Characterization and causal model of the holistic dynamics of the integral sustainability of the agrifood system

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Abstract

The transformation of the food and industrial agricultural production system into adaptative and sustainable systems capable of being productive within social, environmental, and economic limits are relevant to reducing the risk to food security and economic growth. However, the analysis structure the effect of these variables in sustainable environments is unknown, considering technology and processes as variables of the equivalent critical level as those already mentioned. The purpose of this study is to design a model that allows the characterization and causal model of the holistic dynamics of the agri-food sector, from the determination of sustainable variables from a sustainable and integral systemic approach. Tools such as the viable systems model are used to analyze the dynamics and generate the balanced scorecard, to which the items of learning and continuous improvement are added. Finally, the impact of the principles of sustainability versus the variation of sustainability in the agri-food system is recognized, and useful to determine the appropriate levels that

guarantee the balance between the foundations of circularity. This model from a systemic approach can be adopted by agronomists and scientists to design alternative strategies for the management of food sustainability.

Introduction

In the agri-food sector, activities of great importance are developed due to their contribution to the economy and to human life itself, in consequence the interest in studying them from the perspective of holistic dynamics [1], that is, from the changes and interactions that arise in its whole, constituted by the flow of people, information, energy, materials, among other structures and organizations, and that through its activity issues of economic, social, environmental, technological utility arise from the execution of the processes it demands, affecting the health, well-being and balance of an entire local, regional, national and international ecosystem [2,3].

However, considering its productive activity, human beings are the ones who exploit the land and other resources causing an effect on the environment; the space occupied for crops represents 37% of the arable land surface and the use of water for these corresponds to almost 2/3 of the total area of arable land [4,5]. An effect on the environment is pollution by nitrates, phosphates, and pesticides, acting as a source of production of greenhouse gases, methane, and nitrous oxide which affects air and water quality [6,7].

The poor management of the land leads to stress which produces degradation by salinization, excess water extraction and contamination of groundwater by agrochemical residues. This is due to the use of quantities higher than those needed by crops and generating an imbalance in the ecosystem, affecting the environment, productive capacity, economy, and society [8–10].

According to the studies of Benabderrazik et al., food security and economic growth in the regions must be associated with a balanced interaction between social and economic well-being and the protection of natural resources, since an intensification of activities in these sectors leads to unsustainability, putting at risk the general well-being of the population and the productivity of the region, affecting the ecological environment. These components interact in a nonlinear, complex, and dynamic way, so it is pertinent to analyze the feedback received by the system to offer sustainable and adaptable solutions to environment situations[11].

The theory of adaptive systems represents an effective framework for the analysis of the dynamics of systems in terms of their transitions, as cyclical evolution seeks equilibrium as changes arise, the agri-food sector articulates a type of complex adaptive system in which there is an exchange of matter, energy and information internally and with external structures, through the ability to self-manage corresponding to its systemic functionality [12].

The incorporation of strategies such as life cycle analysis (LCA) allows the development of products in a conscious way about the impacts they generate in each of their stages, from design to final disposal, which leads to reasonable agri-food production, improving their environmental, economic, health and well-being properties, this with the help of technologies that contribute to this end, also improving the levels of efficiency and productivity of the processes by making better use and disposition of the resources that will have an impact on the accessibility of future generations [13,14].

Through the application of the circular economy from the perspective of reducing, reusing, and recycling in work models with the influence of eco-design and the use of raw materials from renewable sources, a considerable reduction in waste generation is expected, favoring society, the environment, the economy and the efficiency of processes guaranteeing the sustainability of operations from the management of technology and information [15,16].

This article aims to characterize and causal model holistic dynamics from an integral sustainability approach to the agri-food system. As a complex adaptive system, it is relevant to identify the elements and relationships that make up the system, then graph the dynamics, considering the interconnections of the variables, followed by an analysis from the model of viable systems for the conclusion of a balanced scorecard that serves as a support tool for the management of the improvement and learning of the system, that is, the evolution of the system towards the objectives set.

