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Efforts in the Development of Sustainable Hydroponics

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Abstract The potential for hydroponic development in Indonesia is high due to the increasing demand for quality vegetable products. To date, the majority of hydroponic products are produced by small-scale companies. These players should be prioritized to be given business development assistance according to their individual needs and capabilities. This study aimed to analyze the influence and dependence of key variables on the development of a sustainable hydroponic business. The method used was a descriptive analysis of the key variables using MICMAC Analysis. The data was obtained from a focus group discussion involving 30 respondents consisting of farmers, researchers, and lecturers from West Java, Indonesia. The FGD yielded ten key variables for sustainable hydroponic business development: 1) markets, 2) locations, 3) human resources, 4) SOP, 5) prices, 6) branding, 7) installation systems, (8) distributions, 9) consumer preference, and 10) promotions. The human resource (HR) variable was a key driver in sustainable hydroponic development because it held the strongest direct influence on other key variables. The markets, consumer preferences, and prices affected sustainability, but they depended on other variables. Branding, SOP, business locations, distributions, and promotions carried a minor influence and high dependence on other variables. The efforts to develop hydroponic farming in the future needed to focus on promoting the advantages and benefits and improving the distribution mechanism.

Keywords Hydroponic Farming, Focus Group Discussion, MICMAC Analysis, Key Variables, Smallholder Businesses

1. Introduction

During the COVID-19 pandemic, the demand for horticultural products in Indonesia, especially fruits and vegetables, increased along with the increasing need for healthy food. As such, the domestic market for horticultural products continues to operate despite the slight overall decline. During the pandemic, 83.49 percent of agricultural business actors continued to carry out their activities, with 50 percent running their business as usual [1]. The overall decline in the agricultural sector was the lowest among other economic sectors, which shows resilience in facing a global disruption such as the COVID-19 pandemic. The performance of the horticulture sector was marked by a production growth of 9.68 percent [2]. As the economy reopened, the remaining 24.72 percent of agricultural activities that had stopped due to the pandemic have now resumed operations [1].

The challenges faced by agricultural entrepreneurs are the increasing demand for good quality horticultural products, as well as meeting this demand while preserving the environment [3]. On the other hand, rapid urbanization and industrialization have reduced the availability of agricultural land and led to agricultural practices that may harm the environment. Modification of growing media could be an alternative to support more sustainable production activities. Simultaneously, this could conserve agricultural land and water resources [4]. An example of this modification is the soilless cultivation methods to grow healthy food crops or vegetables [5]. Hydroponic cultivation is one of the most popular techniques because it efficiently manages resources during production [4]. By controlling the water and fertilizer, and managing the climate and pests, hydroponics can be carried out on land where conditions are not feasible for planting, and yet

manage to produce consistent quality products [6], [7]. Farmers claim that hydroponic cultivation is easier because it is cleaner and does not require heavy work such as plowing, seeding, fertilizing, and crop rotation [8].

Allen Cooper in 1965 developed hydroponics commercially using the NFT (Nutrient Film Technique) concept [9]. In its development, most of the cultivation of plants with hydroponics was not successful due to a lack of nutrients [9]. Plant growth in a hydroponic system will be better if it is in an environment suitable for plant production. One of the conditions for achieving a suitable environment is through hydroponic cultivation in greenhouses. Hydroponic plants cultivated using greenhouses provide higher yields compared to hydroponics in open land [10]. The difference in results is due to the existence of a controlled environment in the greenhouse and the reuse of nutrient solutions.

Hydroponic cultivation technology with greenhouses can be utilized and has the potential to increase crop production and quality throughout the year. Yield increases with the efficient use of inputs can be achieved with protected cultivation. The advantage of hydroponic cultivation with a greenhouse is the efficient use of natural light [10]. However, hydroponic cultivation with greenhouses faces challenges, including relatively high maintenance and operating costs, especially for controlling temperature and maintaining nutrient concentrations in the water [10].

The use of Internet of Things (IoT) technology allows us to control and monitor environmental conditions in greenhouses. By integrating IoT technology with a greenhouse, it will become a smart greenhouse (SGH). The development of IoT-based SGH for organic farming gives good results and monitors microclimates such as temperature, humidity, TDS, PH, and light conditions [11]. The realization of IoT makes it easier, more effective and efficient for farmers to work because farmers do not need to control machines, but machines will control themselves and collaborate with other machines [12]. Until now, some farmers have carried out microclimate control manually in SGH, but it is a pity that conditions cannot be monitored and property changes can be made so that crop yields are still not optimal [12].

