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Review

PEST analysis of the future Chinese vertical farming market: Environmental sustainability and energy savings

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Abstract: To provide people with an insight into market development in the Chinese vertical farming (VF) industry, this work has conducted a PEST analysis to identify the external market environment from political, economic, social and technological perspectives. VF is developing at a rapid speed with great market potential and opportunities. Environmental pollution and consumers´ increased awareness of a healthy lifestyle drive Chinese people to seek "safety, healthier and clean" food more than anyone else in the world. The increasing gross domestic product enables more and more people to afford VF-produced products. The great market opportunities have attracted many domestic and international investors to join the market. Until 2020, there were more than 200 plant factories operating in China, and the number is increasing. Nevertheless, the development of vertical farms is in the initial stage in China, which can be summarized as follows: 1) the high investment and operational costs are the main barriers to profitability; 2) technology development still lags behind other VF-advanced countries, such as in the development of intelligent crop management equipment; 3) insufficient government support, as promoting a vertical farm market requires more efficient political and financial support from the Chinese government; and 4) consumer public awareness of VF is too low.

Keywords: vertical farming; consumer acceptance; plant factories; macro-environmental analysis; urban

Abbreviations: VF: vertical farm; PF: plant factory; PFAL: plant factory with artificial light

1. Introduction

According to the United Nations report, the growth of the global population is projected to reach 9.8 billion by 2050 [1]. As the food demand increases, how to produce sufficient food to feed the growing population will eventually be one of the main challenges. Furthermore, with people's living standards improving, food quality and security have received more and more attention. A new approach to increasing food supply and rising production yield with fewer resources used is vertical farming (VF). The characteristic of VF is to use sensors and LED technology to plant crops in controlled lighting and closed environments in which plants can grow without the restriction from the sun and the unsuitable climate [2]. Compared to traditional farms, VF saves on resource utilization and space, serving to increase the output amount and production speed.

1.1. What is a vertical farm and which are its advantages & challenges?

VF is another form of agricultural farming. The concept was first created by an American geologist Gilbert Bailey in 1915, and the techniques have been developed for centuries with the aim of mitigating the population pressure and resource shortage faced by agricultural development in the future. It is a novel system of planting crops in skyscrapers, and the vertical design enables the maximum use of the land, whereby all plants and fungi are cultivated vertically above each other [3]. The technology used in VF includes an LED system, nutrient solutions (hydroponic and aeroponic), controlled environmental systems and smart devices [3].

In the VF system, no soil is used; instead, the crops are cultivated usually hydroponically. A soilless method where plant roots are directly immersed in a nutrient solution to supply all vital nutrients needed for the plants [3]. It can save 95% of water and the production yield is almost 10 times higher than the standard soil planting method [4]. By using LED and sensor technology, the crops can grow without the need for sunlight and soil, independently of the outdoor climatic conditions [5]. The LED light works as an artificial light with the characteristics of long-lasting cost and energy efficiency [5], while the sensors are close to the plants to control and adjust the climate to the optimal growth environment so that the plants can grow all year-round. Moreover, the environment is fully controlled in a VF system [6]. Both indoor farm technology and controlled environment agriculture technology are utilized in VF to control environmental plant factors, such as temperature, light, humidity and gases, which enable crops to grow more efficiently [7]. The controlled climate in VF enables crops to grow in areas with a lack of sunlight and unsuitable climates, such as desert areas, and, because the layer of plants can be stacked on top of each other, crops are produced at a much higher yield per unit of land compared to a traditional farm [8,9], which increases the efficiency of land use innovating toward original crop varieties. Besides, VF also has the following advantages: 1) all year-round crop production [10]; 2) maximization of alternative energy, such as wind and solar, where it can even use wastewater at times [11]; 3) high-quality crops are produced without pesticides and pollution; 4) the plant can grow anywhere without climatic or other restrictions.