Literature review

In the agri-food sector, the production, distribution and consumption of food is one of the sectors most affected by the crisis of climate imbalance [5], and unfavorable practices in its operation altering its holistic dynamics [17], which has a direct impact on sustainability reducing the opportunity to guarantee better levels of health, food and an environment and an efficient level of water, air and soil for future generations, however it is the agro-industrial sector that can most help improve conditions regarding environmental problems that are already worrying today [18,19]. In Europe, research and development are being carried out to increase the value of unsuitable food materials for human consumption (wrappings) and to consider food waste and residues, focusing on economic and environmental variables [20].

Riemens et al., focused their research on the holistic improvement of herbicide chemicals to increase the sustainability of the agricultural sector, because they are critical in the management of weeds that compete with crops for resources such as light, water, nutrients and visible space, affecting crop yield and the environment and human health [21].

Water scarcity is another factor that conditions the integral sustainability of the agri-food system, making use of water resources without considering the effects that lead to socioeconomic problems and degradation of resources; therefore, it is necessary to study the underlying variables in the agri-food system to avoid unforeseen effects [11]. Water is one of the resources that is affected by climate change, and high temperatures have achieved the scarcity of this resource due to low rainfall and dryness or, on the other hand, the large amount of rain in short periods of time overflows because you drag particles that pollute bodies of water such as rivers, gaps, among others putting at risk the quality and productivity of the activity of the agri-food sector, other aspects are the wells of illegal underground aquifers diverting the courses of the aquifer sources or contaminating them by the mismanagement of the same, highlighting the crisis of governance in the sector [22].

Diogo et al. highlighted the importance of the social component within the sustainability model; in their research, they demonstrated that it is the least developed element and that no evaluation tool allows us to recognize the dynamic interaction of ecosystems with communities [23].

On the other hand, Cook et al. argue that expansionism has dehumanized agricultural activities influenced by power and the desire to improve productivity by ignoring the significant contribution of farmers, who must adapt to new technologies or give up their labor, which the authors point out as unfair from the social point of view, recognizing also that change in complex systems must include commitment to the members existing, which carry out the day-to-day practices in that system. Additionally, they state that the work of women is minimized in the implementation of the expansionist concept and that the results in terms of the productivity of the sector and the welfare of farmers are not evident [24].

However, works such as [25] consider expansionism as a tool that can allow the fulfillment of SDG 2 of the United Nations, in which it is projected to end extreme poverty and hunger, consider that this strategy of transfer of knowledge and technology to farmers can contribute to the solution of problems specific to the work and the environment in which it takes place, but it also argue that it is necessary to put aside the attention on specific behavioral changes and move it to the creation of awareness, with which learning will become more productive. In addition, it adds that sustainability, behavioral change, and technology adoption are less relevant than increasing farmers' self-confidence engaging and playing a role in the agricultural development process.

Studies have been carried out to understand the elements that obstruct the ability to exercise practices that contribute to nature conservation. These studies are based on innovation systems approaches, with real emphasis on the development of multiscale frameworks that are specific to each environment and relevant to evaluate in an integrated way the sustainability of changes in agricultural intensity [26].

The tools available for the application of systems that are linked to the circular economy are aimed at large companies, leaving aside SMEs, who to a lesser extent are also aware of the need for the transformation of the productive system that has visions about the general welfare of society, the economy of the regions and the conservation of the environment; However, Industry 4.0 is already offering sustainable practices focused on the circular economy in these organizations [27,28].

Life cycle in the agri-food sector. The processes are given by two components, one biological and the other technical [29]. The first is capable of being reintegrated into the biosphere with which it is intended to create alternatives of waste instead of accessing processes of biochemical extraction, composting and reincorporation into the biosphere, while the second is destined to be revalued without entering the biosphere, since at the end of its useful life they could be repaired, reuse, ultimately remanufactures recycling to avoid extraction of new raw materials [30,31].