These advantages of hydroponic cultivation encourage the development of commercial hydroponic agriculture among many agricultural entrepreneurs. The main challenge in developing hydroponic technology is how to keep investment, operational costs, and dependence on human labor as low as possible [13]. Meanwhile, complexity in hydroponic cultivation systems [14] requires a high level of managerial ability [15], production knowledge of various plants, technical skills, and adequate experience [15]–[17], as well as the commitment to carry out activities according to the established procedures [18]. Therefore, the initial and operational costs of hydroponic cultivation are higher than land cultivation [19]. The movement toward hydroponic production is not because of the low production costs but because of the allowance for accurate predictions and the control over the business and market order in the future [20].

Consumers are most concerned with the quality attributes of hydroponic vegetables. Hence, they are willing to pay twice the price of conventional vegetables [21]. Currently, there are 221 business actors in Bogor, West Java, Indonesia, who produce food using hydroponic cultivation. This number will likely continue to grow [22]. The majority of hydroponic business actors in Bogor are small and periodical companies. Like the global trend, public interest in hydroponic products in Indonesia is also increasing. During the midst of the COVID-19 Pandemic, a hydroponic business can provide benefits that it is very useful in supporting the economic resilience of the community [23]. The finding of hydroponics entrepreneurship in Jakarta, Bogor, Depok, and Bekasi (West Java Province) showed that the quality of hydroponics products and customer responsiveness become the strengths of hydroponics. Meanwhile, the efficiency of production and innovation turn out as the weaknesses of the activities [24].

Therefore, there is a need to improve technical and managerial skills, especially in this increasingly competitive market. Smallholder businesses have limited resources, so they need to set a priority scale in their business development. The key variables for the business of hydroponic that have a stable influence on other variables can be set to be a priority variable to be developed. Research related to hydroponic cultivation has largely focused on the technical aspects. What needs to be explored is the efforts to maintain business sustainability based on key variables. Therefore, the current research aims to fill the gap in identifying the influences and dependences of key variables of sustainable hydroponic business development.

2. Materials and Methods

Business sustainability is crucial for hydroponic entrepreneurs because investment costs are high [19], yet research has not been done. This study was conducted between January and December 2021 in West Java, Indonesia. The identification of key variables for horticulture development was obtained using the forum group discussion (FGD), with 30 participants consisting of horticultural farmers practicing land cultivation who were also the heads of farmer groups, horticultural farmers practicing hydroponics in a semi-smart greenhouse system (SSGH), horticultural farmers practicing hydroponic in a smart greenhouse system (SGH), entrepreneurs providing greenhouse technology, as well as researchers and lecturers in West Java Province, Indonesia. It should be noted that the difference between SSGH and SGH lies in the use of automation tools in the cultivation process. SSGH has not yet implemented automation technology for real

microclimate adjustments.

The invited participants were the heads of 5 farmer groups. They are members of the Mujagi Farmer Group Association (Mujagi FGA). It was founded in 2009 and located in Pacet sub-district, Cianjur Regency, West Java. This association produces highland vegetables with high economic value. It has 110 members and is also partnered with 10 farmer groups (as many as 450 members). Mujagi FGA is well known in West Java for its long experience in developing businesses and producing vegetables cultivated on land with good quality products. Therefore, its participation in FGD was valuable.

The representation of SSGH was 5 employees of PT Momenta Agrikultura (Amazing Farm). The company was founded in 1998 and develops vegetable cultivation using aeroponic and hydroponic (DFT system). Located in highland of Lembang sub-district; West Bandung Regency; West Java, it has been exporting to Singapore since 2005. It currently has a 7.5 ha greenhouse. PT Momenta Agrikultura is known as the pioneer of hydroponic company and its participation in FGD to represent SSGH.

