0.09%	0.07%
Nitrogenous fertilizer	2.51%	1.16%
Phosphatic fertilizer	2.17%	0.55%
Pesticides and other agricultural chemicals	3.73%	0.00%
Other real estate services	6.81%	34.67%
Commercial and industrial machinery and equipment rental and leasing services	2.60%	13.23%
Leasing of nonfinancial intangible assets	0.04%	0.18%
Other computer-related services, including facilities management services	0.12%	0.09%

Appendix A: Consumer Preferences for Foods Raised in Vertical Farms

Consumer preferences drive food purchase decisions. Therefore, a component of this project involved surveying consumers to measure their preferences for food products raised in vertical farms. The project team engaged Prolific, a market research company, to recruit consumers to respond to the online survey, which was designed in Qualtrics. On Aug. 21, 2023, the survey launched, and it closed on Sept. 5, 2023.

The survey analysis provided in this appendix reports the findings from 1,730 respondents who met these six qualifying criteria: 1) were 18 years old to 100 years old, 2) identified as a family's primary or co-primary grocery shopper, 3) provided a valid five-digit zip code, 4) lived in Missouri or a neighboring state (i.e., Arkansas, Illinois, Iowa, Kansas, Kentucky, Nebraska, Oklahoma or Tennessee), 5) correctly responded to two attention check questions included the survey and 6) purchased at least one of the nine products of interest at least once a month. Exhibit A1 shows the distribution of respondents by state.

Exhibit A1. Survey Respondent Distribution by State



Source: University of Missouri Vertical Farming Consumer Survey, Summer 2023

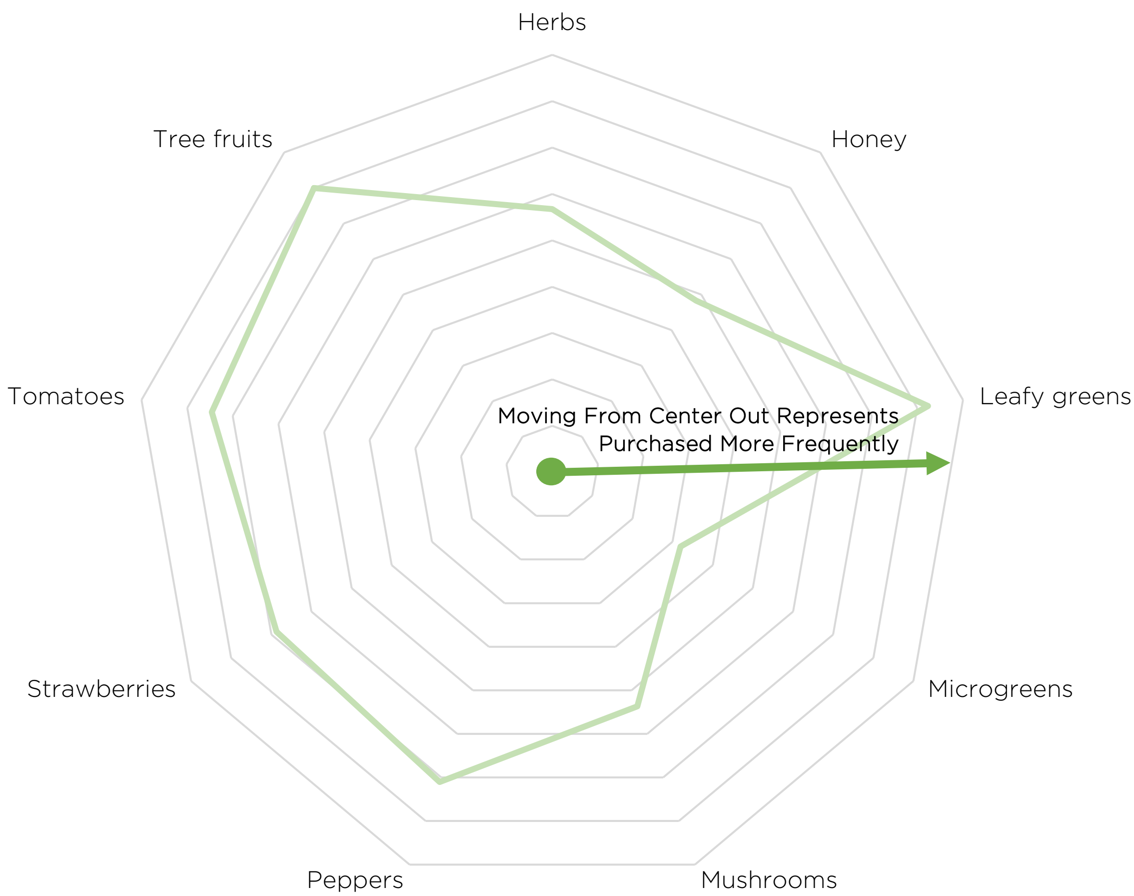
The survey assessed purchase frequency, purchase location and attribute preferences for nine products: leafy greens, microgreens, herbs, strawberries, tree fruits, tomatoes, peppers, mushrooms and honey. These products have a demonstrated history with indoor production, or they have been discussed as future candidates for pairing with indoor growing environments. The following discussion shares highlights of the survey findings.

