High-Tech Plant Factories:
Challenges and Way Forward

Policy Brief
October 2017

Stella Liu and Paul Teng

RSiS Nanyang Technological University
S. RAJARATNAM SCHOOL OF INTERNATIONAL STUDIES

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Policy Brief

HIGH-TECH PLANT FACTORIES:
CHALLENGES AND WAY FORWARD

Stella Liu and Paul Teng
October 2017

TABLE OF CONTENTS

Abstract

Natural disasters in the Asia Pacific have substantially affected the agricultural sector with crop losses amounting to $28 billion USD. These incidences are expected to increase because of climate change. Plant factories, completely indoor environmentally controlled farming systems, have been touted as a solution to “climate-proof” agriculture. This policy brief highlights the challenges in this space that plant factory operators face and presents policy recommendations gleaned from best practices in Japan, China and Taiwan – the countries that have witnessed the greatest growth in plant factories in the past few decades.

Introduction

Widespread flooding in Indonesia… Japanese tropical cyclones that caused force winds of 63 km/h… Intense heat waves that led to thousands of deaths in India… Natural disasters in the Asia Pacific region have set a global record. In the 2015 Natural Disasters report, the United Nations Economic and Social Commission concluded that the Asia-Pacific is one of the world's most-disaster prone regions. The region alone accounted for half of the world's disasters with economic damage that surpassed $45 billion USD.[1] The agricultural sector is disproportionately affected. The FAO's post-disaster needs assessment estimated that natural disasters account for 29.4% of total agricultural losses in developing countries. Asia was noted to be the most affected region with total crop and livestock losses amounting to $28 billion USD or 40% of total global agricultural losses related to natural disasters.[2] In light of climate change, experts are anticipating that these impacts will only increase.[3]

---

[1] "Disasters in Asia and the Pacific: 2015 Year in Review," *United Nations Economic and Social Commission for Asia and the Pacific,* (March 2016). http://www.unescap.org/resources/disasters-asia-and-pacific-2015-year-review.

[2] "The Impact of Natural Hazards and Disasters on Agriculture and Food Security and Nutrition," *United Nations Food and Agriculture,* (May 2015). http://www.fao.org/3/a-i4434e.pdf

[3] "Global Increase in Climate-Related Disasters," *ADB Economics Working Papers,* (November 2015).

With this in mind, governments and entrepreneurs have been investing heavily in high-tech indoor plant factories with the hope that they can "climate-proof" agriculture. These indoor plant factories mainly grow vegetables all year round in an artificially controlled system that replaces the sun with LED lights and soil with nutrient-rich water. The completely controlled environment allows the factories to grow produce no matter how harsh its external environment is. For instance, in the middle of the South Pole, the Japanese Showa Station successfully used a mini indoor plant factory to produce fresh vegetables.[4] Plant factories are promising alternative farming production systems that can help countries secure their food supply in places that are vulnerable to major temperature changes or disasters.

While plant factories have been growing in number, they still only produce a small percentage of overall food supply, and mostly vegetables. Given the high food security potential of leveraging these plant factories, there is a sense of urgency underlying the aim for these factories to produce a greater percentage. This brief summarizes challenges that are preventing the growth of plant factories. Policy

https://www.adb.org/sites/default/files/publication/176899/ewp-466.pdf

[4] Shimamura, Shigeharu, "Indoor Cultivation for the Future," *MIRAI,* http://www.fieldrobotics.org/~ssingh/VF/Challenges_in_Vertical_Farming/Schedule_files/SHIMAMURA.pdf

recommendations on creating an enabling environment for these plant factories are gleaned from best practices from Japan, China and Taiwan – the countries with the greatest concentration and growth of plant factories. Japan currently leads the plant factory market with an estimated 210 plant factories in operation.[5] The Yano Research Institute projected that the market for plant factories can grow to $105 billion Yen in Japan alone.[6] Taiwan and China have around 140 plant factories each.[7]

[5] "The Rise of Asia's Indoor Agriculture Industry," *Newbean Capital,* (January 2016), http://1usaeh37xc8k42ejdw3evw3c-wpengine.netdna-ssl.com/wp-content/uploads/2016/01/The-Rise-of-Asias-Indoor-Agriculture-Industry-White-Paper_FinalProtected.pdf.