However, the challenges of high investment expenditure, operating expenditure and sustainability limit the growth of VF [12]. The initial investment cost of a 10-tier VF is 15 times more than the respective cost for a greenhouse. Because of the requirements in "height", "vertical distance", as well as "crop harvest cycle" [5], currently, only small, high-value leafy greens with fast growth cycles can be planted in VF [13]. The variety of crops is limited. Moreover, Kozai [14] emphasized that advanced

technology such as Internet of Things (IoT) and Artificial Intelligence (AI) should be investigated to reduce the cost and increase the efficiency of VF. Kozai also stated that robotics and industrial automation should be developed to replace heavy and dangerous manual work [14].

1.2. Plant factories in China

China is the world's most populous country. According to official predictions, the population in China is projected to reach 1.44 billion in 2050, and among that, the urban population will reach 1.16 billion, which accounts for 80% of the total population [15]. The increasing population results in a huge demand for food. In 2019, the national vegetable production was 0.72 billion tons, and among them, only 0.55 billion tons were sold to customers, and around 32% of total production was damaged in transportation [16]. To find a sustainable solution to feed the burgeoning urban population, the country has been investing into developing a modern vertical farming system. There are hundreds of companies engaged in the research and development of vertical farms and related technical equipment. In order to reduce the operational costs, most Chinese plant factories use artificial light for plant growth. In terms of nutrient solutions, the utilization of the nutrient film technique (NFT) and deep flow technique (DFT) technology is the mainstream [17]. In plant sowing, many medium sizes of plant factories with artificial lighting (PFAL) in China adopt automatic or semi-automatic seeding; however, most activities, such as planting, harvesting, packaging and cleaning, are still done manually, except for a few large-scale factories that have a high level of automation [18]. The following are several large-scale domestic plant factories built in the recent years.

SANANBIO is a photobiological system technology provider. The company was jointly initiated by the Chinese Academy of Science and Fujian Sanan Group in 2015, and it focuses on research on biotechnology, photobiology, indoor agriculture and other VF technology areas. The company is investing in sustainable, fresh indoor food and crop production. The business model is to provide vertical farm solutions and hardware, as well as ongoing technical support, to those who want to enter the VF market [19].

In 2016, the first plant factory with artificial light was built with a size of around 10,000 m^2 in Fujian province, with a total investment of 7 billion Chinese yuan. So far, more than 300 types of leafy vegetables, fruits, medical herbs and edible flowers have grown successfully in the factory. The daily output of produced vegetables has reached 1.8 tons, and the vegetables have been sold to more than 130 supermarkets in Xiamen, Fuzhou and other cities in Fujian province [20]. In 2018, the second stage project was initiated by focusing on developing VF with AI technology [21]. The research facilities are distributed in Fujian and Anhui provinces, and large indoor farms are operated in Beijing, Shanghai and other major cities. In technological development, both the RADIX, a modular multilayer hydroponic growth system, and ULIFT, an unmanned vertical agricultural production system, have been released; the products are sold to more than 20 countries [22].

JingDong Group, one of the biggest Chinese e-commerce companies is known as JD.com. In December 2018, the company has announced to build a plant factory by cooperating with Japan's Mitsubishi Chemical Holdings Group. The factory located in TongZhou, Beijing covers 11,040 m^2 and has a total cost of 800 million Chinese yuan. The hydroponic system is used in factories and hybrid with solar light and artificial light, the annual output of vegetables has reached 300 tons. Mitsubishi Chemical Holding provides technological, and expert support on seed selection, equipment, phytonutrient fluids, and hydroponics technology. From the introduction of the JD group, in their plant

factory, only 500 mL water is needed for planting seeds to grow vegetables. Compared to traditional planting methods, more than 90% of water is conserved through the use of this approach. The phytonutrient fluids can also be recycled, and the entire PF factory is close to zero-emission, which achieved environmental-friendly. Currently, cabbage, coriander, lettuce, spinach, and arugula are the main products and have been sold to their own high-end offline supermarket in Beijing [23].

