Journal of Sustainability Science and Management *eISSN: 2672-7226*
Volume 16 Number 8, December 2021: 134-157

HETEROGENEOUS IMPACTS OF AGRI-TECH ON MULTI-DIMENSIONAL ASPECTS OF AGRICULTURAL SUSTAINABILITY: THE CASE OF WATER-SAVING TECHNOLOGY AND POLYHOUSE

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Submitted final draft: 29 December 2020 *Accepted: 18 February 2021* http://doi.org/10.46754/jssm.2021.12.010

Abstract: The debate over the role of technology in maintaining sustainable agriculture has garnered significant attention. This study evaluates the role of technology on multi-dimensional aspects of agricultural sustainability in Vietnam. Based on the foundation of indicator-based assessment approach and expert elicitation method on two comprehensive evaluation frameworks SAFA - FAO (2014) and RISE 3.0 - Grenz *et al.* (2016), and guided by the assessment protocol of Van Asselt *et al.* (2014), 14 indicators are identified as suitable for the local context. Welch's ANOVA and Scheffé tests are applied to compare traditional, semi-modern and modern farming. Overall, the results showed that the application of modern technology sustained agriculture in economic and social dimensions. There were no significant environmental differences due to equivalent detrimental consequences among farm types. Noticeably, the alarming level of greenhouse gases (GHG) at hydroponics farms indicates a necessity for more environmentally friendly technology. The overall sustainability scores were in favor of modern farming. Welch's ANOVA rejected the null hypothesis to signal significant differences among farm types that reinforced our endorsement over the supportive role of technology in sustaining agriculture.

Keywords: Agricultural sustainability, technology, multi-dimensions, greenhouse gas.

Introduction

The world's population is estimated to reach 9 billion people by 2070 (Lutz *et al*., 2001). By 2050, it was forecasted that the world population would be increased by 50%, which would put pressure on food demand (Tilman *et al*., 2001). To meet the demand, it is necessary to raise productivity of agricultural land (Garnett *et al*., 2013). If traditional methods are maintained, and if productivity is held constant, the current agricultural land area will have to be doubled (Tilman *et al*., 2001). However, such expansions is impossible because agricultural land is on the shrinking trend (Carvalho, 2006; Singh *et al*., 2011). Furthermore, expansion of agricultural land area has negative impacts on the environment such as the increasing amount of greenhouse gas, the lack of biodiversity, and biological balance (Garnett *et al*., 2013). In addition, traditional agriculture is facing multidimensional sustainability problems, including the environment (e.g. the excessive use of chemical pesticides or fertilizers) (Berg & Tam, 2012 ; Berg & Tam, 2018), economic (e.g. increased production costs), and social (e.g. lower labor wages) (Singh *et al.,* 2011). As a result, conventional agriculture is no longer suitable to feed humans and preserve the ecosystem (Lichtfouse *et al.,* 2009); thus, the development of a more sustainable agriculture is being sought worldwide, especially in developing countries where agriculture plays an important role in improving the livelihoods of people.

Nowadays, technology breakthroughs are expected to ramp up agriculture to the next level by minimizing cost in every aspect of sustainability. Nevertheless, there are trade-offs in modern technological applications. A study of hydroponic lettuce in the United States reports that hydroponic offers 1.7 times higher yields, but requires 11 times more energy compared to conventionally produced lettuce (Barbosa *et al.,* 2015), which are regarded as an underlying reason of greenhouse gas emissions into the environment (Spangenberg, 2002). However, there are noticeable discrepancies about the role of technology in sustaining agriculture among different countries. In fact, Aerni (2009) studied the diverging views in the public debate over sustainable agriculture and found that stakeholders' perception varied upon different agricultural policies; while New Zealand respondents believed that changes in technology were necessary for agricultural sustainability, Swiss respondents perceived that new technologies were likely to weaken the sustainable state of their agriculture due to the country's conservative agricultural policy. Khan's (2018) review of hydroponic farming revealed many benefits and few drawbacks. Unlike other economic sectors, agriculture depends on natural resources, so researchers have focused on environmental aspects (Edwards *et al.,* 1993; Lewandowski *et al.,* 1999; Berg & Tam, 2012; Berg & Tam, 2018). However, the integration of economic, social and environmental dimensions is needed to build sustainable agriculture (Quintero-Angel & González-Acevedo, 2018). The relevant literature mainly concentrates on the unidimensional impacts of modern technologies on agricultural sustainability (e.g. Manda *et al.,* 2016; Ahmadaali *et al.,* 2018), as such, Christianson and Tyndall, (2011) called for broader consideration for the philosophical implications of technology in agriculture from future research. Moreover, it is necessary to conduct more research on the effects of technology on sustainable agriculture in a multidimensional way. This offers a clearer view and facilitates comparison among different agricultural production systems (Quintero-Angel & González-Acevedo, 2018). The results of this study can provide quantitative evidence on the role of technology in agricultural sustainability. This study aims to provide empirical evidence on the role of technology on multidimensional aspects of agricultural sustainability.

The contribution of this paper is twofold. On the theoretical aspect, given the complex but generic nature of sustainability frameworks in use (i.e. SAFA and RISE), the contribution of this paper lies in the advent of a tailored sustainability framework which takes into account context specificity, thus is useful for future studies of analogous assessment in a developing country. On the practical perspective, studies assessing the impact of technologies on multidimensional agricultural sustainability in Vietnam are lacking, which this study aim to contribute to the current body of literature.

Methodology

This paper followed the sustainability assessment protocol of agri-food production systems (Van Asselt *et al.,* 2014). A consultation group of seven experts with knowledge on multidimensional sustainability assessment (economic, social, and environmental) was formed. Due to practical difficulties to appoint a policymaker, an expert was selected to play this role, as recommended by Van Asselt *et al.* (2014) and Dang, (2020). This soil scientist works in the faculty of land and real-estate management at Nong Lam University. He also worked closely with local authorities in various past projects; thus, he was very familiar with the local policymaking process. He was not involved in the case study definition stage, but hereafter participated in the assessment protocol. All eight steps of the assessment protocol were carried out as instructed except the weighing tool as the authors intended to compute the sustainability index manually to facilitate future replication and to mitigate dependence on tools.

Definition of The Case Study

The research was conducted in Da Lat City to examine the influence of technology on maintaining agricultural sustainability. Water-saving technologies (i.e. sprinkler and dripping systems) and polyhouse were the technologies of choice owing to their ubiquitousness in the study site. Lettuce production was investigated as the most ubiquitous in local leafy green produce that appeared lucrative from technological application.