The representation of SGH was 5 employees of Bogor Agricultural Development Polytechnic (BADP). SGH of BADP was first operated back in 2020, and it is relatively new compared to other companies. Recently, the use of SGH in cultivating fruits and vegetables has started to increase in Indonesia. Smart greenhouse system includes the use of sensors to control microclimate (air and water temperature, humidity, and light intensity) and is connected to Android. Unlike Mujagi FGA and Amazing Farm which are located in highlands, SGH is located in low land. To adjust temperature and humidity based on plant needs, it uses electronic equipment. The employees' experiences in managing SGH were considered sufficient to participate in FGD.

The other participants were 5 persons of entrepreneurs providing greenhouse technology packages, 5 persons of researchers, and 5 persons of lecturers. Providers/entrepreneurs of technology packages usually provide development assistance and management of activities, so that they understand the vegetable cultivation process in greenhouses sufficiently. The selected researchers and lecturers are respondents who often conduct research on vegetable hydroponics.

The method used was the Matrix of Crossed Impact Multiplication Applied (MICMAC) approach, which relies on analytical thinking through systematic problem-solving [25]. MICMAC uses three stages of activity [26], namely 1) identifying the main influencing variables and the influenced variables, 2) mapping the relationship between variables and the relevance of variables, and 3) explaining the causal chain in a system. In the implementation, the steps taken for data collection are as follows:

1. The FGD should be carried out in at least two stages [27]. Phase one focuses on identifying key variables and their operational definitions, as well as aligning understanding and perception. Phase two requires respondents to assess the relational value between variables while confirming the results of the system under study, enriching information, understanding the system, and identifying key drivers of the system.
2. MICMAC analysis uses ordinal data, with the value 0 showing no relation but with a potential to develop in the future, 1 is a weak relation, 2 is an average relation, and 3 is a strong relation. If the respondent does not assign a value, the item is coded 'P' to indicate that the cell is empty.
3. The FGD is conducted by dividing the participants into three tables, with each table being led by an appointed person. A supervisor manages the overall process.
4. Each table is assigned to discuss the key variables. After the participants reach an agreement, they are asked to assess the relations between the key variables, as outlined in point 1.
5. Based on the agreed values, the MICMAC module data is then entered.
6. The participants are randomized at each table. Only the appointed person in charge of the table remains at the same table. This activity is repeated three times in the process of value determination. This aims to achieve stable variables and values because a stable system can distinguish clearly the influencing and the influenced variables.
7. The final results are disseminated to all FGD participants to reach the final agreement.

The sustainability analysis using MICMAC was carried out by downloading and installing the software via the La Prospective website at http://www.laprpective.fr [25].

3. Results and Discussion

The FGD provided ten key variables for sustainable hydroponic development, namely 1) markets, 2) locations, 3) human resources (HR), 4) standard operating procedure (SOP), 5) prices, 6) branding, 7) installation systems, 8) distributions, 9) consumer preferences, and 10) promotions. These are presented in a 10x10 cross-impact matrix called MDI (Matrix of Direct Influence). MDI describes the potential influence between variables, consisting of a very strong, moderate, weak, or no effect (Figure 1).

3.1. Relationship among Variables

The MDI data was then analyzed using the influence-dependence map, consisting of influence variables, relay (leverage) variables, dependent variables, and excluded variables (Figure 2). The influencing variable was human resources, and the relay variables consist of market variables, consumer preferences, and prices. The dependent variables are branding, SOP, business location, distribution, and promotion. The excluded variable was installation.

	1 : Market	2 : Location	3 : HR	4 : SOP	5 : Price	6 : Branding	7 : Install	8 : Distrib	9 : Preference	10 : Promotion
1 : Market	0	3	0	3	3	3	0	3	3	3
2 : Location	3	0	0	0	2	0	0	3	0	0
3 : HR	3	3	0	3	2	3	2	3	1	3
4 : SOP	0	0	2	0	2	3	3	0	0	0
5 : Price	3	3	0	2	0	2	0	3	3	1
6 : Branding	3	0	0	0	3	0	0	2	3	1
7 : Install	0	3	0	3	0	0	0	0	0	0
8 : Distrib	3	2	0	0	3	0	0	0	0	0
9 : Preference	3	0	0	3	3	3	0	0	0	3
10 : Promotion	0	0	0	2	3	3	0	0	2	0

Note: Influence ranges from 0 to 3, with the possibility of identifying potential influences (0: No influence, 1: Weak, 2: Moderate influence, 3: Strong influence)

Figure 1. Matrix of Direct Influence (MDI)

The HR variable was a key driver in sustainable hydroponic development because it was one of the critical success factors for business operations and continuity. In managing hydroponic cultivation, workers need to be highly skilled, given the system's complexity. They need knowledge of various plants' production, technical ability, experience, and commitment to managing a hydroponic business [14], [18], [28], [29].

