PECULIARITIES OF THE MANAGEMENT PROCESS IN THE HYDROPONIC GREENHOUSE SECTOR IN THE CONTEXT OF ENSURING SUSTAINABILITY: A CRITICAL REVIEW

Elena TOMA (DIACONU), Ionuț VOCHIN

University of Agricultural Sciences and Veterinary Medicine Bucharest, 59 Marasti, District 1, 11464, Bucharest, Romania, Phone/Fax: 0040744647410; E-mails: elenatoma2001@yahoo.com, ionutvochin@yahoo.com,

Corresponding author: elenatoma2001@yahoo.com

Abstract

Agriculture's impact on the environment, such as biodiversity loss, water pollution, and soil degradation, necessitates a balanced approach to farm management that integrates the ecological, economic, and social dimensions. This article aims to investigate the evolution of farm management practices towards sustainability and highlight current management approaches aimed at improving resource efficiency and reducing environmental impact. Our assessment suggests that innovative technologies such as precision agriculture, smart greenhouses, and soilless cultivation systems lead to increased sustainability. However, despite these advances, the adoption of sustainability assessment tools remains limited due to data availability, high costs, and implementation challenges. In conclusion, effective farm management requires a comprehensive integration of sustainability principles into all decision-making processes. Continued research and development of more accessible and practical sustainability assessment tools are critical to improving agricultural practices' long-term sustainability.

Key words: *farm management practices, sustainable agriculture, hydroponic greenhouses, sustainability assessment tools*

INTRODUCTION

The horticultural sector represents an important part of agriculture, providing the necessary vegetables and fruits for the population. The horticultural sector has been subject to continuous modernization to ensure food security in the face of limited agricultural resources and climate change. Thus, agriculture in protected spaces has increasingly developed, especially in greenhouses with modern technology designed to provide an optimal environment for maximizing agricultural productivity and protecting crops from adverse weather conditions. The expansion of intensive agriculture in greenhouse-type structures has been facilitated by technological progress in recent decades. It involves numerous inputs, such as chemical fertilizers, pesticides, mechanical equipment, fuel, electricity, etc. [46]. Currently, smart greenhouses use sophisticated control methods, communication networks, monitoring systems, and, above all, management systems that precisely control microclimate factors, guaranteeing optimal conditions for crop development.

Promoting horticulture in protected areas brings social and economic advantages but can hurt biodiversity and ecosystem services (such as water resources, soil erosion, etc.). However, there are several important elements for ensuring the sustainability of horticulture in protected areas, such as [10]: governance; sustainable and efficient use of water; conservation of biodiversity; circular economy; technology and knowledge transfer; image and identity. Designers created greenhouses to foster the growth of high-yielding crops and safeguard against unfavorable weather conditions. With technological advances, greenhouses have evolved from basic structures to advanced facilities that optimize agricultural production and minimize costs. In recent years, the horticultural sector in protected spaces has grown significantly, focusing on the creation of greenhouses that achieve higher production throughout the year while using fewer resources. For example, vertical systems (vertically stacked layer crops) aim for system sustainability and improve production by optimizing land and water use. This concept has led to the introduction of new farming methods like hydroponics, which reduce agriculture's ecological impact. Greenhouses that rely on automation and robotics include environmental sensors (programmable controllers, control systems, and cyber systems), automated decision-making tools, wireless sensor networks (tools that provide a friendly interface for greenhouse visualization and remote control of environmental parameters via GSM/GPRS, 3G/4G, Wi-Fi, Bluetooth, etc.), autonomous mobile robots that collect data on humidity, temperature, carbon dioxide concentration, etc.

Hydroponic greenhouses use the practice of growing plants without soil but with a nutrient-rich water solution that allows for increased yield and water conservation. In practice, there are two types of hydroponic greenhouses, namely DFT (Deep Flow Technique) and NFT (Nutrient Film Technique) [84]. Because it requires less water and allows for nutrient solution recirculation, hydroponics maximizes production while minimizing resource use. Hydroponic systems are fully automated and use fewer water resources compared to traditional methods. Elvanidi et al. [16] implemented the circular economy concept in hydroponic greenhouses using two-level cascade culture systems. These systems use a primary crop's drainage solution to irrigate a secondary crop, reducing freshwater consumption by approximately 30%. Benko et al. [6] say that hydroponic greenhouses have many benefits, such as the ability to grow plants in places that aren't good for it, no need for crop rotation, less water use, automatic nutrient application based on plant development stage and greenhouse microclimatic conditions, fewer diseases and pests, faster harvests, and higher productions. The following disadvantages are indicated: high initial investment; higher costs; technical skills; requires high-value species to cover costs; difficulties in disposal/reuse of inorganic and synthetic substrates. Unlike open field cultivation, hydroponics minimizes the use of resources (land, pesticides, water, etc.), avoiding biotic and abiotic stress factors, and greenhouse cultivation allow control of temperature, humidity, light, and carbon dioxide. This approach enhances production yield, optimizes scheduling, and enhances irrigation efficiency, all while reducing water consumption [80]. This type of greenhouse uses a nutrient solution for plant support, which is a mixture of water, macronutrients, and micronutrients, either with or without a substrate. Substrates for hydroponic growth can be *organic* (peat, coconut fibers, sawdust, straw, etc.), *inorganic* (perlite, sand, clay, pumice stone, zeolite, etc.), *synthetic* (polystyrene, polyurethane, and urea-formaldehyde foam). This type of smart greenhouse contributes to sustainability because it can integrate renewable energy (solar, including photovoltaic systems, hybrid photovoltaic/thermal modules, etc.) to maximize production yields and minimize water and energy consumption. Moreover, by integrating solar and wind energy sources, such a greenhouse can become energy-independent [37].

Due to these specificities, the management at the hydroponic greenhouse level must ensure the proper management of the environmental factors that affect production, namely light, temperature, air humidity, and carbon dioxide concentration. This can be achieved by controlling the light intensity, the optimal temperature, the relative humidity, and the water pH [36]. In the pursuit of sustainability, we underscore the significance of managing organic waste and converting it into energy [52], while also stressing the necessity of cost reduction to maintain profitability and efficiency [53]. From the perspective of business management, it's crucial to highlight that hydroponic greenhouses necessitate sophisticated management expertise. This includes understanding crop production, possessing technical skills to operate the automated system, understanding production flow, nutrient supply, and storage, and understanding disease and pest management, with a focus on sanitation measures.