BEO Technology Group Co., Ltd, a Chinese electronic components producer, famous for its core business on interface devices, IoT systems, and smart medicine. In 2014, the company built a plant factory in Daxing, Beijing with a total 4,500 m^2 cultivation area and a height of 9 meters. The factory is built with artificial light. The factory focuses on developing AI technology for cultivation and planting. In 2019, through cooperating with Baidu AI Studio, many AI products such as EASYDL, Paddle and EdgeBoard were utilized to provide intelligent water and soilless solution, intelligent environmental control system, and insect intelligence warning, which make it possible to monitor the entire life cycle of hydroponic vegetables. "*We are using deep learning and gram weight recognition model in AI technology to analyse plant growth factor data to predict the growth status of crops, which enables us to plan supply chain*" said Li, a technical expert in BEO plant factory [24]. So far, more than 30 varieties of vegetables were grown in the factory, such as cabbage, red amaranth, green basil, etc. Even though the plant factory industry is developing rapidly, however, compared to food demand and supply, the market share is still very little [25]. According to a recent study, a very large share of Chinese consumers does not know or are not familiar with the vertical farm concept [26].

2. Materials and methods

Despite Avgoustaki et al. [27] and Despommier [26] and many known researchers in the field, stress that only a part of the population has heard about the VF concept in China, a wonder of the status quo of the VF market development is initiated. As described above, VF has many advantages in terms of food production, environmental protection, etc. But why is the market share so little in China, what´s the reason behind it, and how is the VF market developed in China? There is an increasing number of studies on VF technology and market research, however, only a few pieces of research have been conducted regarding the development of VF in China, especially in terms of market analysis. China has a huge market demand which has attracted many companies to invest and develop business in VF industry. Before entering the market, it is important to have the insight to sense the prospects and challenges of China's VF industry.

2.1. Research question

Hence, the study will conduct PEST research to provide people with an overview of the vertical farm market environment development in China in political, social, economic, and technological terms. After that, the potential opportunities and challenges will be discussed. Hence, the main research question under investigation is:

"*What´s the current status of vertical farm development in China and what are the opportunities and challenges moving forward?"*

2.2. Delimitations and limitations

The study only looked into a generic market environmental research, namely focusing on the macro-environmental factors influencing the sector in China; hence, the study will neither dive deep into the analysis of the whole industrial value chain nor make a comparison with other countries. The project is limited in the research part in the amount of empirical data collected. In fact, only little has been published on the technology of VF in China, and among that, most are focusing on intelligent production equipment [28,29]. Hence, to present the newest technology, the paper primarily focuses on technology in production equipment as well.

2.3. Methodology

By taking an exploratory approach, the paper, although, it mostly is a theoretical analysis initiated from public data, it aims to investigate a macro environment analysis to identify the practices of vertical farm development in China as well as identify the underlying opportunities and challenges that could impact the industry as a whole. The project takes a qualitative method, so the data is collected from existing literature, studies, media as well as websites and are used to provide the reader with an insight into the external market environment of vertical farm development in China. Moreover, the aim of the paper is to present the state of the art of the external environment of Chinese vertical farms, which requires the data should be "new" and up-to-date. Hence, all the empirical data in this work are collected from articles, and online reports published in the recent years.

3. Results

3.1. PEST analysis

3.1.1. Political analysis

The Chinese government always invests and supports heavily green, sustainable and new technology industry development. Agriculture is one of the pillars of the Chinese economy. VF as a possible solution to confront the food crisis has attracted increasing attention from the government, which was presented in several political events and governmental commitments, such as the known peri-urban farming for Beijing consumers [30].

The development of vertical farm technology officially began in 2013, when the project "Intelligent Plant Factory Production Technology Research" was initiated on the "National "Twelfth Five-Year" 863 plan" and the sponsor was the Chinese Academy of Agricultural Sciences. The projects comprised of 7 topics, involving LED light, hydroponic cultivation, temperature and environmental control, phytonutrients fluids and other technologies regarding plant factories. More than 160 scientists from 20 science and education units participated with a total project funding 46.1 million yuan. In 2016, the first smart LED plant factory was developed by "The facility of Plant Environmental Engineering Team" at the Institute of the Chinese Academy of Agricultural Sciences was first time displayed at "the National Twelfth Five-Year Exhibition of Scientific and Technological Innovation", which received great attention and affirmation from national leaders. Since then, many scientific research institutions and business units joined the industry. At the same time, a large amount of

financial support had been launched by local governments to promote VF industry development [31]. In 2016, the Agricultural Lighting Professional Committee of the Chinese Illuminating Society was established, which is the first national academy platform focusing on investing in technology to promote the development of PFAL [32].