The second group is the relay variable—a highly sensitive and unstable variable. Any intervention on this variable will impact the system as a whole [25]. These included markets, consumer preferences, and prices. Not only do they have an effect, but they are also dependent on other variables. Markets are undoubtedly sensitive to human resources. They also depend on consumer preferences and prices. For example, vegetable markets in Sub-Saharan African countries continue to increase in volume, product variety, and supply availability. This results in an expansion of international markets and a transformation of the trade structure [30]. The transformation includes the position and structure of the supply chain and the provision of facilities for companies involved in the supply chain. Increasing product demand such as this requires a competitive strategy in developing the product's variety, packaging, and processing. Additionally, it depends on whether or not businesses can meet the quality standards of consumers, the ability to invest in quality product production and maintain relationships with farmers and intermediaries.

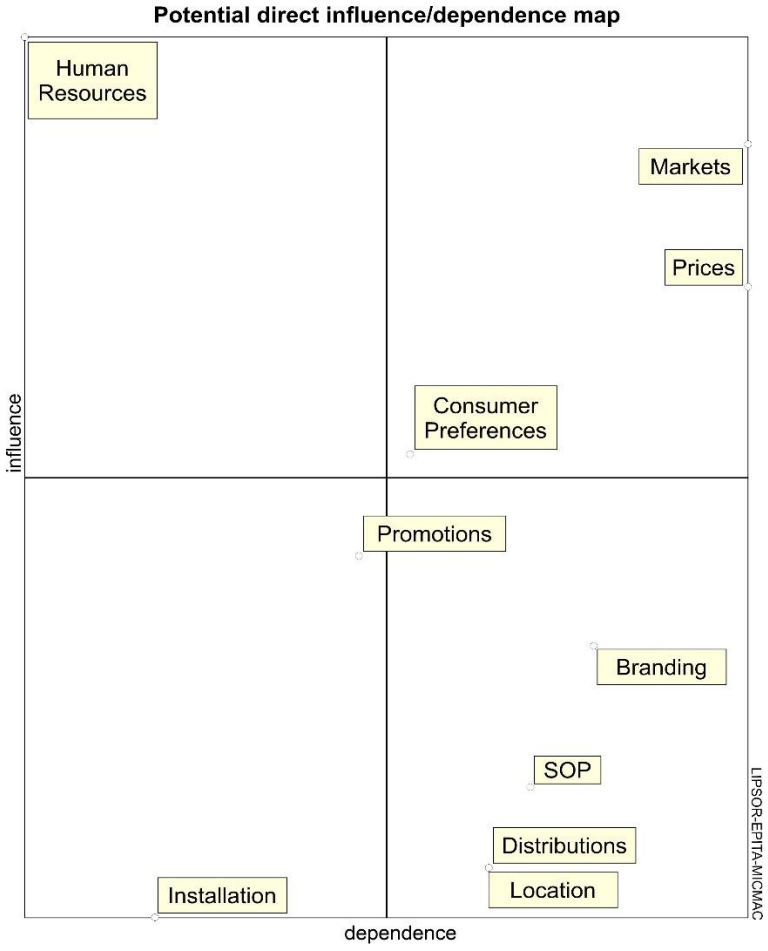

Figure 2. Influence-dependence map

Consumer preferences are driven by consumers' perceived benefits, which continue to the attitude toward the purchase, and lastly, is the intention to buy. Therefore, communication strategies related to environmental sustainability need to be highlighted by companies in marketing their agricultural products [31]. Attractive product attributes will increase purchasing decisions and consumer satisfaction [32]. In the case of vegetables, these include appearance, aroma, texture, and nutritional value [33]. Many consumers are willing to buy vegetables at relatively high prices because the products are available out of season, exotic, organic, and high quality [34].