In this context, the paper aimed to investigate the evolution of farm management practices towards sustainability and highlight current management approaches aimed at improving resource efficiency and reducing environmental impact.

MATERIALS AND METHODS

The study highlights the unique aspects of hydroponic greenhouse management by synthesizing the major specialized works in the field. To achieve the mentioned goal, it was carried out a bibliographic study that allows to present the aspects related to management in agriculture and the horticultural sector, the managerial challenges faced by hydroponic greenhouses, and methods and indicators for the evaluation of sustainability at the level it's firm. In other words, this paper uses a systematic approach to analyze management processes in the hydroponic greenhouse sector, with a focus on sustainability.

Our review considered articles presenting management practices, sustainability indicators, or case studies focused on sustainability assessment in hydroponic systems. This allowed us to carry out a qualitative analysis to assess the effectiveness of different management practices and their impact on sustainability. In the process of critical evaluation, we assessed the methodologies used in the studies, the validity of their findings, and their relevance to contemporary challenges in hydroponic greenhouse management. We have paid particular attention to how these practices either contribute to or hinder the goals of sustainability.

So, by systematically reviewing and synthesizing the literature, this paper aims to provide a comprehensive overview of the current state of management practices in hydroponic greenhouses and their implications for sustainability.

RESULTS AND DISCUSSIONS

General aspects of agricultural management and adaptation to sustainability requirements

Agriculture is the most important activity in human society, and farm management has become a vital endeavor for the efficient acquisition of food, fiber, fuel, etc. Interest in sustainable farm management has increased in recent decades, with a focus on concerns related to rural communities, ecosystems, biodiversity, ethics, technology, and agricultural policy. Under these conditions, we can say that farm management has become a complex process, depending on the different approaches to it. In general, however, it is considered that agriculture requires a sustainability-oriented approach that includes the management of biological, financial, social, etc. resources [35]. To develop sustainable food systems, it is necessary to understand that the increased use of agricultural practices (pesticides, fertilizers, and tillage) as well as the abandonment of agricultural land (due to urbanization, job prospects, or population aging) have significant negative effects on biodiversity and natural resources [10]. Since this is the case, we need to use new farming methods and management styles that are more in line with sustainable farming models. These models should make sure that the social, economic, and environmental parts of farming systems are all connected and affected by each other [22].

Farm management involves choosing the best way to allocate agricultural resources (nutrients, water, etc.) to protect the environment and efficiently transform plants and animals into products that meet consumer needs [59]. At the same time, farm management integrates elements such as the manager's technical expertise, pedo-climatic conditions, risk management, etc., or in other words, technical knowledge and land use technologies with commercial business practices [53].

Since the 2000s, there has been a growing discourse on management practices that integrate sustainability principles [45]. This is due to the emergence of numerous viewpoints about the adverse effects of agriculture on the environment, including water pollution, heightened greenhouse gas emissions, and biodiversity loss. Consequently, the agricultural policies of the European Union and other regions have shifted their focus towards promoting sustainable agriculture, a move further solidified in the European strategy of 2006.

Under these conditions, EU agricultural policy has targeted elements such as water quality (pollution by pesticides, nutrients, and chemical fertilizers), air quality (ammonia and greenhouse gas emissions), soil erosion (extensive grazing, river clogging, and desertification), biodiversity conservation (affecting ecosystems by reducing species and natural habitats), landscape protection (loss of landscape features provided by hedges and ponds), food safety and animal welfare (use of pesticides and medicines found in the product), and finally, genetically modified organisms [42]. Additionally, cross-compliance, which introduces rules for good agricultural practices, links direct payments to agricultural practices, while the second pillar of the CAP introduces agri-environment schemes, providing incentives to farmers who surpass the minimum requirements outlined in the code of good agricultural practices.

Farmers' decisions at the farm management level, in the context of these incentives and restrictions, represent the basis for implementing sustainable development in practice. Management applied at the farm level must use specific techniques to achieve sustainability goals, which has often led to protests from producers against environmental requirements that, from their point of view, affect market competitiveness. Since 20 years ago, we have observed a clear behavioral shift in farmers' management practices, a result of both political mandates and technological advancements.

Thus, we currently have farmers who have improved their management by gradually introducing environmentally friendly agricultural practices (related to resources, soil, water, animal welfare, etc.); farmers who directly implemented new technologies based on innovations in the sector (precision-agriculture based on sensors, drones, etc.); farmers who introduced from the state "turnkey businesses" with computerized solutions based on specific pedological and climatic indicators (such as hydroponic greenhouses, aquaponics, etc.) [86]. In other words, in the process of controlling the harmful effects of agriculture on the environment, farmers have had a variety of options available, from minor changes in the management process to meet the demands of agricultural policy to a complete change in agricultural practices.

Sustainability management, commonly known as the integration of sustainability elements into a company's strategic planning and strategic management process, has become necessary to ensure firms' competitiveness [24]. Schaltegger and Hörisch [64] assert that sustainability management upholds economic competitiveness by mitigating negative social and environmental impacts.

Peculiarities of the management process in the horticultural sector

Given that the agro-food industry intensively uses natural resources, accounting for 70% of water resources for irrigation, animal husbandry, and aquaculture [18] and 25% of global energy consumption [19], it is evident that conventional agricultural methods are inadequate to meet the increasing food demands.

In recent decades, there has been increasing talk of implementing sustainable agriculture principles and precision agriculture equipment as solutions to improve agricultural production and protect the environment at the same time [34]. Specialized farming, such as greenhouses with SCSs, allows horticultural crops to be grown in various environments, including marginal and arid lands. These systems maximize yield and extend growing seasons by controlling environmental factors like light, temperature, and humidity. This leads to improved economic and environmental sustainability [47].

Smart greenhouses, which offer improved energy and water management solutions and enable automatic and intelligent indoor climate adjustment, are starting to be created to support the growth in agriculture [51]. They incorporate the most recent advancements to minimize water usage and achieve zero energy and pesticide consumption [7].

Controlled environment agriculture involves growing plants (in horizontal or vertical greenhouses, chambers/compartments, or plant growth factories) using advanced horticultural techniques and technologies to increase yields and improve product quality [25]. Greenhouses, constructed from transparent materials, regulate microclimatic parameters to boost plant growth and productivity, ensuring year-round production [68]. However, obtaining horticultural products in greenhouses represents one of the most intensive agricultural systems in the world, due to the following elements: high yield and energy consumption per surface unit [85], excessive use of chemical fertilizers and pesticides [46]; climatic factors (sunlight, temperature, and air composition), etc. Designed and engineered to stimulate off-season fruit and vegetable production, greenhouses allow harvesting over multiple production cycles throughout the year, which can lead to some environmental problems, including high use of non-renewable energy, loss of biodiversity, nitrogen and phosphorus pollution, etc. [71].