On food consumption, according to "The 13th Five-Year Plan for the Organic Food Industry development", in 2016, both "The 13th Five-Year Plan for the Development of the Organic Food Industry" and "Vegetable basket plan" were launched by the central government to foster the development of organic food industry and made the transformation from traditional to green and sustainable agricultural development. The reports stated that the organic food industry was expected to reach 30% in 2020 [33].

In terms of financial support to the domestic vertical farm industry, unlike in Japan, a specific amount of subsidy has been provided by the government, in China, even though the VF industry is highly boosted and fostered by central and local government, the specific number of subsidies will depend on the factory size, local governments, type of plant factories and other factors, which is kind of complicated, especially for small businesses that just enter the market and need support from the local governments.

3.1.2. Economic analysis

For twenty years, China's economy has grown rapidly. According to data from the National Bureau of Statistics China, in 2020, the GDP reached $14.72 trillion, which ranked second in the world after the United States and GDP per capita was around $10.261 in 2019 with a growth rate of 2.8%, the GDP in each region has a great difference (Statista, 2021). According to the statistics, the majority of cities with high GDP are concentrated in the first-tier and provincial capital cities and this is where most vertical farms are built in China. Most plant factories are generally located outside of the cities [34].

However, in recent years, the consumption power is moving from first-tier megacities to 3rd and 4th tier cities [35]. For instance, people in 3rd and 4th tier cities with monthly salaries above 10,000 yuan showed great demand for organic food (accounting appr. 60% of total bio food consumers) and stated that quality/taste is their main consideration [36]. Avgoustaki et al. [27] found people who like bio-food also have a high tendency to purchase VF products. In terms of price, they found also that most people thought it is understandable that the price for VF products is higher than general farming food, and among them, 94% can accept if the price is 1–2 times more [37]. It is found that the price for organic lettuces sold in 7-fresh (owned by JD group) is 6 yuan/200g, while VF-produced lettuces are 7.5 yuan. "During the epidemic, the demand for VF-produced vegetables increases rapidly since customers start to be aware of food safety and hygiene again" said Zongsheng Wu, the project manager in JD plant factory [38]. Scholars Shao et al. [4], developed a software tool for the assessment of the efficiency of a vertical farm and found that a vertical farm is more valuable in areas with a high cost of vegetables, low energy cost and high labour costs.

The total funding and the number of investors for the VF industry in China are increasing year to year. For instance, Plenty and Crop One have expressed a great desire to enter the Chinese market. Matt Barnard, CEO of Plenty, said that Plenty made a roadmap to contribute 25 to 50 percent of their business in China market in the future and the company is already scouting for locations and distributors in Beijing, Shanghai and Shenzhen. The company plans to build 300 vertical farms in China, and an experience centre is planned to build in Beijing and Shanghai where customers can visit

and taste agricultural products. Such companies like Panasonic and Infinite Acres have already built plant factories in China [39].

3.1.3. Social analysis

Agriculture is one of the main pillars of the Chinese economy. However, in the past 20 years, pollution, shortage of water resources, and other environmental issues are damaging the capacity of agricultural production. Climate change resulted in the reduction of soil fertility, erosion, and the variation of acidity, and more than 35% of arable land is suffering from degradation [40]. Pollution is another issue that Chinese people are facing. 82% of pollutants contain inorganic toxins, such as cadmium, lead arsenic, and chromium, which can damage people´s health. The consumption of pesticides and fertilizer is one of the main reasons causes of Organic pollutants, as China is the biggest fertilizer each year, and the consumption accounts for one-third of the whole world [41]. The shortage and pollution of water resources threaten Chinese nature as well. In China, water resource per capita accounts only for a third-world average and is distributed extremely unevenly. The available water resource is only 15% in the south of China, and although water is abundant in the southern region, it is polluted severely due to heavy industry [42].