Reasonable prices that benefit both producers and consumers play an important role in a sustainable hydroponic business. Structured market demand (market with production contracts) will form a specific price that benefits both parties [35]. In many cases, the supply of products from smallholders is based on a contract, either with an individual, cooperatives, or intermediary traders. Farmers benefit from contracting schemes through increased access to inputs, reduced production, and marketing risks, increased technology and productivity, and ultimately increased income [35]. Vegetables produced under contracts with export companies provide a direct benefit amounting to 47 percent of household income, and an indirect benefit is in the form of technological and managerial spillover effects [35]. Human resources play an important role in developing a contract system because education level is an important determinant in export contracts and production [35].

The third group is dependent variables, characterized by high dependence but a small effect [25]. These variables included branding, SOP, business location, distribution, and promotion. A hydroponic business can be located on land whose soil characteristics are not technically suitable for vegetable cultivation [6], [20]. Before purchasing hydroponic products, consumers consider brands and social media presence [36]. Competent human resources [29] who create products according to consumer preferences [33] can build the branding for their business. Branding is established because of consumer trust, and that trust is formed because of the consistency in maintaining product quality and service. The contribution of agricultural entrepreneurs to the development of local communities influenced the sustainable performance of agricultural businesses [37].

SOP in hydroponic cultivation is straightforward for workers/farmers because the production process is more accessible, cleaner, and does not require heavy labor [8]. Hydroponic products consistently have high quality and high nutritional content [6]. They are also fast to harvest, safe, and do not damage the environment [3]. Superior product quality is achieved when SOP is implemented consistently [38]–[40]. In addition, higher investment and operational costs require the workforce to be highly skilled and knowledgeable to carry out SOP to produce quality products [19].

Compared to soil-based cultivation, the preference for hydroponic systems does not depend on soil type or climate [20]. However, the cultivation location in a hydroponic system is still important to determine the use of technology [6], [20], [28], [39]. In addition, the location of cultivation will be more profitable if it is closer to the market and consumers because transportation costs will be lower. Regarding promotion, it could help drive business success, especially because the prices of hydroponic products tend to be higher. Reaching a certain segment of consumers is imperative.

The fourth group is the excluded or autonomous variables, which have little influence and minimal dependence because, without this variable, the system will not stop functioning [25]. Installation variables were not an important variable in developing sustainable hydroponic cultivation. Many hydroponic systems can be used. It is not the type of installation that matters but the operator’s technical knowledge, especially in a business with capital-intensive hydroponic cultivation [28]. Also, the chosen installation will only produce high-quality products in certain locations and climates [39].

The use of technology in hydroponic cultivation needs capable human resources and is strongly influenced by market demand, investment funds, and location [20], [41]. Of course, maintaining the installation properly is needed so that the system continues to work correctly and can produce the best products. This needs to be considered because the technological dimension is a method that is a less important method for business sustainability than the environmental, economic, and institutional dimensions [42]. The utilization of IoT for hydroponics and management [43], such as in SGH, can facilitate problem-solving and decision-making and reduce human errors [44].

3.1. Direct and Indirect Influence

Subsequent analysis was carried out to determine each key variable's influence based on the direct effect (Figure 3) and the indirect effect (Figure 4). The direction of the arrow indicates the effect, and the thickness of the line shows the magnitude of the influence [25]. The direct and indirect relations between these key variables are a detailed explanation of the influence-dependence mapping in the previous section. The intensity of the relations can be used as a reference for setting priorities in developing a sustainable hydroponic system.