In the case of protected spaces and modern greenhouses, we find many innovative technologies, such as sensors for real-time monitoring, computerized decision systems that control heating, ventilation, lighting, irrigation, etc., retractable roofs, movable walls, thermal curtains, infrared growing systems, UV protection, and climate filters, improved plastics, hydroponic and aquaponic growing systems, etc. Soilless cultivation techniques, such as hydroponic, aeroponic, and aquaponic systems, not only enhance productivity and quality by providing greater control over the root-level environment but also significantly reduce the need for water and nutrients due to the lossless recirculation of solutions [62]. As previously noted, greenhouses have become technologically complex production units (automated and with sophisticated climate and irrigation control systems) in recent decades, necessitating crop management systems adapted to these technologies [81]. Furthermore, managerial activity itself has become more complex due to quality and environmental standards, price fluctuation [82], and supply-demand imbalances caused by intermediaries [4].

Improving the management process can be achieved by using sophisticated crop management approaches, such as adhering to good agricultural practices, using integrated production and pest management strategies, practicing integrated soil health management, and adopting organic farming methods. These techniques guarantee the long-term sustainability of horticultural crop production systems.

Farm management entails the optimal use of production resources and profit maximization, emphasizing risk management (which ensures the response to uncontrollable natural conditions and market price volatility), production management (including protection of crops, the environment, etc.), marketing management, human resource management, financial management, and so on. It must implement strategies that ensure sustainability (including long-term profitability), use increasingly automated technologies and identify resource planning tools adapted to constraints given by varieties, climatic conditions, and so on. To maximize productivity, effective management in horticulture requires the transfer of know-how and technology to be integrated into classic farming systems on modern varieties and equipment. In addition to these, there is an increasing emphasis on market orientation, post-harvest management and loss reduction, farm-level processing, ensuring quality standards, developing export activities, organic products, developing marketing cooperatives, and crop development in protected areas [70].

To operate efficiently, horticultural companies must ensure the efficient use of management functions (planning, organization, human resources, leading, and control) but also ensure the functional activities of management (production, marketing, and finance). Thus, production management must be ensured. Marketing management, financial management, human resource management, resource and inventory control, quality management, and so on. Decisions regarding functional areas are interrelated and influenced by production volume, input accessibility, access to funds, employee motivation, etc. In theory, we encounter a multitude of tools for evaluating and implementing management decisions, such as operational, technological, strategic, and risk response plans; financial instruments (budgets, annual reports, financial forecasts, break-even analysis, etc.); risk management tools, etc. However, most managers in horticulture do not implement complex analysis tools to ensure increased profitability and value creation in the agri-food chain. According to McConnell and Dillon [43], farmers refuse to implement management theories and tools for several reasons: they are based on experience; decision-making according to theory can be too complex and expensive; it requires a lot of data, the collection of which is time-consuming and costly; there is uncertainty in the sector that does not justify the use of analytical tools, etc.

Understanding how we can use management tools effectively makes a difference in the market, especially due to the changes of the last decades: the orientation of farmers to the market and the reduction of support from the state; increased competition; logistics capabilities supporting large supply chains; concentration of processing at the level of transnational and multinational companies; the development of short market chains and increased vertical integration; consumer demand for horticultural products throughout the year; technological changes (plant genetics, precision agriculture, automated decision products, pest management, irrigation scheduling, etc.); capitalizing on production based on patents, property rights and certifications; concern for biodiversity and sustainability, etc.

Techniques and metrics for assessing the company's sustainability in an attempt to enhance the decision-making process

Understanding how management decisions at the farm level influence the environment helps to develop management plans that can improve long-term sustainability [57]. Measuring and evaluating the sustainability of agricultural practices at the farm level is also believed to be crucial to achieving a sustainable food system [1] [17]. It is believed that the transition of agriculture towards sustainable development necessitates the use of sustainability assessment tools to support on-farm decision-making [23], but that the actual adoption of sustainability assessment tools by agricultural practice is relatively limited [75].

The realization of sustainability assessment tools is influenced by several factors, such as available data, time limitations, and financial limits, but also by the integrative aspect, i.e., by the integration of the three dimensions of sustainability [55]; the scope, the target group (farmers, decision-makers, etc.), the selected indicators, the aggregation method, the time of realization and interpretation, etc. [8].

According to Franks and Frater [21], literature research indicates that existing tools for assessing agricultural sustainability are based on four main approaches:

-Life cycle analysis (LCA) is a method that requires a lot of data over long periods and abstracts from economic and social indicators or qualitative data [39];

-Ecological accounting, a method that requires a significant amount of data and a monetary translation of ecosystem services, was introduced by Halberg et al. in 2005 [30].

-The ecological footprint considers elements such as greenhouse gas emissions and carbon footprints but disregards others [83].

-The sustainability index (the method does not have a unique way of selecting factors and variables but allows obtaining a single value that provides an overview of sustainability and allows comparisons at the farm level [26], industries [50], localities [32], or countries [2].

The OECD and the Institute for Sustainable Development created the "Bellagio STAMP" sustainability assessment and measurement principles in 1996, and they revised them in 2009 [54]. The Bellagio STAMP proposes to consider the following elements in the assessment process: vision, objectives, perspective, purpose, progress, accessibility, communication, participation, permanence, etc.

However, there is a multitude of works that propose different models and indicator systems for measuring sustainability ([78], [48], [67], [27], [38], [3], [61], [49], [1], [72], [33], [12], [44], [66], etc.