Due to the issues mentioned above, food security is always the main concern for Chinese consumers. The research from Mckinsey "China Consumer Survey Report 2016" showed that around 72% of consumers worried about food sources and security. The consumption pattern was changing from mass products to high-end products since most people began to seek a healthier lifestyle for families and individuals. The report revealed that more than 50% of consumers prefer to purchase healthy and nutritious food. Among that, "organic/green food" is a hot topic and has become the primary criterion for Chinese consumers to judge food safety [43]. "Health, Quality, and Taste" are considered the main driver coming in front of the price [35]. This is consistent with the direction and concept of VF products. Avgoustaki et al. [27] found that "safety" is the core reason that people buy VF vegetables. The advanced control of the plant growth process in plant factories enables vegetables to grow away from the natural environment, and products are safer and healthier than traditional farming vegetables with less pollution, and fewer pesticides.

A survey made by Avgoustaki et al. [27] regarding Chinese consumer's attitudes towards VF products, revealed that more than 84% of people agreed that plant factories will be a future direction for Chinese agriculture; however, only 34% of people have heard about plant factory technology, within that, 29% had the experience of buying the product from VF. The rank for favourite VF products is leafy greens (81%), berries & melons (70.1%) and vine vegetables (42%) and the acceptable price is between 5–10 RMB (59%) and 10–15 RMB (31%). When asking the reason why people do not buy PF products, 67% stated that they did not have any knowledge of it and 16% of people were stopped by the high price. Around 80% of people showed great willingness to visit a PF factory, since it is a chance for them to go close to a vertical farm and learn PF knowledge, hereby increasing purchasing desire. They stated also that people who have PF knowledge are more easily to buy PF products; Furthermore, people who age are between age 31–40 with an income range of 10,001–20,000 Chinese Yuan showed the most interest in PF technology and buying PF products.

3.1.4. Technological analysis

In recent years, the utilization of smart devices and artificial intelligent equipment in the vertical farm has become one of the hot topics that many researchers and companies are dedicated to developing an advanced intelligent system to improve the production of plants and increase efficiency. The same in China, many Chinese plant factories have put a great effort into it; therefore, to present the latest technology and equipment in China, several advanced types of equipment developed and currently used in Chinese plant factories are presented in this section.

Crop growth produces a large amount of data, and the data are very important since they provide great knowledge for plant growth. Companies use different simulation models to collect, structure, and analyse these data to make the day-to-day operation successful and minimize the use of labour to take care of plant growth [44]. Companies such as BEO plant factory is developing AI and IoT-based solution. The company uses big data, IoT, and simulation modeling to constantly monitor, analyse, and review the growth data and improve prediction accuracy in the whole growth cycle of crops. AI products such as EasyDL—a customised image recognition system and PaddlePaddle—a deep learning platform, are developed to provide intelligent agricultural land parcel recognition and promote the digitalization of agricultural land. Moreover, satellite remote sensing technology is developed to monitor cultivated land in different growth stages. The multi-modal data is used to analyse the growth of vegetables, such as withering identification, weight estimation and pest identification [45]. The models can effectively monitor disasters and estimate yield to save manpower and improve work efficiency. With the use of AI technologies, experts´ personal experience can be transformed into an automatic system, so that general workers can manage the cultivation process without the guidance of experts. In environmental control, BEO coupled with IoT, sensors and cloud computing technologies to obtain data on air humidity, air moisture, air temperature, CO_2 concentration, light intensity, and video images remotely. The collected data is transmitted to their cloud through 3G/4G/Nb-IoT/LoRA/WiFi and other networks. All the data is integrated into the system and is further analysed in the crop growth model to improve productivity and reduce operating costs. Moreover, the nutrient solution proportioning and convey system is automatic too. By using different kinds of sensors and actuators, the data for nutrient solution level and growth status of plants are sent to the central room to monitor the vegetable growth remotely (Figure 1) [45].

Figure 1. Sprout, a sensor-based environmental monitoring & automatic operation system [47].