It is necessary from the moment of design to consider the elements that will be part of this and the appropriate technologies to minimize its impact in terms of abiotic resources, acidification, eutrophication, global warming, depletion of the ozone layer, human toxicity, ecotoxicity in fresh water and soil, formation of photochemical oxidants, which brings an imbalance in ecosystems affecting the environment, health and therefore society, economic impacts for its repair and affecting the efficiency of production processes in general of the agro-industrial sector, mainly those of a biological nature [7].

In the absence of efficient design of sustainable processes and products under the framework of circularity, there are aggravating situations such as food waste, which currently accounts for a third of total food. It is estimated that edible food waste in the European Union is approximately 89 million tons each year, of which 42% is responsible for households, 39% for food manufacturing processes, 14% for catering services, and 5% for the distribution sector [31].

Product Lifecycle Management (PLM) as a tool for managing the life cycle of a product allows visualization of the development and progress in projects of the creation of products and services, being pertinent to know in advance the costs and other information of interest of that product, allowing a better vision about the best options, in such a way that it is of help to make efficient decisions, which also does not interfere negatively with the environment. This tool facilitates the integration of project stakeholders by making available the information and traceability of this at each stage of its development [20,32–34].

PLM is a vital tool from conception to final disposal of the product [35]. This process occurs in 3 phases, beginning of life, half, and the end of the life of the product itself, with which it coincides [36]. Additionally, Salonitis and Stavropoulos argues that the conventional PLM system only focuses on the first phase, so it suggests an extension to the other phases. Recognizing other limitations highlights the integration of different tools in a digital platform, the interoperability of systems and devices both internal and external, and the number of files and data exchanges between stakeholders in all phases of the life cycle [35].

On the other hand, PLM contributes to the transition of Industry 4.0 from the digitalization of processes to better control, monitoring it from good traceability and follow-up practices for better decision making. In addition to Industry 4.0 tools, such as artificial intelligence, IoT, machine learning, big data, it should be integrated into the agri-food sector and precision agriculture to optimize productivity and resource efficiency [28,37–39] .

LCA and the circular economy led to cleaner production spaces. The first contributes to the quantification of the environmental impacts present in the study system [40] while the second helps to identify and define the scenarios to improve the characteristics of such a system [41], which is an iterative process that allows measurement of good practices and their real effects [15,40]. However, authors such as Poponi et al. argue that LCA study proposals have been criticized for not being suitable for specific products, since it is a methodology designed for products at a general level [42].

In general, the processes require a focus on meeting the United Nations Sustainable Development Goals (SDGs), in which SDG 12 focuses on ensuring sustainable consumption and production patterns and includes targets that aim to achieve a more efficient use of resources [43], Therefore, the management and analysis of the life cycle is of great relief because they lead to this compliance from early stages such as design until the product is no longer in a final useful life phase [44].

Technological advances today there are tools such as specialized analysis software that due to their complexity are easier to perform through them. Life cycle analysis can be mentioned in several of these programs with some payments and others free and multiplatform, including Air.e LCA, Open LCA, SimaPro, and Eco-it, which are helpful because they allow clarity on the levels of climate change, human toxicity, ecotoxicity, and depletion of biotic resource information of interest to make decisions within the development of products [13].

In general, the relevance of tools such as management and life cycle analysis on the sustainable approach and circularity are necessary due to the estimates made for 2050, the year in which there will be an increase between 60 and 70% in food consumption, which compromises the resources available today. For water consumption, for example, it must increase by 30%, while energy demand will have to increase by 45%. However, the transport sector is the one that has the most representation among the registered carbon footprints, with 18% of the total. The transport of food products accounts for between 15 and 30% of the carbon footprint of the food and beverage industry, recognizing that this is a great ally for the distribution, mobility and accessibility of raw materials, inputs, final products, people, and machines among foals that are also part of the agri-food sector [31,45,46].