Numerous studies in the specialized literature have addressed the creation of an index for

measuring sustainability at the farm level. Among them, we mention:
-Rigby et al. [58] aimed to build an indicator of the sustainability of agricultural practices. The methodology was based on sustainable land management indicators, land quality indicators, and sustainable agriculture indicators. The sample consisted of 80 organic and 157 conventional producers from the United Kingdom.
-Hanuš [31] used three aggregate indicators and a set of partial indicators to assess the ecological, economic, and social aspects of the agricultural system at 30 farms. The author took into account six groups of indicators: environmental monitoring indicators (soil quality, nutrients, biodiversity, etc.); energy and material consumption (total mass transformed for a given process; biomass production and its use; indirect energy from pesticides and fertilizers and direct energy from machinery and the irrigation system, etc.); ecological footprint (fossil energy expressed by surface area, impact of activities on resources, waste production and environmental function, etc.); the production process (crop rotation, frequency of cultivation, nutrients, plant protection; inputs and outputs during packaging, distribution and consumption of agricultural products, etc.); socio-economic indicators (income, input suppliers, direct links with transport and processing companies, marketing, risks, decision-making process, etc.); size of the agricultural system (subsidy dependence, use of equipment, chemicals and non-renewable energy, jobs, feed use and feed production);
-Gomez-Limon and Riesgo [26] created a composite indicator of agricultural sustainability comparing non-irrigated and irrigated agriculture. The model encompasses economic, social, and environmental indicators, which include income from agricultural products, the contribution of agriculture to GDP, the insured area, employment in agriculture, labor force stability, the risk of abandoning agricultural activity, the economic dependence on agricultural activity, the degree of specialization, indicators related to phosphorus, pesticides, and nitrogen, water for irrigation, energy balance, the subsidized area for agri-environment, average area per plot, and the degree of soil coverage. The methodology was based on multicriteria analysis and weighted sums.
-Castoldi and Bechini [9] created a global sustainability index based on the following economic and environmental indicators: variable costs, gross income, gross margin, nitrogen and phosphorus quantities, energy input, energy output, energy balance, land cover, amount of soil carbon, etc.
-Reig-Martínez et al. [56] constructed composite indicators for the three dimensions of sustainability for 163 farms in Spain, applying a combined DEA-MCDM methodology on a database of 12 indicators. The authors showed that farm size, agricultural cooperative membership, and agricultural technical education exert a significant positive influence on sustainability.
-Franks and Frater [21] created a sustainability index for a dairy farm, taking into account over 40 indicators, grouped into the following categories: nitrogen, phosphorus, and potassium balance; profit margin; dependence on subsidies; productivity; biodiversity; average field size; cultural diversity index, etc.
-Majewski [40] created a sustainability index (consisting of five partial indices and 56 parameters), which served as the basis for the comparison of 120 farms in Poland and allowed us to conclude the importance of low-cost investments and activities in ensuring sustainability.
-Marchand et al. [41] created an indicator for the assessment of total sustainability based on 11 key characteristics that aim to strengthen the management function. However, the tool is not very practical, requiring data collection costs, processing time, and an overly complex interface for farmers.
-Coppola et al. [13] developed an economic sustainability index using FADN data. This index relies on an efficiency indicator and two income indicators, namely a factor profitability indicator and a comparable income indicator, to help determine the balance between efficiency and revenue factors.
We found these works interesting, but the specialized literature identifies a multitude of

sustainability assessment methodologies. They differ according to:
-*the techniques and indicators used, the target group, the period, etc.* [15];
-*approach:* top-down or bottom-up assessment [8]; based on automated calculation models (online, Excel, or specialized software like "Decision Support Tools"), protocols, or econometric models.
-*the sustainability assessment method*: the SAFE framework of principles, criteria, and indicators [77]; the RISE systems-oriented holistic approach (Hani et al., 2003); multicriteria analysis [74]; framework of principles, criteria, and indicators (SAFA) [20]; SEAMLESS [79]; the COSA indicator framework [14], etc.
-*the normative, systemic, and procedural dimensions* [87];
-*the type of impact pursued* (economic, social, and/or environmental impact) [11];
primary data source:
-indices based on FADN data [69]; indices based on surveys and FADN data [73];
-experts and surveys [28];
-farm-level data [29];
-Sebestyén et al. [65] propose an aggregate indicator calculated based on indicators classified into six categories, namely: waste management, water management, climate change, energy, greening, and transport. These categories include the important elements of sustainability in line with other studies that have addressed GreenMetric, GRI standards, etc. Based on these indicators, the authors propose the aspects that require improvement and the objectives to be pursued to increase sustainability.

In one of the most extended analyses in the field, Janker and Mann [33] analyzed 87 agricultural sustainability assessment tools and component indicators, showing that many tools do not properly integrate the social component.
Chopin et al. [12] classified almost 120 sustainability assessment tools into five groups, seven different models, and only two impact elements after analyzing 2,567 papers. Figure 1 displays the five groups of tools identified.

In 2020, Tzouramani et al. [76] used FADN data and a sustainability criteria weighting system based on the AHP methodology to make a composite indicator-based comparative score. The following criteria and indicators were taken into account: environment (GHG emissions at the farm level, the percentage of UAU in the farm with nitrate risk, water consumption per kg of product, N balance, pesticide use); social security (no. of consulting approvals per year per farm, degree of agricultural training of the manager, annual work units; satisfaction with quality of life; social diversification index); economic (output/input, subsidies/FFI, (FFI/FWU)/income, net value added).

Bathaei and Štreimikienė [5] analyzed 157 papers and identified an extensive framework of more than 100 indicators (30 social indicators, 31 economic indicators, and 40 environmental indicators) that can assess the sustainable development of an agricultural firm. The authors group these indicators into the following categories: economic dimension—technology, market access, price; environmental dimension—farm structure, pollution, soil; social dimension—product quality, farmers' and employees' rights. However, simply identifying these indicators does not imply that they are truly commensurable.

Starting from the analysis of 40 articles comparable to the Swedish dairy sector and the RISE 2.0 indicator framework, Robling et al. [60] found that they could not measure 20 indicators ranked below 12 out of a total of 20 sustainability themes, and they could not validate 16 indicators from 8 themes due to a lack of data. Therefore, they selected only 49 indicators from a total of 69 to describe sustainability in Swedish dairy farms. As a result, Robling et al. [60] recommend that sustainability assessment models only use indicators that are comprehensible, transparent, available, and useful in describing the phenomenon.

Regardless of the tool's creation, the primary issue lies in the indicators employed, as they can significantly impact the research outcomes. Schader et al. [63] evaluate 35 sustainability assessment approaches and highlight that they are rarely feasible, and the selection of indicators is actually what determines the assessment results as the indicators are different and inconsistent. Once you select the indicators, you can apply various techniques such as summation, weighting, normalization, and scaling to integrate the information and present it more straightforwardly and comparably. Analysis methodologies such as multicriteria analysis, which allows for the grouping of indicators in classification criteria, and econometric modeling, among others, can be added to these techniques.