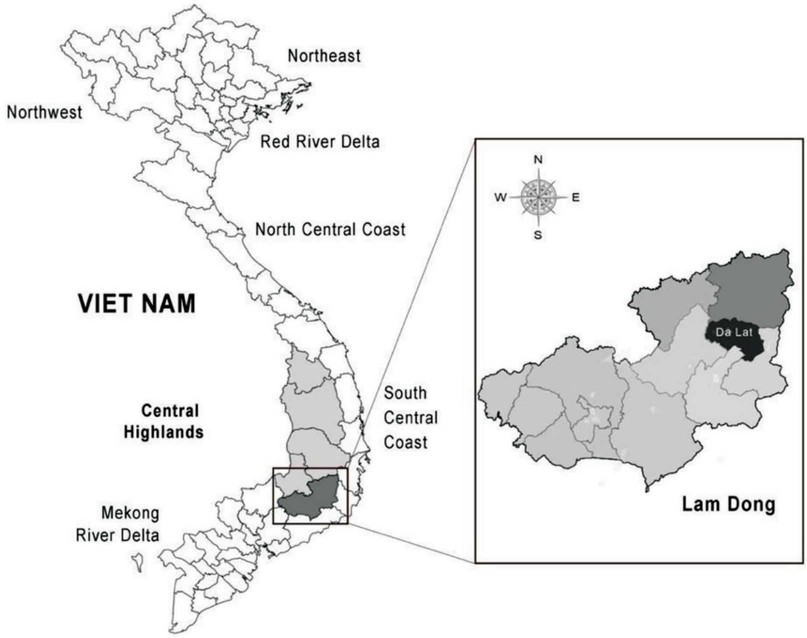

Figure 1: The study site, Da Lat City in Lam Dong Province, Vietnam

Short and Long List of Indicators

Based on literature reviews and expert consultation, a set of themes that addresses sustainability problems within social, environmental and economic dimensions of the case study was selected. Then, specific indicators were elaborated for each theme using the following criteria: (1) they be quantifiable, (2) they must be able to capture changes, (3) they must contribute directly to the theme, (4) they should relate to the case study (Roy & Chan, 2012; Marchand *et al.,* 2014; Dang, 2020).

The long list of indicators was minnowed down to more precise and simple set, based on (1) at least one indicator must be selected for each dimension, (2) at least one indicator of profitability for economic dimension, (3) an indicator of societal support with policy relevance (4) broad indicators should be prioritized to enrich information harness, (5) data availability (Roy & Chan, 2012; Marchand *et al.,* 2014; Dang, 2020).

Evaluation

Similar to Van Asselt *et al.* (2014), this stage was included in the process of shortlisting indicators as the expert who played the policymaker was also involved.

Sustainability Limits

Van Asselt *et al.* (2014) recommended that indicators must be assessed against their sustainability, mid-sustainability, and non-sustainability limits. This classification was based on legal norms, regulated policies, or literature reviews, and they were used to assess to what extent the current farm systems reach the sustainability limits. In case none of the mentioned data were available, best practices were used as an alternative. When only non-sustainability limits and sustainability limits were available, mid-sustainability limits were interpolated from the two. Extrapolation was used in case only one limit was available along with the mid-sustainability limit.

Weighing

Weighing and aggregation were conducted in a stepwise manner. At the first step, weights were assigned by the consultation group based on the scope of the study and their judgment of how important each indicator contributes to the final sustainability index. To make it simple, experts were requested to assign weights at theme levels only, which meant that all indicators were treated equally important, similar to some assessment frameworks, e.g. Rise 3.0 – Grenz *et al.* (2016), SAFA – FAO (2014). The weights were on a 100 percent scale, of which all themes weighed an aggregate 100 percent. In the second step, indicator values were converted to a scale of 100 against defined sustainability limits. At the third step, each theme score was computed by averaging out individual indicators within that theme. The last step was to aggregate theme scores according to weights to derive the final sustainability index.

Data Collection and Analysis

Data were collected by a structured survey on-site among lettuce farmers from December 2018 to April 2019. The snowball sampling method was employed to locate farmers with similar required characteristics from the initial contact list obtained from local extensionists. Five local enumerators were hired to assist in data collection. A total of 119 farm owners were surveyed, including traditional (24.36%), semi-modern (67.22%), and modern farms (8.4%). Three types of farms were defined as:

(1) Traditional farming: Farming on land employing traditional practices without the help of technology and human labor-intensive.

(2) Semi-modern farming: Farming on land with some technological assistance including irrigation technology (e.g. sprinkler, drip systems) and polyhouses.

(3) Modern farming: Farms with a full package of hydroponics technology in a polyhouse.

Primary data were pre-processed on-site to ensure correctness and to avoid missing data. Post-survey data computation was conducted after. After computing the sustainability index, the authors intended to employ ANOVA test to evaluate any existing statistically significant differences of technologies on every aspect of agricultural sustainability and on the overall sustainability index of farms. Despite the robustness of ANOVA under unbalanced sample sizes, the pre-test of ANOVA violated the variance homogeneity assumption, the variance ratios between groups were larger than 1.5 that could threaten the robustness of the F-test and imply Type I error (Blanca *et al.,* 2018). Welch's ANOVA test was the selected alternative to the ANOVA, as the test performs better in the case of asymmetric populations (Levy, 1978). P-values of the alternative Welch ANOVA replaced the pre-values obtained from ANOVA. When the difference in sustainability among different tech groups was significant, the Scheffé test was conducted to evaluate pairwise comparison of technologies that impacted statistically significant different values in the sustainability index.

Indicator Review and Measurements

The selection of indicators was based on defined criteria mentioned above from the literature. After the review of 48 indicator-based sustainability assessment tools, de Olde *et al.* (2016) has reported RISE 3.0 as the most relevant tool to perform the sustainability assessment at farm-level. Inspired by the mentioned study, the indicator list of RISE 3.0 acts as the referential backbone of this research, accompanied by SAFA framework in case complements were needed to fulfil the assessment objectives when particular indicators in RISE 3.0 fail to comply with the filtered criteria due mostly to the local context. The assessment framework of this study was constituted by the following indicators:

Environmental Dimension: The indicators listed in the environmental aspect describe environmental quality in the most general way. Those include greenhouse gas emission, soil quality, water management, crop productivity and diversity of agricultural production, and locally adapted varieties. These indicators are classified into four different themes: atmosphere, water, land, and biodiversity.

Greenhouse Gas Emission (GHG): Annual greenhouse gas emission from farminghas a significant impact on the agricultural environment (Godfray *et al.,* 2010). The concentration of greenhouse gas, especially carbon dioxide has increased over years, leading to global warming and climate change. According to the MNRE (2014) in Viet Nam, the amount of GHG released between 1994 and 2010 increased rapidly from 103.8 million tons of CO_2eq to 246.8 million tons of CO_2eq, where the figure for agriculture sector increased from 52.4 to 88.3 million tons of CO_2eq. The total amount of emissions estimated from 2010 to 2020 will increase from 246.8 million tons of CO_2eq to 446 million tons. The figure for the agricultural sector will rise from 88.3 to 109.3 million tons of CO_2eq. GHG is calculated by estimating the amount of greenhouse gas emitted at every step of the cultivation process. The final GHG index is then compared to sustainability limits derived from RISE 3.0 to estimate the sustainability score on a scale of 100. In this article, the amount of carbon dioxide released into the atmosphere is calculated by Cool farm tool (https://coofarmtool.org), suggested by SAFA.

Water Management: This indicator shows a part of the effective application of irrigation technologies and farmer's knowledge. A rise in population and increased amount of irrigation causes the amount of groundwater to significantly reduce (Pimentel *et al.,* 1997). Lack of water also comes from the shortage rainfall due to unexpected changes in the weather (Pimentel *et al.,* 1997). Therefore, the efficient use of water will preserve water sources and to provide enough water for crops and plants regardless of changes in the weather. This indicator will facilitate readers to comprehend water management practices in sustainable agriculture in Vietnam. This indicator was measured by two factors – monitoring of farms' daily water consumption and measures to improve water consumption. The indicator was rewarded 100 points if a farm applied both water resources management and water conservation measures as much as it can in the farming cycle. In case of monitoring water intake without preservation measures, one can only receive a maximum score of 50. No effort on both activities resulted in a score of zero.