[6] "Plant Factories Market in Japan: Key Research Findings 2013," *Yano Research Institute*, (February 2014), https://www.yanoresearch.com/press/pdf/1213.pdf

[7] Yang, Qichang, "Current situation & prophase exploration on vertical farming and urban agriculture in China, *Institute of Environment and Sustainable Development in Agriculture,* (May 2015). https://vertical-farming.net/wp-content/uploads/2015/03/2015-05-10-Prof.-Yang-Qichang-Intro-to-Vertical-Farming-in-China.pdf

Key Challenges

High start-up costs

The total initial investment of a plant factory with 10 tiers is estimated to be $4,700 USD per square meter with a 5-7 year period to recover the initial investment.[8] This initial cost is about 15 times that of a greenhouse with heaters, ventilators, thermal screens and other equipment. These high start-up costs make it prohibitive for many entrepreneurs to enter into the space.

Issues of profitability

Due to constraints on demand and production costs, plant factories are struggling to break even. Plant factories are limited to a few crops due to the unique stacked, tiered system that plant factories use. Plants must be shorter than 30 cm in height because the distance between tiers is around 40 cm. They also must thrive in relatively low light intensity and high planting density. Thus, many factories tend to produce commodity crops, the most popular being lettuce, which makes it difficult to compete against cheaper traditionally grown crops in the market. On the production

[8] Kozai, T. "Plant factory in Japan-current situation and perspectives." *Chron. Hortic* 53, no. 811.2 (2013).

side, operational costs can be high from manipulating light, wind, nutrient mixes, temperature and other variables. Moreover, a study on Japanese plant factories found that in order to make a profit, over 90% of the vegetables produced must be sold at a reasonable price.[9] Given the nature of the initial trial and error stage that these factories are operating in, obtaining that high metric is very difficult.

Concerns about the final nutritional quality of produce

There are emerging concerns regarding the nutritional quality of vegetables that are grown with nutrient-rich fertiliser water instead of soil. It has been noted since the 1940s that yield increases produced by fertilisers led to the decrease in the concentration of minerals and nutrients in plants. Jarrell and Beverly (1981) conducted a widely cited review that confirmed the evidence of this "dilution" effect. Fertilization produced large increases in plant dry matter, but all other mineral concentrations and nutrients declined.[10] While the factors that led to this decline are complex, this inverse relationship is troubling for plant factories that rely on such nutrient-rich fertiliser water to grow vegetables instead of soil. Because

[9] Kozai, Toyoki, Genhua Niu, and Michiko Takagaki, eds, "Plant factory: an indoor vertical farming system for efficient quality food production," *Academic Press*, (2015).
[10] Jarrell, W. M., and R. B. Beverly, "The dilution effect in plant nutrition studies," *Advances in agronomy* 34 (1981): 197-224.

plants get their nutrients from other variables such as air and light, manipulating other variables can theoretically increase specific vitamins within the plant. A Japanese factory in Japan was reportedly able to alter red LED lights and increase Vitamin A in lettuce.[11] Early innovations show promise but have not delivered consistent results. Additionally, the ability to increase a breadth of vitamins rather than a single vitamin cost-effectively is still under development.[12]

Low supply of talent and needed skills

Running a plant factory requires a diverse set of interdisciplinary skills. Developing the sensor system that controls the environment requires engineering expertise. Plant scientists aid with fine-tuning nutrition mixes and crop selection. Management skills are required to ensure profitability of the factory. There are few people with a mix of these skills and first-hand experiences with plant factory-specific technologies like hydroponic systems.

[11] "Planned vegetable production a reality," *Japan Up Close,* (2015), http://japanupclose.web-japan.org/tech/20150227_1.html
[12] Kozai, Toyoki, Genhua Niu, and Michiko Takagaki, eds, "Plant factory: an indoor vertical farming system for efficient quality food production," *Academic Press*, (2015).

Way Forward

The following six policy recommendations could potentially lay the foundation for the development of a policy framework for addressing the challenges of plant factories. Addressing the challenges of these new plant factories at the level of policymaking is still in the early stage. These recommendations are broad and rely on case studies in Taiwan, China and Japan.

1. Develop a strong subsidy and loan program and/or support the private sector

Due to the plant factories' high start-up and operational costs, heavy financial support is required. Policymakers interested in growing the plant factory market should either set aside budget for loans and subsidies or support companies that want to enter the space. Japan's subsidy and loan program is worth highlighting because of its size and reach. The Japanese government set aside a $15 billion Yen budget to offer subsidies and loans for plant factory owners. More than half of Japanese plant factories received either a loan (20%) or a subsidy and a loan (35%) to establish operations. These subsidies can be very generous; the government offers a 50%

subsidy for commercial plant factory construction.[13] If well-resourced, policymakers should consider providing such financial support for plant factories.