Fig.1. Sustainability assessment models in agriculture
Source: Adapted from Chopin et al. (2021) [12]

CONCLUSIONS

Achieving sustainable agricultural management requires a holistic approach that integrates ecological, economic, and social dimensions. This approach is critical to addressing the negative environmental impacts of conventional agricultural practices and meeting the growing global demand for food. The adoption of advanced technologies such as smart greenhouses and soilless cultivation systems has increased resource efficiency and reduced environmental impact. Advanced technologies such as automated greenhouse climate control systems and precision irrigation contribute significantly to reducing the environmental footprint of agricultural practices and improving overall sustainability.

Currently, there is a clear trend to integrate sustainability principles into farm management practices. This integration involves not only adopting new technologies but also incorporating sustainability considerations into strategic planning and operational decisions. Despite the availability of various sustainability assessment tools, their adoption on farms remains limited. Challenges include data availability, high costs, and the complexity of integrating these tools into existing farm management systems. However, for effective farm management, comprehensive sustainability assessment tools that consider economic, social, and environmental factors are critical. These tools help make informed decisions that balance productivity with sustainability goals. Continued research and development of new sustainability assessment tools and methodologies is essential. This paper draws attention to the current limitations and aims to contribute in this way to improving the efficiency of sustainability assessments in agriculture. Research demonstrates that to enhance long-term sustainability, agricultural management practices must strategically integrate sustainability considerations into all levels of decision-making. This involves adopting new technologies, optimizing the use of resources, and continuously evaluating and improving practices based on sustainability parameters.

REFERENCES

[1]Arulnathan, V., Heidari, M.D., Doyon, M., Li, E., Pelletier, N., 2020, Farm-level decision support tools: A review of methodological choices and their consistency with principles of sustainability assessment. Journal of Cleaner Production, 256, p.120410. https://doi.org/10.1016/j.jclepro.2020.120410

[2]Bandura, R., 2008, A survey of composite indices measuring country performance: 2008 update. https://dl1.cuni.cz/pluginfile.php/1530880/mod_folder/content/0/UNDP_overview_SD%20indices.pdf, Accessed on 15 March 2024.

[3]Barnes, A.P., Thomson, S.G., 2014, Measuring progress towards sustainable intensification: how far can secondary data go?. Ecological indicators, 36, pp.213-220. https://doi.org/10.1016/j.ecolind.2013.07.001

[4]Başbuğ, T., Gül, M., 2016, Problems regarding input use and marketing structure of farms involved in greenhouse cultivating in highland conditions: the sample of Antalya city's Elmali District. Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 16(2), 27-35. https://managementjournal.usamv.ro/pdf/vol.16_2/Art4.pdf Accessed on 15 March 2024.

[5]Bathaei, A., Štreimikienė, D., 2023, A systematic review of agricultural sustainability indicators. Agriculture, 13(2), p.241. https://doi.org/10.3390/agriculture13020241

[6]Benko, B., Uher, S.F., Radman, S., Opačić, N., 2023, Hydroponic Production Systems in Greenhouses. In Climate Smart Greenhouses-Innovations and Impacts. IntechOpen. https://doi.org/ 10.5772/intechopen.113056

[7]Bersani, C., Ouammi, A., Sacile, R., Zero, E., 2020, Model predictive control of smart greenhouses as the path towards near zero energy consumption. Energies, 13(14), p.3647. https://doi.org/10.3390/en13143647

[8]Binder, C.R., Feola, G., Steinberger, J.K., 2010, Considering the normative, systemic and procedural dimensions in indicator-based sustainability assessments in agriculture. Environmental impact assessment review, 30(2), pp.71-81. https://doi.org/10.1016/j.eiar.2009.06.002

[9]Castoldi, N., Bechini, L., 2010, Integrated sustainability assessment of cropping systems with agro-ecological and economic indicators in northern Italy. European journal of agronomy, 32(1), 59-72. https://doi.org/10.1016/j.eja.2009.02.003

[10]Castro, A.J., López-Rodríguez, M.D., Giagnocavo, C., Gimenez, M., Céspedes, L., La Calle, A., Gallardo, M., Pumares, P., Cabello, J., Rodríguez, E. l., 2019, Six Collective Challenges for Sustainability of Almería Greenhouse Horticulture. International Journal of Environmental Research and Public Health. 16(21):4097. https://doi.org/10.3390/ijerph16214097

[11]Chanchitpricha C., Bond A., 2013, Conceptualising the effectiveness of impact assessment processes, Environmental Impact Assessment Review, Vol. 43, pp.65-72, https://doi.org/10.1016/j.eiar.2013.05.006

[12]Chopin, P., Mubaya, C.P., Descheemaeker, K., Öborn, I., Bergkvist, G., 2021, Avenues for improving farming sustainability assessment with upgraded tools, sustainability framing and indicators. A review. Agronomy for Sustainable Development, 41, pp.1-20. , https://doi.org/10.1007/s13593-021-00674-3

[13]Coppola, A., Amato, M., Vistocco, D., Verneau, F., 2022, Measuring the economic sustainability of Italian farms using FADN data. Agricultural Economics/Zemědělská Ekonomika, 68(9). https://doi.org/10.17221/169/2022-AGRICECON

[14]COSA, COSA Methods. Committee on Sustainability Assessment, https://thecosa.org/wp-content/uploads/2014/03/COSA-Methods-20141031.pdf Accessed on 15 March 2024.

[15]De Olde, E.M., Oudshoorn, F.W., Sørensen, C.A., Bokkers, E.A., De Boer, I.J., 2016, Assessing sustainability at farm-level: Lessons learned from a comparison of tools in practice. Ecological Indicators, 66, pp.391-404. https://doi.org/10.1016/j.ecolind.2016.01.047

[16]Elvanidi, A., Benitez Reascos, C.M., Gourzoulidou, E., Kunze, A., Max, J.F., Katsoulas, N., 2020, Implementation of the circular economy concept in greenhouse hydroponics for ultimate use of water and nutrients. Horticulturae, 6(4), p.83. https://doi.org/10.3390/horticulturae6040083

[17]Fanzo, J.. haddad, L., Schneider, K.R., Béné, C., Covic, N.M., Guarin, A.. herforth, A.W.. herrero, M., Sumaila, U.R., Aburto, N.J., Amuyunzu-Nyamongo, M., 2021, Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals. Food Policy, 104, p.102163. https://doi.org/10.1016/j.foodpol.2021.102163