Diversity of Agricultural Production: The index refers to the diversity of plants and production. It was calculated by two factors: the presence of rotation/intercropping and types of plants on the farm. Intercropping and rotating cultivation are recommended worldwide in different farming settings to enhance the effectiveness of land use and also improve soil fertility. In Brazil, intercropping corn plants and beans on the same hectare has shown productivity advantage. In a more difficult environment, corn can be replaced by other crops (sorghum) that can withstand higher drought and stimulate a higher yield of legumes (1.25-1.58 times). The intercropping and rotational methods not only demonstrate stability in production but also reduce soil erosion and increase soil nutrient content (Altieri, 1999). Zero points were assigned to farms cultivating lettuce only. The most diversified production received the maximum points of 100.

Crop Productivity: Crop productivity was measured on crop yields in the same unit of area. The expansion of agricultural land seems impossible, so productivity plays a leading role in economic growth in the best way (Gerdin, 2002). This indicator helps farms to measure soil quality (Arshad & Martin, 2002) and estimate environmental degradation in the form of farming (Smit & Smithers, 1993). A compelling reason to choose this indicator is that farmers spend too much money and effort into technologies to enhance productivity. Crop productivity can be considered as a proxy of soil quality. A maximum of 100 points was given to the farm with the best productivity in the local context, while the average productivity was marked with 50 points.

Economic Dimension: According to Van Asselt *et al.* (2014), to assess the economic aspect of agricultural sustainability, studies are required to have at least one indicator of profitability. Moreover, through the survey results, farm owners believe that the stability of production and supply of market inputs are indispensable factors to maintain the sustainability of a farm. So, this article investigates net income, the stability of production, the stability of supply, the stability of the market, and safety nets.

Net Income: Net income is known as a key indicator of sustainable agriculture (Smith & McDonald, 1998; Roy & Chan, 2012). To achieve sustainable farming, one must be able to at least break even, and this indicator could elucidate the role of technology adoption for agricultural sustainability. This index was calculated based on net farm income over five years. One hundred points were awarded to farms with above zero net income in the last five years. On the contrary, farms that incurred losses each year in the past five years received zero points. This measurement followed SAFA framework (FAO, 2014).

Safety Nets: The indicator measures farmers' access to formal or informal credit to ensure their production against liquidity crises (Gerdin, 2002). Some countries in Africa and many developing countries found that access to credit remained low and was a hindrance for increasing productivity in agriculture (Junge *et al.,* 2009; Namwata *et al.,* 2010). Small households often face a greater barrier to approach credit. Thus, insufficient capital was more likely to blockade farm investment and lower the chance of recovery in case of risks (Tumusiime & Matotay, 2014). Because sustainable farming requires a large amount of capital, access to credit facilitates farms' technological investment (Namwata *et al.,* 2010), to shorten the way to sustainable agriculture (Mutyasira *et al.,* 2018), and reduces potential farming risks (Reardon *et al.,* 1997). This index was given zero points when there was no credit accessibility, which was also rare in the study. The upper limit derived from farms that can access five funds from formal and informal sources.

Stability of Production: Production activities (quantity and quality) are sufficiently resilient to withstand and be adapted to environmental, social, and economic shocks (FAO, 2014). To achieve the goal, there is a need to implement the most effective solutions to manage risks and ease negative impacts on production. Unfavorable climatic conditions (prolonged drought or insufficient rainfall) are also one of the risks of agricultural production (Gerdin, 2002). This index is measured based on farmers' perceptions of risks and associated solutions. zero points were provided when the farm owner did not identify risks or could recognize them but did not take measures to resolve those risks. A list of potential production risks, collected from literature and consulted with the expert panel and local extension agents, were used to elicit farmers' perception of risks and risk management practices to measure the stability of production.

Stability of Supply: This indicator refers to the stable business relationships in providing inputs to farms (FAO, 2014). It is considered stable if inputs are sufficiently satisfied in terms of quality, quantity, and planned delivery time. The stability of supply is also reflected by quality assurance and many choices of input supply, which ensures an uninterrupted production process. Providing stable inputs is extremely important since it supports farmers in planting and harvesting on time (Gerdin, 2002). Therefore, this indicator is considered by farmers to be indispensable in supposedly sustainable agriculture. The indicator measures whether farms implement different methods to minimize the risk of supply. Zero point were given to farms without any risk-minimizing measures or mechanisms to guarantee input supply or to reduce supply risk. Similar to the stability of production, to facilitate the survey, a list of supply risks was identified to be investigated.

Stability of Market: Accomplishing market stability means that farms always maintain a sufficient number of buyers and marketing channels, thus income structure is diversified (FAO, 2014). The indicator measures how effective a farm is at minimizing the risk of market accessibility. Research shows that sustainable agriculture always has stable input and output markets (Clay *et al.,* 1998). Market access is said to be an important part of sustainable agriculture, especially in a developing country, but it is considered a local challenge (Mahon *et al.,* 2017). In terms of stability of the market, a non-sustainable farm has one or two buyers only, who are responsible for 100 percent of the annual income obtained from the product sold, and that no actions or mechanisms have been implemented to diversify and consolidate income structure. A sustainable farm has at least three or more buyers, where no buyer is responsible for a substantial part of the income obtained from products sold, and that the actions and mechanisms to maintain the income structure are underwritten contracts or agreements for at least more than a year, *ceteris paribus*, the number of buyers that one has determined his sustainability score.

Social Dimension: This indicator includes wage and income level, safety at work, capacity development, and social relationship to illustrate the living standards, the level of the accident with respect to labor, the right to develop self-capacity, and social relations at work.

Wage and Income Level: The goal of this indicator is to measure hourly wages that allow workers, including the self-employed, to live comfortably above the minimum subsistence level when working normal hours (Grenz *et al.,* 2016). This provides a measure of the financial attractiveness to work, a central aspect impacting any businesses. It is worth noting that RISE 3.0 assigns specific points to defined conditions. Yet, to comply with the current assessment protocol, this study assigned the minimum wage to the mid sustainability limit of 50 and 100 points to an hourly wage that is double the minimum wage. Non-sustainability limits were derived from extrapolation. The hourly wage was calculated thanks to the minimum monthly salary regulated by the government under Decree 157/2018/ND-CP for Da Lat City.

Safety at Work: The goal of this indicator is to assess whetherwork-related accidents and illness on a farm are at its minimum to none (Grenz *et al.,* 2016). Agricultural laborers are exposed to harmful substances, such as chemicals, insecticide and dust, which cause health problems (Berg & Tam, 2018 ; Stadlinger *et al.,* 2018). To actualize sustainability, addressing laborers' health concerns is obvious as humans play a central role in every business. Farms with no work-related accidents or reported illnesses in the last five years, along with proper safety practices were awarded 100 points, while the worst case with the biggest number of incidents reported held the non-sustainability limit with zero points.