Facing complex problems such as determining the sustainability of a system, the best way to approach them is system dynamics, systemic approach, systemic thinking in general, because being complex, their behaviors are not linear, as a consequence of the feedback loops of the interconnections of the various variables that constitute them as systems. Various authors have employed tools such as causal loop analysis to understand the systemic dynamics of the systems under study and establish possible solutions to support improvement [47–50].

Materials and methods

This work was developed using qualitative and descriptive research within the framework of approach, dynamics, and systemic thinking. The methodology used is based on Sterman's model [51], which is described in detail in [52]. The implementation process is illustrated in Fig. 1 and begins with identifying a problematic situation in the field of study, drawing on the contributions of Peter Checkland [53,54]. This process acknowledges the gap between perception and reality and aims to address this difference in order to achieve an ideal outcome.

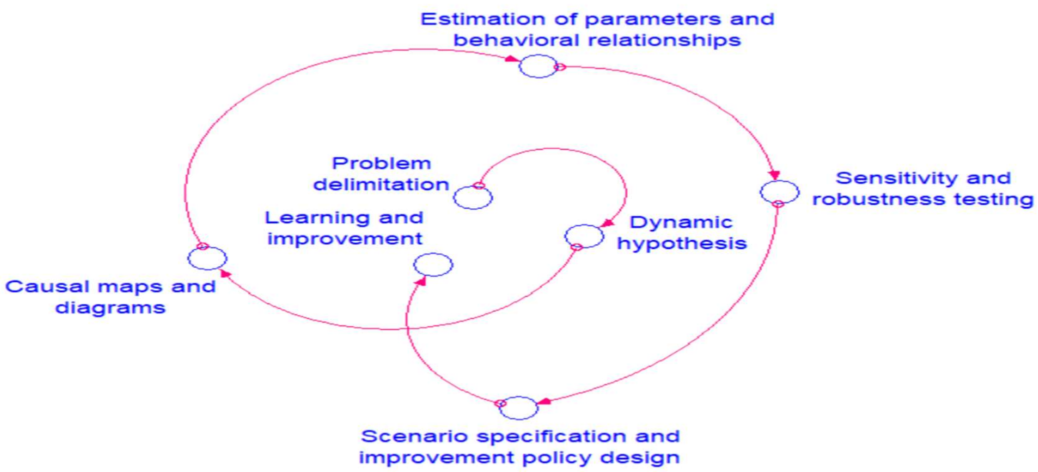

Fig. 1 Methodology considering Sterman's essential steps taken from [52]

Then, a dynamic hypothesis is established in which the main variables are identified, and their possible interaction is determined. Having clarity about the variables is necessary to design improvements to the system by creating purposeful systemic models where those variables are interrelated.

Then, causal maps and supporting diagrams are made to reflect the interconnections, for which the model of viable systems proposed by Beer [55,56] is also used, from which parameters and estimates of behavior of the system of the variables are established. Due to the modeling, the results are analyzed giving a knowledge of the dynamics of the system allowing us to act on the performance of this system. Through of the application of the methodology proposed by Kaplan and Norton [57] for the creation of the balanced scorecard, favorable and viable changes are estimated according to the specifications of scenarios and the design of improvement policies, which leads to a new reality of the system that will again be contrasted with problematic situations perceived in this new phase and this methodological process will be applied iteratively generate knowledge, learning and continuous improvement of the system under study.

For the characterization of the sustainable holistic dynamics of the sector, it was necessary to define the variables of interest that constituted the pentagon of integral sustainability, that is, the five main variables for this model. Subsequently, an evaluation of influence between these variables is carried out, that is, in a range of 1 to 5, with 1 mild effect and 5 strong effects as each of these variables influencing the others. The points awarded are added for each variable, and the highest result indicates which is the variable that receives greater influence from the rest becoming the most affected of the system, so we proceed with the characterization of it for analysis within the system under study considering the other variables of interest of the model.