[18]FAO AQUASTAT Homepage, 2011, Water use, fao.org/aquastat/en/overview/methodology/water-use/index.html, Accessed on 15 March 2024.
[19]FAO, 2024, Land and water, https://www.fao.org/land-water/en/, Accessed on 15 March 2024
[20]FAO, 2013, Sustainability pathway, https://www.fao.org/nr/sustainability/food-loss-and-waste/en/ , Accessed on 15 March 2024.
[21]Franks, J., Frater, P., 2013, Measuring agricultural sustainability at the farm-level: A pragmatic approach. International Journal of Agricultural Management, 2(4), pp.207-225.https://doi.org/10.5836/ijam/2013-04-04
[22]Garbach, K., Milder, J.C., DeClerck, F.A., Montenegro de Wit, M., Driscoll, L., Gemmill-Herren, B., 2017, Examining multi-functionality for crop yield and ecosystem services in five systems of agroecological intensification. International Journal of Agricultural Sustainability, 15(1), pp.11-28. https://doi.org/10.1080/14735903.2016.1174810
[23]Gasparatos, A., Scolobig, A., 2012, Choosing the most appropriate sustainability assessment tool. Ecological Economics 80:1-7. https://doi.org/10.1016/j.ecolecon.2012.05.005
[24]Gebhardt, M., Thun, T.W., Seefloth, M., Zülch. H., 2023, Managing sustainability—Does the integration of environmental, social and governance key performance indicators in the internal management systems contribute to companies' environmental, social and governance performance? Business Strategy and the Environment, 32(4), pp.2175-2192, https://doi.org/10.1002/bse.3242
[25]Gómez, C., Currey, C.J., Dickson, R.W., Kim. h.J.. hernández, R., Sabeh, N.C., Raudales, R.E., Brumfield, R.G., Laury-Shaw, A., Wilke, A.K., Lopez, R.G., 2019, Controlled environment food production for urban agriculture. HortScience, 54(9), pp.1448-1458, https://doi.org/10.21273/HORTSCI14073-19
[26]Gómez-Limón, J.A., Riesgo, L., 2009, Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain. Journal of environmental management, 90(11), pp.3345-3362. https://doi.org/10.1016/j.jenvman.2009.05.023
[27]Gómez-Limón, J.A., Sanchez-Fernandez, G., 2010, Empirical evaluation of agricultural sustainability using composite indicators. Ecological Economics 69 (15), 1062-1075.
https://doi.org/10.1016/j.ecolecon.2009.11.027
[28]Gómez-Limón, J.A., Arriaza, M., Guerrero-Baena, M.D., 2020, Building a composite indicator to measure environmental sustainability using alternative weighting methods. Sustainability, 12(11), p.4398. https://doi.org/10.3390/su12114398
[29]Guo, X., Wang, C., Zhang, F., 2022, Construction of an index system for sustainability assessment in smallholder farming systems. Front. Agr. Sci. Eng, 9(4), pp.511-522. https://doi.org/10.15302/J-FASE-2022463
[30]Halberg, N., Verschuur, G. and Goodlass, G., 2005, Farm level environmental indicators; are they useful?: an overview of green accounting systems for European farms. Agriculture, ecosystems & environment, 105(1-2), pp.195-212. https://doi.org/10.1016/j.agee.2004.04.003
[31]Hanuš, L., 2004, Sustainability analysis of agricultural systems. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, Vol. 52(10, 103-112 ref. 35.
https://doi.org/10.11118/actaun200452010103
[32]Izac, A., Swift, M., 1994, On agricultural sustainability and its measurement in small-scale farming in sub-Saharan Africa. Ecological Economics, 11(2): 105–125. https://doi.org/10.1016/0921-8009(94)90022-1
[33]Janker, J., Mann, S., 2020, Understanding the social dimension of sustainability in agriculture: a critical review of sustainability assessment tools. Environment, Development and Sustainability, 22(3), pp.1671-1691. https://doi.org/10.1007/s10668-018-0282-0
[34]Karanisa, T., Achour, Y., Ouammi, A., Sayadi, S., 2022, Smart greenhouses as the path towards precision agriculture in the food-energy and water nexus: Case study of Qatar. Environment Systems and Decisions, 42(4), pp.521-546. https://doi.org/10.1007/s10669-022-09862-2
[35]Kemp, D.R., Girdwood, J., Parton, K.A., Charry, A.A., 2003, Where is Farm Management Going?. Conference Paper, 14th Congress, Perth, Western Australia, August 10-15, 2003. 10.22004/ag.econ.24351
[36]Khan, F.A., 2018, A review on hydroponic greenhouse cultivation for sustainable agriculture. International Journal of Agriculture Environment and Food Sciences, 2(2), pp.59-66. https://doi.org/10.31015/jaefs.18010
[37]Lachheb, A., Marouani, R., Mahamat, C., Skouri, S. and Bouadila, S., 2024, Fostering Sustainability through the Integration of Renewable Energy in an Agricultural Hydroponic Greenhouse. Engineering, Technology & Applied Science Research, 14(2), pp.13398-13407. https://doi.org/10.48084/etasr.6939
[38]Lebacq, T., Baret, P.V., Stilmant, D., 2013, Sustainability indicators for livestock farming. A review. Agronomy for Sustainable Development 33, 311-327. https://doi.org/10.1007/s13593-012-0121-x
[39]Lindeijer, E., 2000, Biodiversity and life support impacts of land use in LCA. Journal of Cleaner Production, 8(4), pp.313-319. https://doi.org/10.1016/S0959-6526(00)00025-1
[40]Majewski, E., 2013, Measuring and modelling farm level sustainability. Visegrad J. Bioecon. Sustain. Dev. 2(1), 2–10. https://doi.org/10.2478/vjbsd-2013-0001
[41]Marchand, F., Debruyne, L., Triste, L., Gerrard, C., Padel, S., Lauwers, L., 2014, Key characteristics for tool choice in indicator-based sustainability assessment at farm level. Ecol. Soc. 19 (3), art. 46. https://doi.org/10.5751/ES-06876-190346
[42]Matthews, A., 2003, Sustainable development research in agriculture: Gaps and opportunities for Ireland. Dublin, Ireland: Department of Economics, Trinity College. https://core.ac.uk/download/pdf/7045551.pdf Accessed on 15 March 2024.