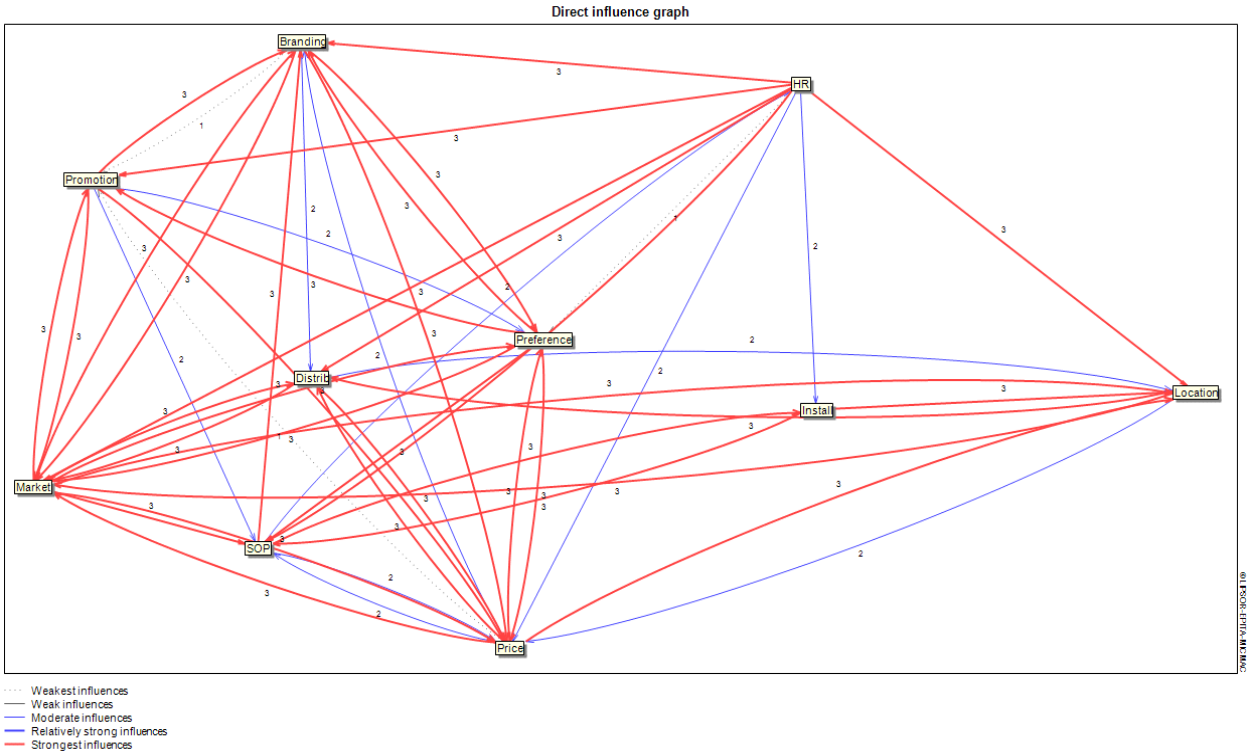

Figure 3. Direct Influence Graph

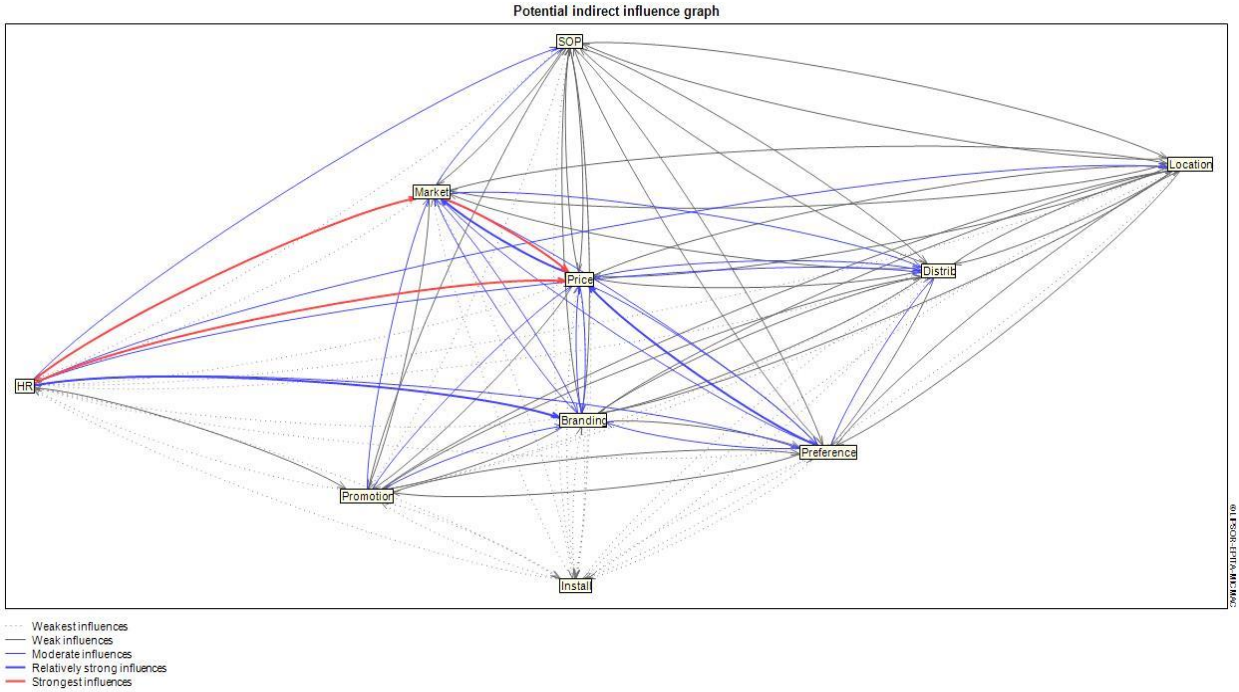

Figure 4. Indirect Influence Graph

Human resources (HR) was a key driver (influences variables) and held the strongest direct influence on almost all key variables, especially pronounced on product prices and hydroponic installations and less evident on consumer preferences. HR also had an indirect effect on all variables, and the influence was the strongest on prices and markets. The challenges and opportunities of human resources for hydroponic business managers along with the increasing demand for supermarkets are 1) being able to manage risks and look for alternative market options; 2) being ready to face competition from wholesalers, and 3) being able to develop investments in risk management, product

diversification, increasing value addition, and market expansion [41].

The market was included in the relay variable group because it was directly and strongly influenced by human resources, distribution, location, and—to a lesser degree--promotion. In addition, the market was also strongly and indirectly influenced by HR and strongly and indirectly influenced by prices. The ability of HR to manage the market related to design arrangements, site selection, and operations is critical to maintaining product quality [45].

The most decisive direct influence on consumer preferences comes from branding and the market, followed by promotion's fairly strong direct influence. An indirect, fairly strong influence on consumer preferences comes from human resources and prices. At the same time, consumer preferences also have a strong indirect influence on product brands. Increasing public awareness of healthy eating patterns and community income will positively impact the demand for quality horticultural attributes. This will, in turn, support hydroponic businesses. Therefore, business managers must be able to capitalize on it [34].

The price variable as a relay variable is also influenced by and affects other key variables directly or indirectly. The strongest direct influence on the price variable comes from HR and distribution, a fairly strong direct influence comes from promotions, and the strongest indirect influence comes from HR. The price variable has a weak direct influence on location and a fairly strong indirect effect on the market and consumer preferences. The government usually does not regulate the price of horticultural crops and—unlike in the food crop sector—does not regulate the market. In future developments, government support is needed to improve market information systems, price information systems, and public access to capital [34].