Alternatively, electronics and LED light manufacturing industries that can supply equipment to future plant factories could draw private-sector financing. Taiwan's private sector took a more decisive role to finance plant factories when the crowded electronics and semi-conductor markets increased pressure for the manufacturers to innovate. Upon seeing plant factories use massive LED fixtures and other electronic components, they raced to set up plant factories with the goal to export their technologies.[14] The Taiwanese government supported their efforts by providing assistance in setting up designated zones for the plant factories.[15]

2. Create land use policies that support multi-functional land use approaches to plant factory development

[13] The Rise of Asia's Indoor Agriculture Industry," *Newbean Capital,* (January 2016), http://1usaeh37xc8k42ejdw3evw3c-wpengine.netdna-ssl.com/wp-content/uploads/2016/01/The-Rise-of-Asias-Indoor-Agriculture-Industry-White-Paper_FinalProtected.pdf.
[14] Chiang, Benjamin, "High-tech Urban Ag: Plant Factories," *Commonwealth Magazine,* (September 2012), http://english.cw.com.tw/article/article.action?id=653
[15] Chang, Meg, "CEPD targets plant factories for promotion," *Taiwan Today,* (April 2013), http://taiwantoday.tw/news.php?unit=6,6,23,45,6,6&post=11582

"Multi-functionality" landscaping – the idea of expanding a single function to other ones - can create new revenue opportunities for plant factories to sustain the business. Policymakers should actively encourage this type of approach and adjust land use policies to accommodate multi-functional land use. Plant factories can combine mini-plant factories with restaurants, retail, schools and shopping malls to educate consumers and raise awareness with the public. For instance, a smaller plant factory was built inside of a Chinese restaurant in Grand Front Osaka, Japan where chefs can harvest the produce when cooking meals.[16]

3. Incentivize the research development of improved LED lighting and automation technology

The greatest cost drivers for plant factories are electricity (28%) and labour (26%). Lighting accounts for the majority (70-80%) of the electricity cost.[17] There is therefore considerable scope to implement better LED lighting technology and robotics that can significantly reduce the costs of plant factories. Policymakers should actively support

[16] Kozai, Toyoki, Genhua Niu, and Michiko Takagaki, eds, "Plant factory: an indoor vertical farming system for efficient quality food production," *Academic Press*, (2015).
[17] Kozai, Toyoki, Genhua Niu, and Michiko Takagaki, eds, "Plant factory: an indoor vertical farming system for efficient quality food production," *Academic Press*, (2015).

research projects that investigate energy-efficient lighting and labour-saving technologies. Such advances in cost reduction can be passed to the consumer in the form of lower price points and make the sector more attractive for more entrepreneurs to invest in.

4. Support associations that encourage multi-sector stakeholders to coordinate and exchange knowledge

Issues in profitability can also be addressed by innovating new technologies and best practices that alleviate constraints on demand and production costs. Coordinating and organizing different stakeholders are conducive to innovation in many ways such as information sharing and collaboration through joint processes or products. Policymakers should support these efforts. Associations that bring cross-sector stakeholders together in China, Taiwan and Japan have proven to be useful mechanisms to facilitate such communication and innovation. The National High Science and Technology Project in China that was supported by the Ministry of Science and Technology brought together researchers, farmers and companies to develop breakthroughs in intelligent plant factory production technology.[18] Taiwan has multiple associations that were

[18] Yang, Qichang, "Current situation & prophase exploration on vertical farming and urban agriculture in China, *Institute of*

instrumental in enabling the horizontal and vertical connection and integration of companies.[19] The Japan Plant Factory Association initiates collaborative research and development projects with its corporate member companies.

5. Create a certification policy and program that regulates the safety and nutritional quality of plants produced[20]

Agricultural certifications schemes such as organic and fair trade helped motivate good corporate behaviour and educate the end consumer. To date, there is a dearth of certification schemes that relate to plant factories. As the number of these plant factories grows, certifications that measure the safety and nutritional quality of plant factory produced vegetables should be created. Such certifications can streamline good practices across the industry and incentivize the production of safe, nutritious vegetables for the public.