[43]McConnell, D.J., Dillon, J.L., 1997, Farm management for Asia: a systems approach (No. 13). Food & Agriculture Org. 1997 – 355 pp. https://www.fao.org/4/w7365e/w7365e00.htm Accessed on 15 March 2024.

[44]Movilla-Pateiro, L., Mahou-Lago, X.M., Doval, M.I., Simal-Gandara, J., 2021, Toward a sustainable metric and indicators for the goal of sustainability in agricultural and food production. Critical Reviews in Food Science and Nutrition, 61(7), pp.1108-1129. https://doi.org/10.1080/10408398.2020.1754161

[45]Mullen, J.D. 2002, Farm Management in the 21st Century, Australasian Agribusiness Review, 10:1-18, paper 5. http://dx.doi.org/10.22004/ag.econ.206156

[46]Nakhaei, M., Behdani, M.A., Asgharipour, M.R., Hedayatizadeh, M., 2022, Monitoring and accounting the sustainability of tomato greenhouse production systems of Mirjaveh district, Iran based on emergetic indicators. Current Research in Environmental Sustainability, 4, p.100149. https://doi.org/10.1016/j.crsust.2022.100149

[47]Nicola, S., Pignata, G., Ferrante, A., Bulgari, R., Cocetta, G., Ertani, A., 2020, Water use efficiency in greenhouse systems and its application in horticulture. AgroLife Scientific Journal, 9(1). https://agrolifejournal.usamv.ro/index.php/agrolife/article/view/587 Accessed on 15 March, 2024.

[48]Niemeijer, D., de Groot, R.S., 2008, A conceptual framework for selecting environmental indicator sets. Ecological Indicators 8 (1), 14-25. https://doi.org/10.1016/j.ecolind.2006.11.012

[49]Ode, E.M., Oudshoorn, F.W., Sørensen, C.A.G., Bokkers, E.A.M., de Boer, I.J.M., 2016, Assessing sustainability at farm level: lessons learned from a comparison of tools in practice. Ecological Indicators 66, 391-404. https://doi.org/10.1016/j.ecolind.2016.01.047

[50]OECD. Handbook on Constructing Composite Indicators: Methodology and User Guide. Paris, Organisation for Economic Co-operation and Development.https://doi.org/10.1787/9789264043466-en

[51]Ouammi, A., Achour, Y., Dagdougui. H., Zejli, D., 2020, Optimal operation scheduling for a smart greenhouse integrated microgrid. Energy for Sustainable Development, 58, pp.129-137. https://doi.org/10.1016/j.esd.2020.08.001

[52]Özbilgin, A., Yusuf, İ.N.C.E., 2019, Investigation of silage properties of organic residues of tomato (*Solanum lycopersicum*), pepper (*Capsicum annuum*) and cucumber (*Cucumis sativus*) greenhouses. AgroLife Scientific Journal, 8(2). http://agrolifejournal.usamv.ro/index.php/agrolife/article/view/700 Accessed on 15 March 2024.

[53]Özgür, M., EngindeniZ, S., Cinar, G., Rahimli, F., 2024, Analysis of entrepreneurial behaviors of greenhouse vegetable farmers: a case study in Türkiye. Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 24(1), 703-714. https://managementjournal.usamv.ro/pdf/vol.24_1/Art71.pdf Accessed on 15 March 2024.

[54]Pintér L., Hardi P., Martinuzzi A., Hall J., 2012, Bellagio STAMP: Principles for sustainability assessment and measurement, Ecological Indicators, Vol. 17, pp. 20-28, https://doi.org/10.1016/j.ecolind.2011.07.001

[55]Pope, J., 2006, Editorial: what's so special about sustainability assessment? Journal of Environmental Assessment Policy and Management 8(3), v-x. https://doi.org/10.1142/S1464333206002505

[56]Reig-Martínez, E., Gómez-Limón, J.A., Picazo-Tadeo, A.J., 2011, Ranking farms with a composite indicator of sustainability. Agricultural Economics, 42: 561-575.https://doi.org/10.1111/j.1574-0862.2011.00536.x

[57]Rigby, D., Cáceres, D., 2001, Organic farming and the sustainability of agricultural systems. Agricultural systems, 68(1), pp.21-40. https://www.csun.edu/~hmc60533/CSUN_630E/studentpresentations_S2007/Robinson_can_all_farms_be_SA.pdf Accessed on 15 March 2024.

[58]Rigby, D., Woodhouse, P., Young, T., Burton, M., 2001, Constructing a farm level indicator of sustainable agricultural practice. Ecological economics, 39(3), pp.463-478. https://doi.org/10.1016/S0921-8009(01)00245-2

[59]Robertson, A., Pratley, J. 1998, From Farm Management to Ecosystem Management, In J. Pratley and A. Robertson, (eds), Agriculture and the Environmental Imperative, CSIRO Publishing, Bathurst. http://www.agronomyaustraliaproceedings.org/images/sampledata/specialpublications/9%20From%20Farm%20Management%20to%20Ecosystem%20Management%20Robertson%20and%20Pratley.pdf Accessed on 15 March 2024.

[60]Robling, H., Hatab, A.A., Säll, S., Hansson, H., 2023, Measuring sustainability at farm level – A critical view on data and indicators, Environmental and Sustainability Indicators, Vol. 18, 100258, https://doi.org/10.1016/j.indic.2023.100258

[61]Ryan, M., Hennessy, T., Buckley, C., Dillon, E.J., Donnellan, T., Hanrahan, K., Moran, B., 2016, Developing farm-level sustainability indicators for Ireland using the Teagasc National Farm Survey. Irish Journal of Agriculture and Food 55 (2). https://doi.org/10.1515/ijafr-2016-0011

[62]Savvas, D., Passam, H., 2002, Hydroponic production of vegetables and ornamentals, Athens: Embryo publications. pp. 15-23.