Cultivation SOP, business location, distribution, and promotion held an extremely high and direct dependence on HR. The strongest direct effect comes from a location on distribution. A direct and fairly strong influence comes from the installation variable on cultivation SOP and business location. The SOP has a direct and strong influence on product brands, while promotions strongly influence prices, preferences, branding, markets, and SOP. Variables with a direct but not strong influence on business location are SOP, human resources and prices, and distribution.

The main advantages of hydroponics are the production in unsuitable soil conditions and better control over water, fertilizer, climate, and pest factors for plants. These result in higher productivity and income [6]. In addition, hydroponic products are fast to harvest and have consistently good quality and high nutrients [6], and the cultivation improves the environmental quality [28]. These are attributes of hydroponic products [32] that are attractive to consumers [36].

The installation variable as the excluded variable has a substantial direct influence on SOP, a strong influence on the business location, and receives a fairly strong influence from HR. Automation is an important aspect of minimizing the workforce, but given the technical constraints and budget availability, business decisions must be strategic [38], [39]. Internet of Things (IoT) allows agricultural operators to remotely monitor the farms in real-time from anywhere, although the system depends on the Internet connection and consumes high energy [44].

The interconnectivity suggests that sustainable hydroponic development can be carried out properly only if there is good governance in the business. Good governance requires costs, good quality, good delivery, product variety, innovation, food safety, and quality management systems involving producers, post-harvest managers, and other actors in the supply chain [30]. Good governance is important because the development of sustainable hydroponics has considerable potential, both from a technical and economic perspective. It should be noted that this is not because of the low capital costs but because hydroponic cultivation can accurately predict and has more control over businesses, future agricultural production, and market size [20]. Controls must be comprehensive to obtain the most appropriate method from the planting system, nutrient content, use of planting media, and pre and post-harvest to meet the nutritional demand sustainably [46].