Product Purchase Frequency

Of the nine products evaluated in the survey, respondents most frequently purchased leafy greens (e.g., lettuce, spinach, kale), tree fruits (e.g., apples, peaches, pears) and tomatoes. They bought peppers and strawberries on a moderate basis. Exhibit A2 shows respondents noted making less routine purchases of microgreens, honey, mushrooms and herbs.

Note, to indicate how frequently they purchase products addressed in this survey, respondents selected from “often,” “sometimes,” “rarely” or “never.” Often meant at least once a week. Sometimes meant once a month or a few times a month. Rarely meant less often than once a month. Never meant a respondent does not buy this product at all. Exhibit A2 communicates participants’ selections as scores to indicate their overall purchase frequency by product.

Exhibit A2. Degree of Product Purchase Frequency



Source: University of Missouri Vertical Farming Consumer Survey, Summer 2023

By state, consumer-respondents did report some differences in product purchase frequency. Those from Illinois tended to be most likely to purchase all nine of the targeted products compared with consumer-respondents in the other eight states. Relative to their counterparts in neighboring states, Missouri consumer-respondents ranked third in terms of their purchase frequency of the nine observed products. For all of the nine products, consumers in Tennessee ranked second for their frequency of purchases.

Purchase Locations

To further assess purchase behaviors, respondents who reported purchasing a given product at least monthly had an opportunity to denote where they buy that product. The survey provided nine purchase location options: CSA, farmers market, food co-op, grocery store or supermarket, on-farm, roadside stand, supercenter, U-pick and warehouse or club store. Respondents selected from this list to indicate the location(s) where they shop for a product, and they ranked the locations they selected to indicate how frequently they shop at a given location for a given product.

Exhibit A3 shares the results. For all nine products, respondents indicated they most commonly shop at grocery stores or supermarkets. Supercenters ranked as the second most shopped distribution point on average for leafy greens, herbs, strawberries, tree fruits, peppers and mushrooms. On average, the second most popular distribution point for purchasing microgreens, tomatoes and honey was farmers markets.

Purchase location behaviors reported by state largely mirror the regional behaviors. For all nine products, consumer-respondents in every state ranked grocery stores or supermarkets as the most commonly shopped distribution point. Depending on the product and the state, farmers markets and supercenters ranked as the second and third most shopped locations for the products named in the survey.

Exhibit A3. Degree of Product Purchase Frequency

Source: University of Missouri Vertical Farming Consumer Survey, Summer 2023

Attribute Preferences

To assess the importance of product attributes, respondents had two survey tasks to complete. First, they were to select the attributes they felt were important when purchasing a given product. Second, they were to rank the important attributes they selected in order of their relative importance. Exhibit A4 presents the results by product. To interpret the charts, the further a line extends from a chart's center point, the more importance respondents placed on the corresponding attribute.