Capacity Development: For farms to be sustainable, preferable working conditions for employees should be met, including stable employment, internal advancement, capacity development and growth (FAO, 2014). It is possible that employees with promising work conditions contribute to the development of the farm with best performance. Similarly, farm owners with access to resources to improve their own skills and knowledge, strengthen the health of their farms by providing opportunities for training to not only members of the family but also employees. To estimate this, farm owners and employees were asked about the opportunities to increase skills and knowledge on the farm. Since it was hard to measure how farm owners identify best practices or seek training, the proxy of a number of training received from the extension agents was used instead. 100 points were given to farms where both the owners and employees were exposed to training opportunities, while zero points were assigned to farms that never or rarely attend extension training, hire external workers when in need of new skills or greater capacity, and did not give employees the chance to advance.

Social Relation: This indicator measured the quality of life, particularly how on-farm personnel were satisfied with their social relations (Grenz *et al.,* 2016). All interviewees, including farm owners, were asked how satisfied they were with their family situation (communication, interaction…), and social environment (friends, colleagues…). To facilitate quantification, the authors made use of a scale ranging from zero "not satisfied at all" to ten "very satisfied". The upper and lower bounds of the scale were in accordance with 100 and zero points in this regard.

Table 1: The long list of indicators

Dimension	Theme	Indicator
Environment	Atmosphere	1. Greenhouse Gases 2. Air Quality
	Water	3. Water management 4. Water pollution 5. Water Use Intensity
	Land	6. Soil Reaction 7. Soil quality 8. Crop productivity
	Biodiversity	9. Diversity of agricultural production 10. Locally adapted varieties
Economic	Profitability	11. Net income 12. Return on equity 13. NPV 14. (Output-input)/input
	Vulnerability	15. Product information 16. Stability of Production 17. Stability of Supply 18. Stability of Market 19. Liquidity 19.1 Net cash flow 19.2 Safety nets
Social	Working condition	20. Wage and income level 21. Working hours 22. Safety at work
	Human development idea	23. Farmer's age 24. Knowledge 25. Level of education 26. Capacity development 27. Social relation

Table 2: The core list of indicators

Dimension	Theme	Indicator
Environment	Atmosphere	1. Greenhouse Gases (kgCO2eq) [1, 2]
	Water	2. Water management [1, 3]
	Land	3. Crop productivity (Kg/ha/crop) [1]
	Biodiversity	4. Diversity of agricultural production [1]
		5. Locally adapted varieties [2]
Economic	Profitability	6. Net income. (VND) [2, 3]
	Vulnerability	7. Stability of Production [2] 8. Stability of Supply.[2] 9. Stability of Market [2] 10. Safety nets [2]
Social	Working condition	11. Wage and income level (VND) [1] 12. Safety at work [1]
	Human development	13. Capacity development [2]
		14. Social relation [1]

[1](Grenz *et al.,* 2016), [2] (FAO, 2014) [3] (Tisdell, 1996), [3] (Sadati *et al.,* 2010)

Results and Discussions

Descriptive Statistics of the Study Sample

A total of 119 households were surveyed. The number of traditional, semi-modern, and modern (hydroponics) farms were 29, 80 and 10, correspondingly. Generally, hydroponics farmers possessed higher education, mostly tertiary education, notwithstanding less farming experiences (8.5 years) as compared to that of semi-modern farmers (20.81 years) and traditional farmers (22.06 years). Perhaps, this was due to their aim of adopting hydroponics which made its debut in Vietnam in just the past decade. This could also suggest that modern farmers were younger but much more educated to handle the new technology. The average age of hydroponics farmers was 39.1, while their traditional and semi-traditional counterparts were 46.31 and 49.91, respectively. This was in line with many studies that the young tend to try new technology rather than the older generation. This study found a promising application of modern farming over the traditional. Indeed, hydroponics farms were more profitable with average income of 2,474.79 million VND/ha/year compared to semi-modern (539.2 million), and traditional (188.82 million). Of note is that is the amount of greenhouse gas emissions from hydroponic farms, is much larger than that of traditional households. The FAOSTAT database of global emissions from agriculture has shown a growth trend of 1.6% per year and reaching 4.6 Gt CO_2eq year^{-1} in 1961-2010 (Tubiello *et al.,* 2013). Figure 2 shows that the average CO_2eq of hydroponic households has reached an alarming 71.036 tons CO_2eq/ha/year. The overall descriptive statistics of the sample can be seen in Table 4.

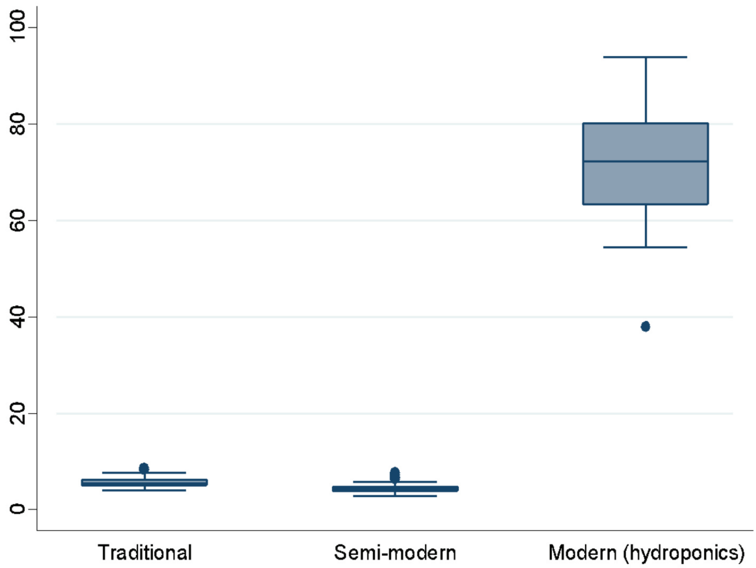

Figure 2: Greenhouse Gases Emission of different farm types (t CO_2 eq./ha/year)

Table 3: Sustainability limits for the core indicators

SN	Indicator	Sustainability Limits (SL)	Mid-Sustainability Limits (MSL)	Non-Sustainability Limits (NSL)	Sources
1	Greenhouse Gases	1.1	2.5	5	SL: 1.1 t CO_2eq/ha MSL: 2.5 t CO_2 eq/ha NSL: 5 t CO_2 eq/ha FAOSTAT (faostat.fao.org)
2	Water management[1]	Monitor +4	Monitor	0	SL: best practice MSL: interpolation NSL: 0
3	Crop productivity	55,000	27,500	0	SL: best practice (kg/ha/year) MSL: average yield NSL: extrapolation
4	Diversity of agricultural production[2]	4	2.5	1	SL: best practice MSL: interpolation NSL: 1
5	Locally adapted varieties[3]	100	50	0	SL: best practice. MSL: interpolation NSL: 0
6	Net income[4]	5	2.5	0	SL: best practice MSL: interpolation NSL: 0
7	Stability of Production[5]	2	1	0	SL: best practice MSL: interpolation NSL: 0

8	Stability of Supply[6]	3	1.5	0	SL: best practice MSL: interpolation NSL: 0
9	Stability of Market[7]	5	2.5	0	SL: best practice MSL: interpolation NSL: 0
10	Safety nets[8]	5	2.5	0	SL: best practice MSL: interpolation NSL: 0
11	Wage and income level	57,969	32,370	6,771	SL: best practice. (VND/ hour) MSL: minimum wage (Decree 157/2018/NĐ-CP). NSL: extrapolation
12	Safety at work[9]	0	2	4	SL: 0 MSL: interpolation NSL: worst practice.
13	Capacity development[10]	all criteria meet	N/A	no criteria meet	SL: best practice MSL: interpolation NSL: 0 (FAO, 2014)
14	Social relation[11]	10	5	0	SL: best practice MSL: interpolation NSL: 0

[1] The indicator measures through two separate criteria. First, whether proper water-use monitoring is applied. If so, how many water conservation measures are practiced? The most sustainable farms were found with 4 water-saving solutions, namely building a reservoir, rainwater storage, modern irrigations, and weather adaptive cultivation planning.