With this evaluation it is also possible to know which variables have the most effects on the others, recognizing the role of systemic analysis that allows connections and integration without ruling out the uniqueness of each variable for a better understanding of the system under study [58].

Initially, a systemic causal model of the agro-industrial sector is carried out through the Ithink 8.0 modeling software, which allows more precisely to proceed with the diagramming of the model of viable systems, analyzing the relationships of the subsystems that make up the system under study considering the external environment, the information is obtained for the creation of the balanced scorecard in order to identify the variables of interest of the sector from the perspective of integral sustainability, the mission, vision, objectives, indicators, goals and actions to be carried out are established, additionally the following fields are integrated: learning, short-term improvement and long-term improvement the last three items are necessary when the goals and the result of the indicators have a level of deviation greater than 5% with the aim of self-regulating the system so that the established objectives are not affected. Which allows a culture of learning and continuous improvement, remembering that it is an iterative process.

Finally, five basic principles are postulated to guarantee integral holistic sustainability, which are analyzed from their link to the process studying their effects on the variables that constitute the pentagon of integral sustainability of the proposed model.

Results

Identification of variables of interest

The model of sustainable integration in the agri-food sector is given by the different variables that have an impact on the fundamental categories or macro variables of the same within which is the traditional Economy, Society, and Environment; in this work, Technology and Processes are also considered. Each of the above contains different variables that define them within the sector under study as shows the Fig. 2 and distinguishes the sustainable integration model.

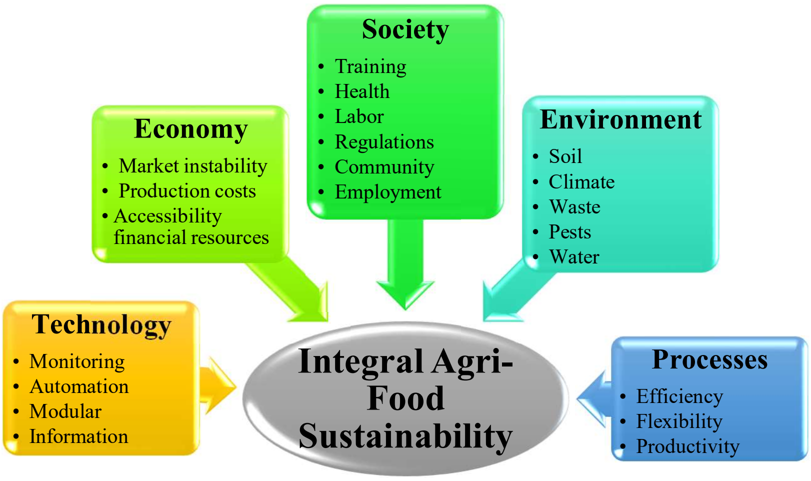

Fig. 2 Elements of the Agrifood Integral Sustainability Model

The relationship of the variables between them starting from the conception of a general systemic approach, is perceived from the way they interact producing an effect, hence the need to achieve a balance that allows the harmonious functioning of the system in Fig. 3 shows the causal map and the Fig. 4 show the level of influence between the variables technology, process, environment, society and economy as the main ones of the integral sustainable system model in the agri-food sector.