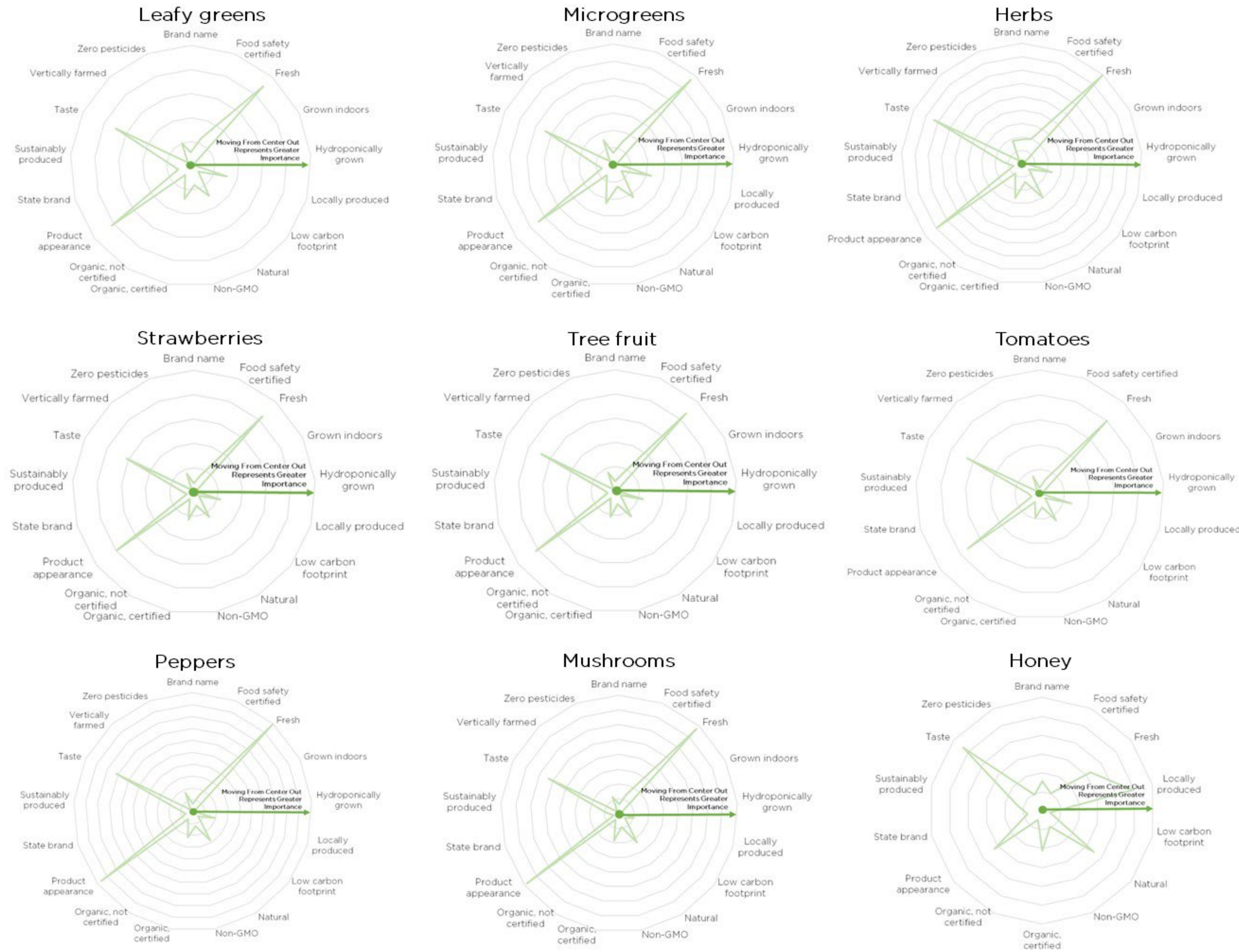
As shown, consumer-respondents tended to bundle three attributes as the most important when purchasing most of the products evaluated in the survey: freshness, product appearance and taste. These three attributes ranked as the most important for all but honey. Attributes holding the most importance for honey buyers were taste and locally produced. Then, product appearance, naturalness and freshness ranked as the next most important attributes shaping honey purchases.

These findings suggest consumer preferences lean toward three attributes that vertical farms can manage: freshness because these farms offer a local supply, appearance because they closely control disease and pest pressure and taste because they manage soil fertility and other factors to enhance flavor. For honey, vertical farms are positioned to provide a local supply and control the product's taste — both attributes bundled as most important to honey buyers who responded to the survey.

Leading product attribute preferences were relatively stable by state. For leafy greens, microgreens, herbs, strawberries, tree fruits, peppers, tomatoes and mushrooms, consumers regardless of their state selected freshness, product appearance and taste as the most important attributes that affect their purchase decisions. The ranks of these top attributes did sometimes vary by state. For example, consumers in most states selected freshness as the top-ranking attribute for leafy green products; however, Kansas and Nebraska respondents reported a marginally greater preference for product appearance than freshness.

In all nine states, locally produced and taste ranked as the top two attributes in terms of their importance to shaping honey purchase decisions. However, the order of preference for these two attributes varied by state. In Arkansas, Iowa, Oklahoma and Tennessee, consumers on average placed the most importance on the locally produced attribute. Taste ranked in the top position for consumers in Illinois, Kansas, Kentucky, Missouri and Nebraska.

Exhibit A4. Attribute Importance by Product



Source: University of Missouri Vertical Farming Consumer Survey, Summer 2023