[2] This indicator takes into account how diversified farms are regarding the number of crop types being cultivated yearly.

[3] This indicator assesses the indigenousness of seed varieties being used on the farm. The most sustainable farms manage to employ indigenous varieties.

[4] Net income is calculated for the last 5 years. The farm's yearly net income must be ensured to equal or greater than zero.

[5] A qualitative interview was deployed to identify farmers' most common production risks and their associated solutions. A list of 3 risks, including unqualified quality, insufficient supply output, and only one variety were found and 2 solutions - crop rotation and intercropping - have been pinpointed by the people to address those risks.

[6] A qualitative interview was deployed to identify farmers' most common of supply risks and their associated solutions. A list of 3 risks - not in time supply, only one supplier and conflict with suppliers - was found and 2 solutions – diversify input resources, and select reputable suppliers. - have been identified by farmers to address those risks.

[7] A qualitative interview was conducted to identify farmers' most common market risks and their associated solutions. A list of 5 risks - only one partner, only one product sold, price fluctuation, market inaccessible and mouth contract - was found and 3 solutions -diversified partners, distinct crops and paper contracts - have been identified by the people to address those risks.

[8] Safety net aims to address farm financial difficulties. The most sustainable farms can access all five credit sources - bank, credit funds, social, family, friends and NGOs.

[9] Accidents at work (on-farm) are measured for the past 5 years. Four workplace accidental events including machinery and equipment accidents, child laborers, contaminated with toxic chemicals, and health problems were found in this study. The most sustainable farms recorded no accidents in the past 5 years.

[10] 100 points were given to farms where the farm owners and employees were exposed to training opportunities, while 0 points were assigned to farms that never or rarely attend extension training, hire external workers when in need of new skills or greater capacity, and did not give the internal employees the chance to advance. For brevity, the proxy of a number of training received from the extension agents was used for comparison.

[11] The satisfaction of farmworkers with colleagues is recorded ranging from 0 "not satisfied at all" to 10 "fully satisfied".

Table 4: Descriptive statistics of farm characteristics and sustainability characteristics

Characteristics		Traditional				Semi-modern				Modern (Hydroponics)			
Mean		S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	
Socio-demo													
Age (years)		46.31	9.95	29	70	49.91	10.7	26	80	39.1	9.95	30	53
Gender (1=male, 0=female)		0.58	0.50	0	1	0.8	0.40	0	1	0.8	0.42	0	1
Area (1,000m^2)		5.22	2.72	1	10	2.80	3.65	0.3	25.9	4.37	6.28	0.5	20
Experience (years)		22.06	9.47	5	50	20.81	11.99	2	50	8.5	8.69	2	30
Education (years)		10.4	2.44	5	16	10.75	3.16	0	16	14.8	2.69	12	20
Sustainability													
GHG (t CO_2 eq./ha/year)		5.82	1.28	4.09	8.61	4.43	1.04	2.85	7.726	71.03	17.13	37.9	93.9
Water management (no. of practices)	Monitor (1=yes; 0=No)	0.48	0.51	0	1	0.27	0.44	0	1	0.8	0.42	0	1
	No. of water management measures	1.55	0.82	0	3	1.23	1.05	0	4	1.6	1.42	0	4
Crop productivity (ton/ha/crop)		17.89	2.19	15	20	21.16	7.64	5	55	32.4	6.93	20	40
Diversity (no. of crops)		2.86	0.78	1	4	1.36	1.65	0	4	1.5	1.17	0	3
Locally adapted varieties (no. of indigenous seeds)		0	0	0	0	12.5	32.31	0	100	0	0	0	0
Stability of production[1]	Risk perceptions	2.4	0.41	2	3	1.76	0.99	0	3	2.79	0.41	1	3
	Risk solutions	0.96	0.18	0	1	0.43	0.52	0	2	0.96	0.18	0	2
Stability of supply[2]	Risks perceptions	2.3	0.67	1	3	1.18	0.99	0	3	2.41	0.68	1	3
	Risk solutions	1.8	0.91	0	2	0.51	0.84	0	3	1.57	0.57	0	3
Stability of market[3]	Risk perceptions	4.2	0.78	0	5	3.51	1.45	0	5	4.55	1.02	3	5
	Risk solutions	2.9	1.37	0	4	1.12	1.18	0	5	2.68	0.71	1	4
Safety nets		1.58	0.98	0	3	1.55	1.25	0	4	2.6	1.42	1	5
Net income (million VND/ha/year)		488.35	420.59	118.8	2000	1,976.51	4,468.48	-16,310.2	22,940	17,844.08	20,185.27	933.5	58,020.4
Wage & income level (1,000VND/hr.)		14.55	1.4	11	17	31.87	11.72	15	62	39.7	17.65	16	63.25
Safety at work		0.58	0.5	0	1	0.96	0.75	0	3	0.3	0.67	0	2
Capacity development		0	0	0	0	0	0	0	0	1	0	1	1
Social relations		8.41	1.18	7	10	8.48	1.12	7	10	8.2	1.47	6	10

Detailed description and measurements are given in the footnote of Table 3.3

Statistics of Sustainable Descriptions of Sustainability Aspects by Farm Types

Overall, the three aspects of the three types of Welch's ANOVA tests showed the differences (Table 5). According to the ANOVA test, there is no strong evidence that the different farm types had varying environmental impacts. Despite one of the ultimate goal of sustainable agriculture is to create systems which minimize or eliminate any negative environment effects (Horrigan *et al.,* 2002) and some studies illustrated that technology applied in agriculture solved and minimized emission problems and thus led to environmental protection (Aerni, 2009). This study stressed that this is not necessarily the case, which is in line with the results of a study in Switzerland that technological application neither reduced the amount of greenhouse gas emissions nor contributed to agricultural sustainability (Aerni, 2009). It was similarly contended that during the cultivating process more than half of the agriculture land area caused ecological degradation and released a large amount of greenhouse gas, which had a detrimental impact on the global environment (Tilman *et al.,* 2001; Agovino *et al.,* 2019).

The Environmental Dimension

Although the environmental aspect showed no distinction, it is more complicated when discussing internal indicators evaluating the environmental impacts among various farm types. Under the environment dimension, Figure 4 reveals the contribution of each indicator, including water management, GHG emission, agricultural diversity, locally adapted varieties, and productivity.