Similar technology is developed by Alesca life as well, an agricultural technology company which operates indoor farming software development and vertical farm (plant factory operates by using containers and compact cabinets) in Beijing. The Sprout, a sensor-based environmental monitoring and automatic operation system for hydroponic farming was developed by Alesca life that provides automatic and optimal environmental conditions for vegetable growth. Sprout system integrates sensors and actuators to automatically monitor, control and adjust the supply of nutrients, circulate water irrigation and other core plantings electronic equipment, such as illumination, and climate control required in the different growing stages of vegetables [44]. The whole process is managed automatically so that users can operate with no need for knowledge of plant growth [46]. Additionally, Alesca Cloud is a web and smartphone-based operation and supply chain management system, in which the cloud platform can organise all daily tasks, track all production lines, and conduct in-depth operation management through customizable dashboards [47].

Sananbio, one of the world's largest indoor farming technology providers, launched the latest AI-powered unmanned operation solution – Uplift, though using robotics and a conveyor system, Uplift can create construction plans based on a specific plant and internal designs so that seeding, transplanting, roots dividing, and other daily growth management can be automated in different stages of plant growth, which achieved "seeds come in and vegetable come out" [19]. It is validated that with the Uplift solution, a farm with only 5000 m^2 can stack up to 20 layers and produce 6-8 tons of vegetables per day. With the same farm size, the productivity of Uplift is 6 times higher than a general 6-layered vertical farm. In their newest water circulation system, 60% of water can be absorbed by crops and the rest 40% is recycled [49].

PlantKeeper, a proprietary indoor framing management system is powered by Sananbio with a large capacity for data storage, analysis and operation so that environmental management, light management, and other growth functions are automated. By using the imported smart database, farmers will receive clear insights into the tasks time of the whole planting cycle from sowing to harvesting as well as the training for cultivation management. It phases out the stages for manual management like manual recording, and calculation, hence improving plant cultivation accuracy. To solve the issue of layer number constraints (usually less than 6 layers) and the issues of light cannot reach to all the layers, Uplift built an intelligent cultivation shelf, which inlaid LED light system and nutrient circulation system to plant frames [49]. Uplift framing platform enables higher yields achieving while reducing operating costs (Figure 2).

Figure 2. Uplift in Sananbio [49].

RADIX—VF grow module, another well-known product in SananBio, "is a fully-integrated system through using hybrid NFT & DWC solution together with an integrated gravity-driven water circulation, the water is converted between constant flow and Ebb& Flow", introduced by SananBio. RADIX module is a form of multi-layers, and each shelf comprises of LED light system and cultivation plate and nutrient solution supply system, which provides the integrated structure of water, electricity, cultivation plate and support system that provides "sunshine" and "land" needed for plant growth. Moreover, the cultivation tank module can be matched with different plug-ins and planting plates to meet the needs of various cultivation forms and densities, such as NFT and DFT. The whole growth process for all leafy vegetables, flowers, and spices can be completed in the module from sowing and seeding to harvesting [50].

4. Discussion

4.1. Opportunities

Vertical agriculture has huge development potential in the Chinese futures market, which the opportunity is summarised in the following aspects. In terms of policies, as mentioned earlier, to boost the development of VF technology, the Chinese government has released a great amount of funding for VF technology research projects, especially after the "853 Plan", the innovative, green, sustainable technology has become the focus of development. In food consumption, with governmental intervention, the agricultural structure is transforming from traditional to green and organic (due to environmental issues that China is facing). The vertical farm industry, with the concept of energy-saving, green, high-yield, and pollution-free, can best correspond to the governmental requirements and match the future market orientation. Moreover, different innovation subsidies are offered by regions and governments to SMEs to stimulate the development of VF industry development. For instance, in 2014, GMY LIGHTING TECHNOLOGY CO., LTD. in Guandong, got 2 million RMB to develop their PFAL [51]. As many researchers have stated, the high initial costs of VF are one of the main challenges for most start-up companies, and the subsidy given by the government will provide sufficient financial support to small and medium-sized enterprises entering the industry.