Environment and Sustainable Development in Agriculture, (May 2015). https://vertical-farming.net/wp-content/uploads/2015/03/2015-05-10-Prof.-Yang-Qichang-Intro-to-Vertical-Farming-in-China.pdf

[19] Kozai, Toyoki, Genhua Niu, and Michiko Takagaki, eds, "Plant factory: an indoor vertical farming system for efficient quality food production," *Academic Press*, (2015).

[20] Yang, Qichang, "Current situation & prophase exploration on vertical farming and urban agriculture in China, *Institute of Environment and Sustainable Development in Agriculture,* (May 2015). https://vertical-farming.net/wp-content/uploads/2015/03/2015-05-10-Prof.-Yang-Qichang-Intro-to-Vertical-Farming-in-China.pdf

6. Strengthen research and development capacity with plant factories

Strong research centres are central to the growth of plant factories by developing technical expertise and know-how. Interested policymakers in this space should support regional and international research centres to be updated with the latest developments in technology and allow for collaborations on existing research. The Centre for Protected Agriculture & Environmental Engineering in China covers a wide range of research topics related to environmentally controlled farming such as greenhouse engineering, hydroponics systems, energy-saving engineering and greenhouse climate control.[21] Japan's Matsudo campus in Chiba University runs a plant factory that has done research on automation technology and plant selection.[22] The National Taiwan University's Bio-industrial Mechatronics Engineering department also has a

[21] Yang, Qichang, "Current situation & prophase exploration on vertical farming and urban agriculture in China, *Institute of Environment and Sustainable Development in Agriculture,* (May 2015). https://vertical-farming.net/wp-content/uploads/2015/03/2015-05-10-Prof.-Yang-Qichang-Intro-to-Vertical-Farming-in-China.pdf

[22] Mekata, Michiru, "Chiba University successfully producing vegetables in factories," *The Japan Times,* (May 2015), https://www.japantimes.co.jp/news/2015/05/03/world/chiba-university-successfully-producing-vegetables-factories/#.WaFe1NOGO1s

plant factory for research and development and provides training courses on plant factory operations.[23]

Conclusion

The sharp increase of natural disasters that plague the Asia Pacific region and cause extensive damage to agriculture has inspired the growth of environmentally controlled farming – the plant factory. These plant factories, if successful, can help bolster the availability of food against threats of climate change. However, the early trial and error stage is fraught with challenges of profitability, high start-up costs and others that have held many back. A few countries, Taiwan, Japan and China, have seen rapid growth in plant factories over the past few decades. The key learnings demonstrate that a strong enabling environment can help overcome these challenges.

[23] Chiang, Benjamin, "High-tech Urban Ag: Plant Factories," *Commonwealth Magazine,* (September 2012), http://english.cw.com.tw/article/article.action?id=653

About the Authors

Stella Liu is a visiting US Fulbright Research Fellow at the Centre for Non-Traditional Security (NTS) Studies, S. Rajaratnam School of International Studies (RSIS), Nanyang Technological University (NTU), Singapore. Her research focuses on emerging consumer trends and technologies that are transforming the agriculture sector. Stella is especially interested in urban agriculture. Prior to joining the NTS Centre, Stella founded an ag-tech start-up company that received attention from the University of California Office of the President and the White House Office of Science and Technology.

Paul Teng is Adjunct Senior Fellow (Food Security) at the Centre for Non-Traditional Security Studies, S. Rajaratnam School of International Studies (RSIS), Nanyang Technological University, and concurrently Senior Adviser, National Institute of Education (NIE). He has over thirty years of experience in developing countries from positions at the World Fish Centre, the International Rice Research Institute and Monsanto Company. Paul's work has included research on new agro-technologies, science-based entrepreneurship, food security and sustainable development, with recent focus on urban food security and attach. Professor Teng has been recognized through the award of an Honorary Doctor of

Science in March 2016 by Murdoch University, Australia; *the Eriksson Prize in Plant Pathology and as a Fellow of the American* Phytopathological Society, and *The World Academy of Sciences.* He has published over 250 technical papers.

RSiS Nanyang Technological University | S. RAJARATNAM SCHOOL OF INTERNATIONAL STUDIES

Nanyang Technological University
Block S4, Level B3, 50 Nanyang Avenue, Singapore 639798
Tel: +65 6790 6982 | Fax: +65 6794 0617 | www.rsis.edu.sg