The water management indicator of semi-modern farms has a sustainability score of 18.5, lower than the other two farming systems (Figure 4). Although the score of modern farms gets the highest value at 51.4 points, it has no difference in comparison with traditional farming (34.62 points). Most farmers in the semi-modern farms choose dripping and misting technologies as water-saving tools, which are also two of the most effective irrigation techniques (Chartzoulakis & Bertaki, 2015). According to Pimentel *et al.* (1997), automatic drip irrigation techniques in Texas saved up to 35-56% of the amount of water per area unit compared to traditional irrigation methods. Similarly, Sheikh (2006) also showed that hydroponic methods saved water up to 10 - 30 times compared with other conventional production models per area unit. Besides the technology, farmers are required to maintain close monitoring of water use and precautions for existing water sources. In this research, an irrigation schedule is almost non-existent because farmers do not have a fixed schedule, which causes excessive water use due

Table 5: Welch's ANOVA of the difference between sustainability aspects among distinct types of farming

Dimension	df	MS	W	p – Value
Environment	2	27.93	1.959	0.1599
Economic	2	23.27	48.947	0.0000
Social	2	23.79	73.195	0.0000
Overall	2	23.43	32.928	0.0000

Table 6: Scheffé test of the difference between groups

Source	Economic		Social		Overall	
	Traditional	Semi-modern	Traditional	Semi-modern	Traditional	Semi-modern
Semi-modern	-20.8401***		6.82543**		-7.31078***	
Modern	6.67241	27.5125***	44.1379***	37.3125***	16.2517***	23.5625***

*, **, *** are significance levels in accordance with 10%, 5%, 1%.

to no water cost. Moreover, farmers have no precautionary measures for water risks. Four effective measures for water management are building a reservoir, rainwater storage, modern irrigation, and weather adaptive cultivation planning. However, all of the three farm types use one or two preventive measures. Therefore, the distinction is inconsequential. Furthermore, greenhouse gas emissions are not only showing substantial dissimilarities between the three farming types but also exceed the permitted level. Specifically, the sustainability score of modern farms is zero while semi-modern and traditional households score 2.75 and 16 points respectively. Farmers' investment in technology seems accompanied by the amount of GHG released into the environment. The underlying root cause is attributed to the excessive use of energy (Tilman *et al.,* 2001). Indeed, hydroponics systems often require the continuous use of electricity or gas for pumps to keep the system functional, which lead to the amount of GHG emitted. It is similar for semi-modern farms.

Although traditional farming households do not consume much energy, changes in land use and excessive fertilizers also result in the release of GHG in the atmosphere. Table 4 shows the average greenhouse gas release into the environment from traditional farms is approximately 6 tons CO_2eq/ha/year, semi-modern farms are around 4.5 tons CO_2eq/ha/year, and notably, modern households reach a peak at 71 tons CO_2eq/ha/year. Regarding locally adapted varieties, the indicator indicates similar practices between the three farming types. Regardless of the important role of seed in preserving the indigenousness, local seeds are inferior to imported ones. In this study, there are only ten semi-modern farms who report the usage of local varieties. In short, water management, greenhouse gas and locally adapted varieties in terms of environmental sustainability do not prove dissimilarities between researched farming systems. In contrast, two indicators of crop diversity and productivity are found different between these farms. The diversity of agricultural production in Figure 4 shows that the average sustainability score of traditional farms (64.75) is nearly twice as high as that of modern (31.4) and semi-modern farms (31.73). This advocates that modern and semi-modern farming are less sustainable than the traditional on this aspect. It can be explained that while technology application is often designated to a homogeneous or interrelated crop, traditional farms, on the contrary, gain much flexibility in crop production. For example, the hydroponic dripping system on strawberry can hardly be applied on lettuce without the medium which requires a constant flow of nutrient and water circulation to the roots. To achieve crop diversity, intercropping and crop rotation were assessed. According to previous research, monoculture is prone to diseases and pests (Lin, 2011; Agovino *et al.,* 2019) while intercropping is a form of biodiversity and ecosystem in agriculture, which maintains soil quality, protects the environment, creates effective deterrent against pests, and produces greater yield on the same land allotment by making more efficient use of the available resources using a mixture of different crops (Dwivedi *et al.,* 2015). Besides, crop rotation boosts soil fecundity, reduces eradication, pests, and diseases (Doran, 2002). In the study, hydroponics farms often grow a single crop all year round but this does not affect their productivity because water, as well as nutrient solutions, is renewed after each harvest. In fact, the productivity of modern farms is much higher than the other two. The average yield of the hydroponic farms is 32,400 kg/ha/crop while that of traditional farms and semi-modern farms are approximately 18,000 kg/ha/crop, and 21,000 kg/ha/crop, respectively (Table 4). Thus, the productivity score of hydroponic farms is the highest (59.2), followed by semi-modern (38.37) and traditional farms (32.32). This outcome might corroborate the hypothesis that crop yields of conventional cultivation methods can be low due to the excessive use of pesticides and chemical fertilizers, which directly affects soil quality (Rasul & Thapa, 2004). In contrast, in hydroponics farms, the nutrient solution is always renewed after harvesting thus the yield remains stable (Sheikh, 2006; Sharma *et al.,* 2018). Nevertheless, it should be noted that 100% of modern farmers had to dispose of the residual nutrient solution directly to the environment before refilling and renewing the tank for the next crop, which have very negative effects for the environment.

The Economic Dimension

In terms of the economic aspect, Welch's ANOVA test signals the difference between three farming types (see Table 5 and Figure 3). The economic sustainability decreases from modern (64 points), traditional (54 points) to semi-modern farms (37 points). This suggests that technology plays a crucial role in the economic growth (Self & Grabowski, 2007). The Scheffé test identifies pairwise differences between farm types on the economic dimension except between the traditional and modern farming (see Figure 3). In the economic indicator set, net income is in favour of traditional farms (100 points) than modern farms (98 points) and semi-modern farms (86.5 points). The indicator measures whether the net income of farms is greater than or equal to 0 in the last 5 years. On the contrary, a research on groundnut farms in Uganda interprets that the net income index of households applying technology is higher than of traditional farming households (Kassie *et al.,* 2011). The inconsistency is expected to rest on the differentiation between assessment methods. While other studies rely on the absolute value of net income in the most recent years, this research investigates the sustainability and the presence of positive cash flows in the most recent and consecutive five years rather than comparing the monetary values. Traditional farms are found with a more stable income due to their form of outsourcing which lessens risks and ensures positive farm profits. It is worth noting, despite being more sustainable, the absolute amount of net income gained from traditional cultivation is way smaller than the other farming systems. The average net income of traditional farms is 488 million VND/ha/year in 2018, which is less than semi-modern farming and modern farming with 1,976 million VND/ha/year and 17,844 million VND/ha/year, respectively (see Table 4).