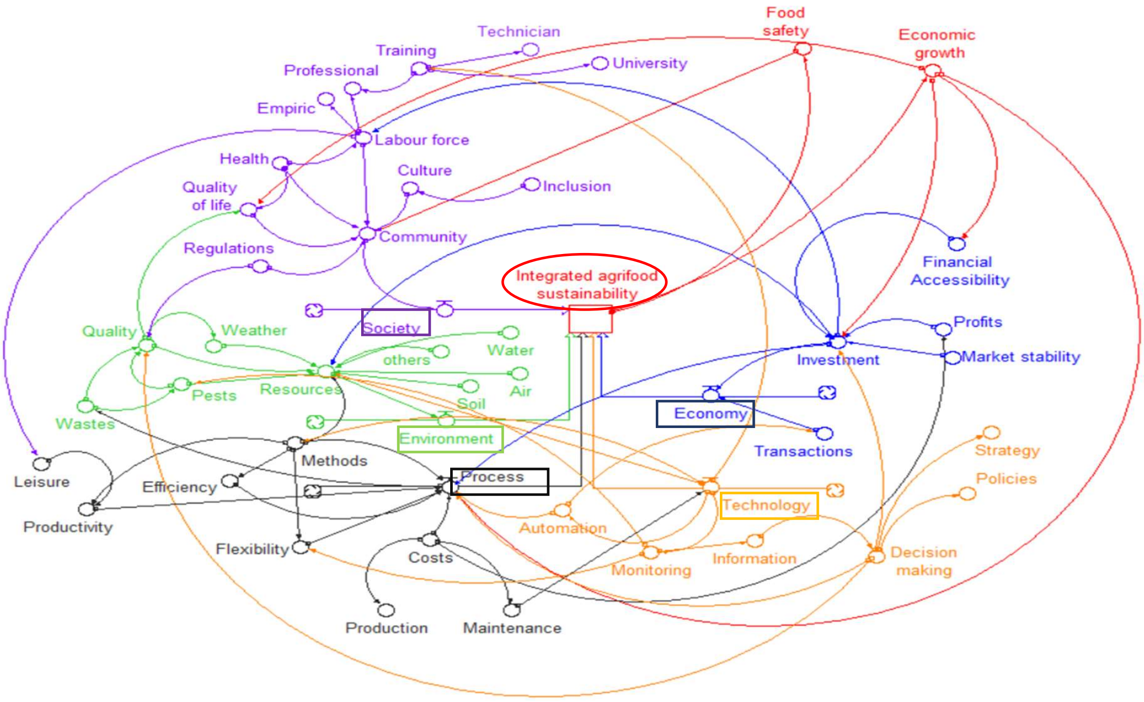

Fig. 3 Causal map of integral sustainability variables.

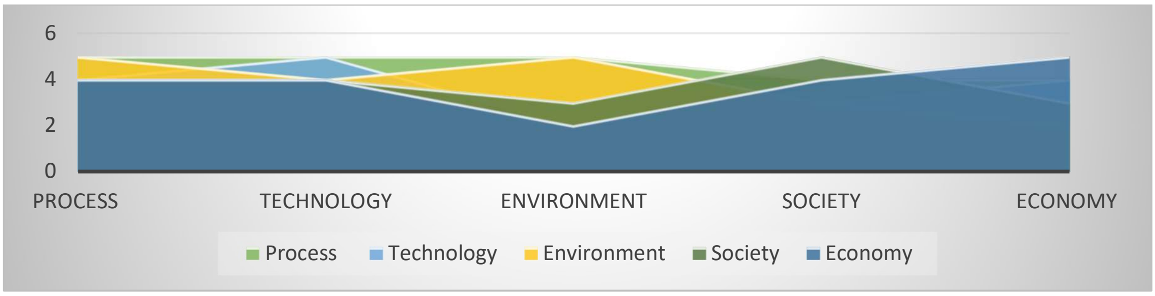

Fig. 3 Influence of integral sustainability variables on each other.

In the Figure 3 it is pertinent to observe which is the variable that receives greater influence from the others in this case is the variable process, and the variables that most influence the others are: process, technology, and economy. Table 1 shows the values of such evaluation.

Table 1 Level of interaction and influence between the main variables of integral sustainability in the agri-food sector.