China's GDP is growing steadily, and both national productivity and per capita increase year by year, which lead to a great economic foundation for the consumption of vertical farm products. Even though the per capita income in China is still lower than, in many advanced countries, the huge market demand for vegetables cannot be neglected. The increasing consumption of Bio vegetables indicated the peoples´ attitude towards food quality and tasty, which is a great benefit for VF products since the survey has confirmed that people who purchase bio (the majority of them in the middle-class who have a relatively high salary and share a concern for food quality) will also be the main consumer group of VF products. Moreover, the concern of the high price of VF products would not be an issue for the high-end Chinese target consumers. As most of them agree that products with high quality should be expensive and more than 30% of them can accept if the price is 50–100% more [27]. These people are mainly living in first tiers cities, with a relatively high income, and are more easily to accept new stuff and pursue a healthier lifestyle. However, the future consumption trend is moving from 1st to 2nd and following tier cities to families whose annual salary is above 120,000 RMB and more aware of the food waste and purchase bio-food. The huge funding from both international and domestic companies is another economic opportunity to promote VF development in China, as the raised investment will

provide more opportunities to develop the technology of VF meanwhile the joining of international companies, will support domestic VF companies and academic science institution to learn the forefront technologies (joint venture policy in China).

For the technological, positive changes in technology usage will bring benefits to vertical farm development. The fast development and the usage of intelligent production equipment in many Chinese plant factories are such a good opportunity, especially for companies that dedicate to integrating AI products with IoT and cloud technologies. Smart plant factory is the current and future trend, as the technology can automate the operational work, increasing work efficiency, achieving mass production and reducing costs. The decreased price of VF–produced vegetables will be accepted by more consumers, so the market share will grow [52]. Moreover, the developed high tech-products such as Uplift and Plantkeeper in Sananbio can attract many investors to cooperate and join the vertical farm businesses. With sufficient fund support, more and more advanced vertical farm technological products will be developed to promote the VF industry moving forward in China. Last but not least, with more and more in-depth research in AI technology, big data and crop growth models, China has a great opportunity to produce more variety of VF–produced vegetables for the market.

Moreover, according to Qiqiang Yang, a researcher at the Institute of Environment and Sustainable Development in Agriculture—IEDA, in China, high energy consumption is another issue that should be solved (light, air- condition) (Yang, 2015). He made an assumption for leafy vegetable production in a general Chinese plant factory. The total costs consist of 52% electricity, labour costs 18%, cost of depreciation 18% and other costs 15%, electricity, and 90% costs from lighting [32]. To minimise energy costs, as mentioned earlier, many domestic PF companies use a hybrid of solar and LED lights in their factory. Therefore, developing more energy-saving and sustainable LED lighting for the vertical farm could be another opportunity in the Chinese PF industry.

4.2. Challenges

Even though there are great opportunities for the VF industry in the Chinese market, it is not an easy business to run. Firstly, there is no doubt that the government is putting effort to boost the development of the VF industry. However, compared to other sustainable and renewable technologies, such as electric vehicles, solar, and wind industry, support is the least. Besides several projects and policies mentioned above, there are no specific regulations and laws released to promote industrial development. The subsidy regulations and amounts differ from region to region, and the information on regulations and subsidy applications is not visible online, which increases the difficulty for small-size start-up companies to enter the VF industry.

Another challenge is profitability and price. According to the estimation, the initial installation cost for a total area of 100 m^2 PFAL is around 600.000 RMB which excludes operation costs – needless to say that for the VFs the operating costs are way higher compared to the capital costs [53]. The expensive start-up investment and high operating costs resulted in a much higher vegetable price than normal farm-produced vegetables so VF-produced vegetables cannot be afforded by most Chinese consumers. According to the statistics made by the Chinese Academy of Agricultural Sciences, in China, the average production price of vegetables is 4.14 yuan/kg in 2016, and vegetable production costs in plant factories are between 8–12 yuan [54]. The high price impedes the majority of people to purchase it, which resulted in the critical challenge of low even non-profitability for some PF enterprises. The good news is, as experts stated, with the development of more efficient technology,

the costs will be reduced further [32].