Apart from net income, the stability of production, supply, and market, and safety nets

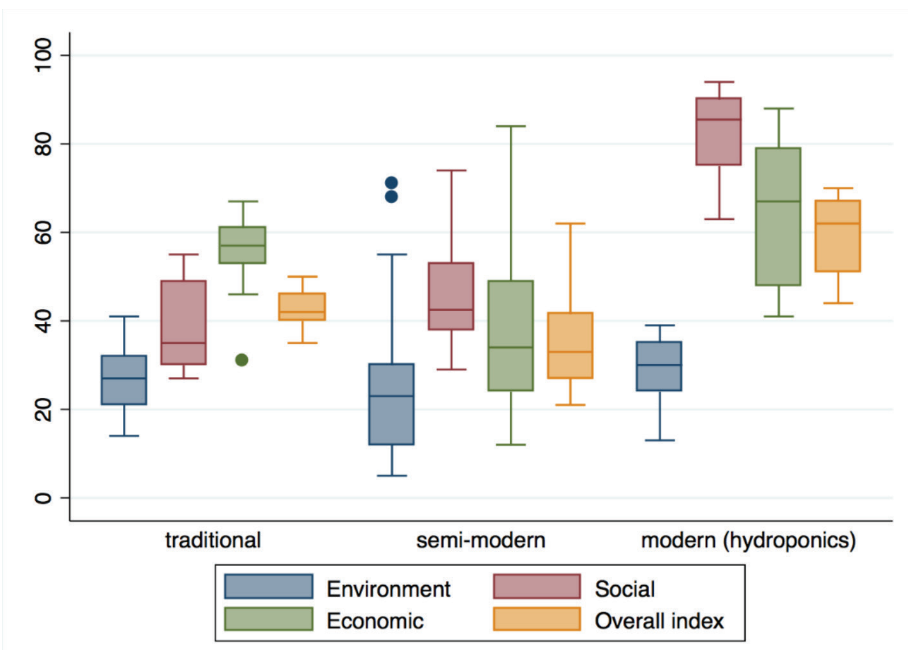

Figure 3: The variation of the sustainability aspects of different farm types

pointed out the dissimilarity between the three farming types (see Table 7). Three indicators such as the stability of production, supply and market are an integral part of the sustainable assessment in the economic dimension. In this aspect, modern farms outperform traditional and semi-modern farms. Farmers' awareness about the production, supply and market risks accompanied by farming seems not enough. It is vital that the household must take measures to address those risks. In Figure 4, these three indicators show the superiority of modern farming over the rest. Regarding the stability of production, three common risks are measured namely unqualified quality, insufficient output and merely one variety of crop. The results illustrate that most farmers acknowledge the existence of those risks, yet very few attempts are made to address the issues. Some farmers have employed two risk remedies - crop rotation and intercropping, but this index remains low for all farms.

In the same way, modern farms occupy the top sustainability score on the stability of supply (60.1 points), while traditional farms and semi-modern score 50.62 points, and 17.06 points, respectively. Most modern farm owners opt for reputable and diverse source of inputs for seeds and fertilizers to ensure on-time planting schedules. Besides, traditional farms are provided all inputs by the contractors/traders, which guarantees stable production activities. For semi-modern farms, most of them are aware of the risks but no actions have been made to tackle those risks. Often times, these households are too reliant on the availability of the suppliers, which make them less ready and more vulnerable to input shortage.

The indicator of market stability is estimated by five risks, including only one trading partner, one kind of product to sell, price fluctuation, inaccessible market, and oral contract. Those risks are the result of qualitative interviews of selected key farmers and local experts including the extension agents. The study found that risks are well-perceived, but coping choices vary among farms. Modern farm owners discern about three to four risks and at least three out of five risks are found on each farm. (see Table 4). Each type of farm practices different measures to mitigate risks, such as finding more trading partners, diversifying crops, and using written contracts. However, traditional farmers prefer oral contracts over paper one due to the convenience; and to them, the credibility of the contractors matter regardless of the legal

Table 7: Welch's ANOVA test of the differences between each sustainability index

Dimension	Indicator	df	MS	F	p - value
Environment	Greenhouse Gases	2	0.1265	0.35	0.999
	Water management	2	23.052	6.482	0.006
	Crop productivity	2	23.096	25.881	0.000
	Diversity of agricultural production	2	26.666	16.265	0.000
	Locally adapted varieties	2	0.1544	0.50	0.606
Economic	Net income	2	0.3632	1.20	0.3148
	Stability of production	2	22.516	26.182	0.000
	Stability of supply	2	23.335	27.875	0.000
	Stability of market	2	23.279	35.719	0.000
	Safety nets	2	0.6063	2.08	0.111
Social	Wage and income	2	21.802	94.073	0.000
	Safety at work	2	46.940	8.384	0.002
	Capacity development	2	14.681	80.71	0.000
	Social relation	2	24.791	.223	0.802

contract. Additionally, owners of modern and traditional farms often combine multiple measures to cope with risks while owners of semi-modern farms only use one such as finding multiple trading partners or crop diversification. Coffee farmers in Daklak were reported to adopt the identical way to overcome risks (Nguyen & Sarker, 2018). Therefore, the sustainability score of semi-modern farming remained lower at (22.75) than traditional farming's (53.79) and modern farming's (58).

Credit assessment is a financial-risk deterring solution. There are five credit sources, including banks, credit funds, social programs, friends and family, and non-governmental organizations, farmers could access to maintain their financial health. Many modern farms chose to access from two to three credit sources such as banks, family, and friends, while semi-modern and traditional farms prefer only one to two sources, mainly from relatives. Modern farmers can access formal sources thanks to their collaterals (Dang *et al.,* 2019). On the contrary, traditional households rely heavily on traders and oral contracts to abate their financial worries because the contractors' supply fertilizers and seeds as a condition to secure output purchases. This is very convenient and risky simultaneously, as it places much reliance on one party. Our qualitative interviews with farm owners indicate that contract breach or the contractor frequently abandons output purchase in the spot market at low prices, which leads to foreseeable financial burden if they cannot find alternative buyers. Therefore, it is reasonable to contend that modern farms are more sustainable than traditional and semi-modern ones at the angle of the credit assessment.

The Social Dimension

The differences between the three categories as well as between each pair of farming in the social aspect can be found in Table 5 and Table 6. Only one out of four indicators in the social dimension does not show differences between the three types of farming are social relations. On the ground of 80 points on the social relationship index, this implies good relationships among workers on their farms.

Three indicators of the social dimension – safety at work, wage and capacity development – show the differences between three farming systems by Welch's ANOVA test. In Figure 4, the indicator of capacity development implies that the application of advanced technologies might require both owners and workers to constantly update their knowledge to keep up with the pace of technology. It is demonstrated by the absolute score level of 100 for hydroponic farming while the two other farming types get the value of zero. The main reason is that modern production models require both good management skills and well-trained laborers to ensure farm development. For households interviewed, most of the owners of modern farming have taken part in extension training and used to study in foreign countries, then they instruct workers on their farms or send them for training. Furthermore, each farming system has various styles of hiring, which makes up the differences in wages and incomes between these systems. The average income of each worker of modern farming is 40,000 VND/hour, which is more than double that of traditional farming (14,000 VND/hour) and higher than that of semi-modern farming (31,000 VND/hour). That is possible that the employees in the modern farming often have a stable salary thanks to the nearly full-time working all year round while the part-time workers of the traditional and semi-modern usually work only 5 to 10 days on each crop for planting, irrigating and fertilizing. Findings from this study confirmed the insights of Kassie *et al.* (2011) that technology application increased labor demand and created more job opportunities for farmers. Modern farming households reach a significantly high sustainability score (62.2 points) while semi-modern and traditional farming get lower scores of 38.71 and 14.86 points, respectively. Table 8 shows that the sustainability value of modern households is higher than the two other farming systems. Modern farms apply advanced technologies to extenuate manual work, which could cause health problems among laborers. A

Table 8: Sustainability indicator value and overall index

Sustainability Indicator	Sustainability Value			Weighting
	Traditional	Semi Modern	Modern	
Environment	**27**	**23**	**28**	**0.3**
Greenhouse Gases	2.75	16	0	
Water management	34.62	18.5	51.4	
Crop productivity	32.32	38.37	59.2	
Diversity of agricultural production	64.75	31.73	31.4	
Locally adapted varieties	0	12.5	0	
Economic	**57**	**36**	**64**	**0.3**
Net income	100	86.5	98	
Stability of production	48.27	22.5	50	
Stability of supply	50.62	17.06	60.1	
Stability of market	53.79	22.75	58	
Safety nets	31.72	31	52	
Social	**39**	**45**	**83**	**0.4**
Wage and income	14.86	48.71	62.2	
Safety at work	56.03	49.06	87.5	
Capacity development	0	0	100	
Social relation	84.13	84.87	82	
Overall	**42**	**35**	**59**	

plausible reason might be associated with farm owners' education level, which predisposes them to insightful managerial knowledge including health governance.