3.2. Rank Comparison

The changes in variable ranking based on the influence and dependence compare the initial conditions (Matrix of Direct Influence, MDI) and after the interaction (Matrix of Direct and Indirect Influence, MDII) [25]. Figure 5 displays the shifts in the order of several variables, suggesting the changes in the variable influence in the future. The predictions are necessary to inform the decision- and policy-making to make hydroponic businesses sustainable. The price variable will decrease in priority, and conversely, consumer preferences will increase in priority to replace the price variable. The location variable will decrease in priority, and product distribution will increase.

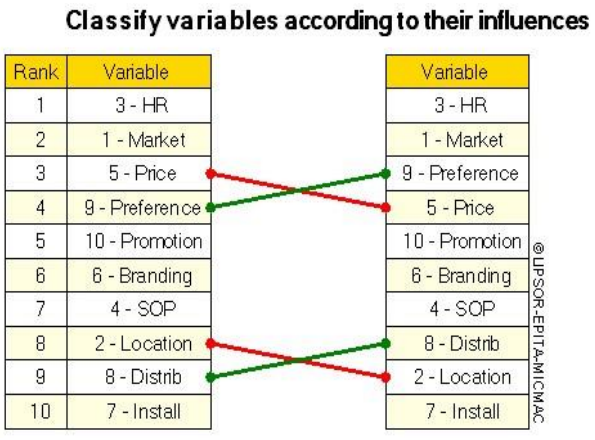

Figure 5. Classification of variables

This priority list suggests that promoting the advantages and benefits of hydroponic products needs to continue because product brands and promotions affect the purchase of hydroponic products [36]. Hydroponic businesses can choose locations close to consumers because soil characteristics are not a critical success factor [6], [20]. In addition, consumer needs in the future may lean more toward quality [30], [34]. This means that a suitable distribution mechanism is needed so that products can reach consumers of good quality [31], [47].

Figure 6 indicates that the price decreases when the market increases. The distribution has decreased by two levels, replaced by SOP and hydroponic locations. Besides, consumer preferences decrease, replaced by product distributions. These changes indicate dynamics that may occur in hydroponic cultivation due to consumer dynamics. Their preferences are determined more by product quality and benefits [31], [33], [47]. Consumers are willing to pay higher prices for quality products [34].

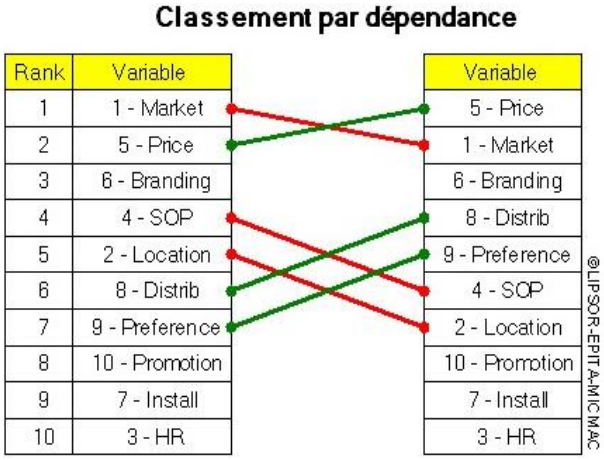

Figure 6. Classification of variables according to their dependence

4. Conclusions

The key variables for sustainable hydroponic business development consist of 1) markets, 2) locations, 3) human resources, 4) SOP, 5) prices, 6) branding, 7) installation systems, 8) distributions, 9) consumer preferences, and (10) promotions. Human resources (HR) was the key driver in sustainable hydroponic development because it held the most decisive direct influence on other vital variables. Markets, consumer preferences, and prices held an impact but were dependent on other variables. Branding, SOP, business locations, distributions, and promotions had a minor influence and highly depended on other variables. Meanwhile, installations possessed a negligible effect and little dependency, and without them, the system would not stop. Efforts to develop hydroponic farming in the future need to promote the advantages and benefits and improve the distribution mechanism.

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