In terms of technology, even though intelligent products and AI technology are fast developing, challenges exist. The first is the crop growth model. As the growth model is the reflection of dynamic simulation of plant growth, yield formation process, and environment, the multiple growth models should be integrated to provide the basis for plant growth decision optimization; however, in China, most companies staying at single plant growth model research, which the models cannot be integrated [55]. This is also validated by BEO, as the expert stated that in the future, the company will focus on developing more crop growth models. Besides, the integration of sensors and information measurement systems is another shortcoming. In the environmental control systems, many domestic companies rely on empirical value setting, in which real-time adjustment cannot be conducted based on crops' biological conditions. The usage of robotics in crop management should also be improved in China. Even though Sananbio has released Uplift to provide an integrated automatic solution, the majority of Chinese PF companies still remain using single-function robotics, and robotics with multiple functions and autonomous operations needs to be developed (Guo et al., 2020). From above, it can be seen that the development of VF intelligent equipment in China still has a distance from those VF technologies are highly developed countries.

For the social part, the low public awareness impedes the market share. Hence, how to promote consumers to learn and purchase VF-produced products is one of the main factors that should be solved. As mentioned earlier, in China, more than two-thirds of people have never heard of or do not have any knowledge regarding vertical farms [26], which is kind of contradictory to the fast development of the Chinese VF industry. As market growth and profitability are the ultimate goals for enterprises to promote the development of industry, it is important to create the chance for consumers to learn about the product. When consumers lack knowledge of vertical farms, people could hold the opinion that crops grown in plant factories are "made from chemicals" and not natural, which harms their health. Moreover, some Chinese people are also confused with bio or greenhouse food [27]. All these factors can be a barrier to people purchasing VF-produced vegetables.

5. Conclusions

In this work, the state of the art of the Chinese vertical farm market environment has been discussed from political, economic, social, and technological perspectives. Generally speaking, the development of vertical farms is in the initial stage in China. The potentials and opportunities in the Chinese vertical farm industry are huge, as the rapidly growing plant factories built in China in recent 5–10 years are good validation. In market demand, because of pollution issues and food security, Chinese consumers are seeking "clean, natural and green" food, especially with the impact of COVID-19, this demand is getting even higher. Moreover, the increasing Per capita GDP in China makes VF-produced vegetables affordable to more and more consumers. As it was revealed, Bio food consumers or consumers who live in 3rd and 4th tier cities with a monthly salary above 10,000 yuan and have a knowledge of vertical farm technology could be the future target consumer of VF products. This provides investors and plant factory companies with a great opportunity to direct, develop and expand their market in China. In terms of technological development, the technology of mechanization and automation of plant factory equipment in domestic PF companies are constantly improving, as Sananbio that already developed a variety of highly advanced AI robotics that promotes industrial development. However, in most Chinese PF companies, the degree of the usage of intelligent

production products is very different and waiting to be improved, especially in the integration of the usage of sensors, crop management, and robotics. In the future, with more investors and research institutions joining the industry, the technology is expected to get closer and closer to PF advanced developed countries and more new advanced technologies—even connection to other sectors [56]—will be developed.

From a political perspective, though the Chinese government has released funding and subsidy support to both academic research institutions and companies to develop the vertical farm, the support is far away than enough. Compared to foreign countries, the formulation of domestic policies and regulations in plant factories is still in the initial stage, which is manifested as a lack of standardised regulations for subsidies, a lack of explicit application process, etc. As plant factories are an important symbol of modern agriculture, the Chinese government should support them from a strategic level to increase scientific and technological research and development, meanwhile increasing policy and financial support for plant factories. Besides, the high initial costs, operational costs, and energy costs are still the main barriers to making plant factories profitable for most domestic PF companies, which indirectly resulted in the high price of VF-produced products [57]. Even though it is acceptable to increase customers, for the majority of Chinese consumers, the price is still too high. Hence funding support from the government is extremely important to keep the enterprise operating at the same time developing high technologies to reduce costs which makes VF products affordable to more customers. Last, while developing the technology, the market should be promoted at the same time, so that consumers can learn and understand the VF products, and then purchase the crops produced in vertical farms. Plant factories enterprise should use social media to increase the consumer´s public awareness and knowledge of vertical farm technology and products, as it is one of the main foundations for people to learn and accept VF products.

Conflict of interest

Both authors declare no conflicts of interest in this paper.

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