Conclusion

This study examines the role of modern technologies in agricultural sustainability. In terms of the economic aspect, hydroponics households tend to be more sustainable than traditional households. Regarding the social perspective, the sustainable level of soil-less households ranks first among the three farm types, followed by semi-modern and traditional households. Under the sustainability assessment, the social aspect is well-maintained among those who apply technology against their non-tech counterparts. The technological prevalent farms tend to ensure their long-term maintenance, secure income, and nurture and develop their employees, whereas their non-tech competitors prefer to hire temporary employees based on their workload, and tend not to invest in the employees. In terms of the environmental aspect, there is no difference between the three sorts of cultivation. In this regard, the low average environmental scores reflected the obvious negative impacts of all categories. It is worth noting that greenhouse gas has reached an alarming level of 93,920 kg CO_2eq/ha/year/farm in the case of hydroponics. This casts doubt on the environmental friendliness of modern technologies. Lower GHG from the traditional farms corroborated this contention (the largest amount of GHG emitted from the traditional households in the observed sample is only 7,726 kg CO_2eq/ha/year/farm). Perhaps, the world needs to rethink new environmentally friendly technologies. This also suggests future research

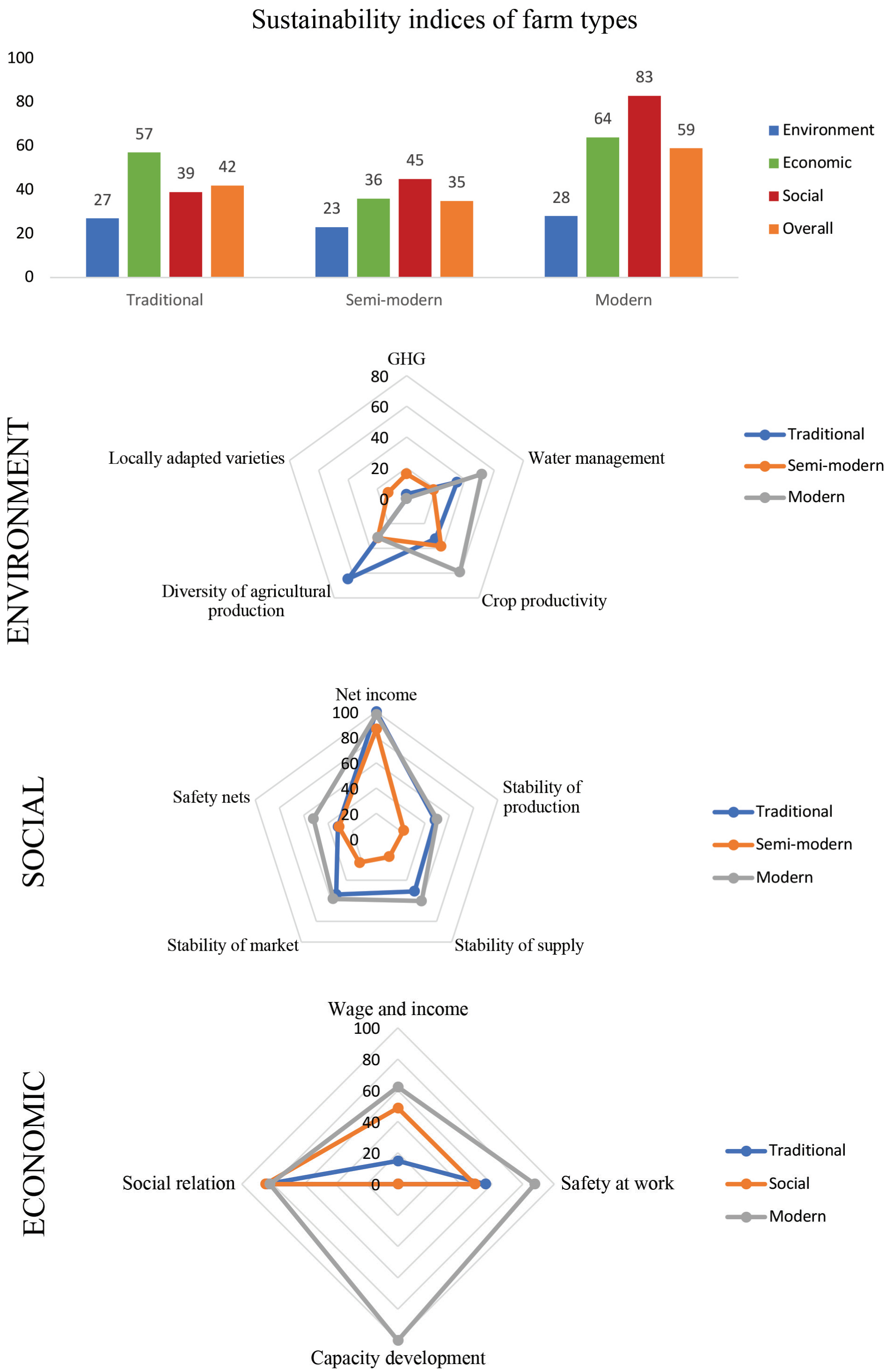

Figure 4: Charts comparing the sustainability indices of farming methods.

is needed to rigorously revisit the role of technology in sustaining agriculture, especially the environmental dimension.

Limitation and Recommendation

One of the obvious limitations of the study is the unbalanced sample size. However, this is due to the limited number of local hydroponics farms that are gaining traction gradually so future research of larger sample sizes can act as an extant to this study. Additionally, the sustainability assessment framework used in this study is highly contextual which depends on the farming commodity (e.g. lettuce), and the socioeconomic and geographic characteristics in the context of Vietnam, a developing country. Later researchers should pay attention to the compatibility of different approaches tailoring to their specific studied context. Furthermore, the type of examined technology in this paper is narrowed to the greenhouse and water-saving technology in agriculture. The results are unlikely to generalize to other technologies, indicating a tremendous demand for more research down the road for a plethora of different technology application in agriculture. For policy implication, the benefit of technologies in agriculture has its unequivocal merits and thus should be promoted through enhancing the economic and social aspects of the models. Also, local governments should never allow outdated technologies or technologies that are malignant to the environment. One potential way to incite the application of green technologies in agriculture is to impose heavy environmental taxes to offset and revive the environmental consequences and to pay incentives to those who protect the environment through the tax cuts.

Acknowledgements

We would like to express our sincere thanks to 119 farm owners and their employees, some of which were extremely helpful in referring their colleagues to facilitate the data collection process. Special thanks are to the anonymous reviewers and associate editor and editor in chief who handled the paper. This research has been funded by Nong Lam University under grant number [CS-SV19-KT03].

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