[63]Schader, C., Grenz, J., Meier, M.S., Stolze, M., 2014, Scope and precision of sustainability assessment approaches to food systems. Ecol. Soc. 19 (3), art.42, http://dx.doi.org/10.5751/ES-06866-190342

[64]Schaltegger, S., Hörisch, J., 2017, In search of the dominant rationale in sustainability management: legitimacy-or profit-seeking?. Journal of Business Ethics, 145, pp. 259-276. https://doi.org/10.1007/s10551-015-2854-3

[65]Sebestyén, V., Fejes, R., Tóth, E., Tóth-Nagy, G., Kurdi, R., 2024, University of Pannonia Sustainability

index (UPSi) for corporate sustainability. Environmental and Sustainability Indicators, 22, 100349.https://doi.org/10.1016/j.indic.2024.100349

[66]Silvestri, C., Silvestri, L., Piccarozzi, M., Ruggieri, A., 2022, Toward a framework for selecting indicators of measuring sustainability and circular economy in the agri-food sector: a systematic literature review. The International Journal of Life Cycle Assessment, pp.1-39.https://doi.org/10.1007/s11367-022-02032-1

[67]Singh, R.K., Murty, H.R., Gupta, S.K., Dikshit, A.K., 2009, An overview of sustainability assessment methodologies. Ecological Indicators 9 (2), 189-212. https://doi.org/10.1016/j.ecolind.2008.05.011

[68]Singh, S., Singh, D.R., Velmurugan, A., Jaisankar, I., Swarnam, T.P., 2008, Coping with climatic uncertainties through improved production technologies in tropical island conditions. In Biodiversity and climate change adaptation in tropical islands. Academic Press. pp. 623-666. https://doi.org/10.1016/B978-0-12-813064-3.00023-5

[69]Sinisterra-Solís, N.K., Sanjuán, N., Ribal, J., Estruch, V., Clemente, G., Rozakis, S., 2024, Developing a composite indicator to assess agricultural sustainability: Influence of some critical choices. Ecological Indicators, 161, p.111934. , https://doi.org/10.1016/j.ecolind.2024.111934

[70]Siva K., Ramesha, Y.S., 2017, Horti-Business Management, https://agrimoon.com/wp-content/uploads/Horti-Business-Management.pdf Accessed on 15 March 2024.

[71]Stoessel, F., Juraske, R., Pfister, S., Hellweg, S., 2012, Life cycle inventory and carbon and water foodprint of fruits and vegetables: application to a Swiss retailer. Environmental science & technology, 46(6), pp.3253-3262. https://doi.org/10.1021/es2030577

[72]Streimikis, J., Baležentis, T., 2020, Agricultural sustainability assessment framework integrating sustainable development goals and interlinked priorities of environmental, climate and agriculture policies. Sustainable Development, 28(6), pp.1702-1712. https://doi.org/10.1002/sd.2118

[73]Sulewski, P., Kłoczko-Gajewska, A., 2018, Development of the Sustainability Index of Farms Based on Surveys and FADN Sample. Problems of Agricultural Economics, 3(356), 32-56, https://doi.org/10.30858/zer/94474

[74]Talukder, B., Hipel, K.W., van Loon, G.W., 2018, Using multi-criteria decision analysis for assessing sustainability of agricultural systems. Sustainable Development, 26(6), pp.781-799. https://doi.org/10.1002/sd.1848

[75]Triste, L., Marchand, F., Debruyne, L., Meul, M. Lauwers, L., 2014, Reflection on the development process of a sustainability assessment tool: learning from a Flemish case. Ecology and Society, 19(3). https://www.jstor.org/stable/26269621

[76]Tzouramani, I., Mantziaris, S., Karanikolas, P., 2020, Assessing Sustainability Performance at the Farm Level: Examples from Greek Agricultural Systems. Sustainability. 12(7):2929. https://doi.org/10.3390/su12072929

[77]Van Cauwenbergh, N., Biala, K., Bielders, C., Brouckaert, V., Franchois, L., Cidad, V.G., Hermy, M., Mathijs, E., Muys, B., Reijnders, J., Sauvenier, X., 2007, SAFE—A hierarchical framework for assessing the sustainability of agricultural systems. Agriculture, ecosystems & environment, 120(2-4), pp.229-242. https://doi.org/10.1016/j.agee.2006.09.006

[78]Van der Werf, H.M., Petit, J., 2002, Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agriculture, Ecosystems & Environment, 93(1-3), pp.131-145, https://doi.org/10.1016/S0167-8809(01)00354-1

[79]Van Ittersum, M.K., Ewert, F., Heckelei, T., Wery, J., Olsson, J.A., Andersen, E., Bezlepkina, I., Brouwer, F., Donatelli, M., Flichman, G., Olsson, L., 2008, Integrated assessment of agricultural systems–A component-based framework for the European Union (SEAMLESS). Agricultural systems, 96(1-3), pp.150-165. https://doi.org/10.1016/j.agsy.2007.07.009

[80]Velazquez-Gonzalez, R.S., Garcia-Garcia, A.L., Ventura-Zapata, E., Barceinas-Sanchez, J.D.O., Sosa-Savedra, J.C., 2022, A review on hydroponics and the technologies associated for medium- and small-scale operations. Agriculture. 12:646, https://doi.org/10.3390/agriculture12050646

[81]Verdouw, C., Robbemond, R., Kruize, J.W., 2015, Integration of production control and enterprise management systems in horticulture. In Proceedings of the 7th International Conference on Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2015), Kavala, Greece, September 17-20, 2015, Vol. 1498, pp. 124-135. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=f48ef4fde4980cd7f176ff3cc4786bda568b2732 Accessed on 15 March 2024.

[82]Verdouw, C.N., Robbemond, R.M., Wolfert, J., 2015, ERP in agriculture: Lessons learned from the Dutch horticulture. Computers and Electronics in Agriculture, 114, pp.125-133, https://doi.org/10.1016/j.compag.2015.04.002

[83]Wackernagel, M., Rees, W., E., 1996, Our Ecological Footprint: reducing human impact on the earth. Gabriola Island BC, Canada: New Society Publishers. https://doi.org/10.5070/G31710273

[84]Walters, K.J., Currey, C.J., 2015, Hydroponic greenhouse basil production: comparing systems and cultivars. HortTechnology 25(5):645–650. https://doi.org/10.21273/HORTTECH.25.5.645

[85]Watson, R.T., Boudreau, M.C., van Iersel, M.W., 2018, Simulation of greenhouse energy use: An application of energy informatics. Energy Informatics, 1(1), pp.1-14. https://doi.org/10.1007/s42162-018-0005-7

[86]Westbroek, H., Brouwer, F. M., 2004, Indicators on transition towards sustainable agriculture. https://edepot.wur.nl/30458 Accessed on 15 March 2024.

[87]Wiek A., Binder C., 2005, Solution spaces for decision-making—a sustainability assessment tool for city-regions, Environmental Impact Assessment

Review, Vol.25(6), 589-608, https://doi.org/10.1016/j.eiar.2004.09.009