Integral Sustainability Variables	Process	Technology	Environment	Society	Economy	Variable that most affects
Process	5	4	5	4	4	22
Technology	5	5	4	4	4	22
Environment	5	2	5	3	2	17
Society	4	3	3	5	4	19
Economy	4	4	2	3	5	18
Variable that is most affected	23	18	19	19	19	

The process variable with a score of 23 is the one that most affects the others, in order of influence technology, economy, environment and society; on the other hand, those that have the most impact on the variables with a score of 22 are technology and process. See appendix S1.

Integral sustainable holistic dynamics of the variable process in the agro-industrial sector

It is possible to have two divisions of the materials that circulate in the processes, one biological and the other technique in words of the Cañoles et al., which first refers to the benefit of the organic matter that is produced along the food production chain, from primary production to consumption, and the various organic waste that is generated, such as sludge, agro-industrial byproducts, inedible food remains, and food waste [29].

In contrast, technicians are related to the use of machinery, plastics and other industrial elements used in agricultural properties.

From the Forrester model represented in Fig. 5, the relationship of the variables that are part of the process in general is evidenced, integrating the biological and technical aspects of the agri-food sector.

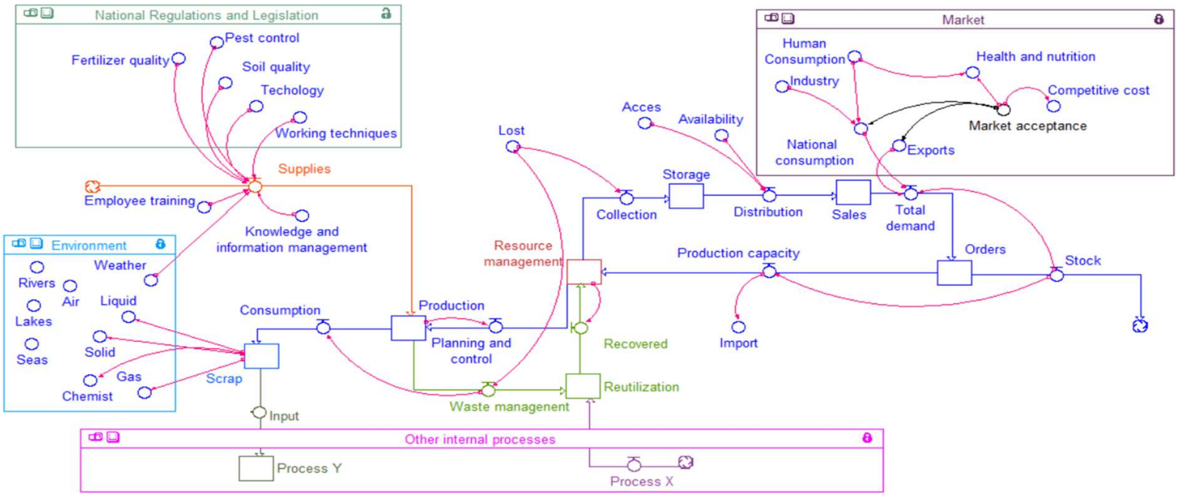

Fig. 4 Systemic model of sustainable integration in the agri-food sector.

The model integrates the internal production variables, from the management of resources where the planning and control of production are considered, starting from the demand, and the capacity of the process to decide whether to import, proceed to produce, considering waste management, reuse and recovery of materials integrated with other alternative processes. In addition, the model includes the variables that are affected by the waste generated such as water sources, soil, air, and the climate present in the environment which can be internal or external; in the same way, it reflects the influence of the standards, legislation and current trends in consideration of quality of fertilizers, pest control, and quality of soil for planting to name a few that affect the work of supplying inputs and/or raw materials. Finally, the influence of market dynamics (economy and society) on demand.

Holistic and adaptive dynamics of the agro-industrial sector based on Beer's viable model integrating the balanced scorecard as an iterative process that contributes to learning and continuous improvement of the agro-industrial sector.

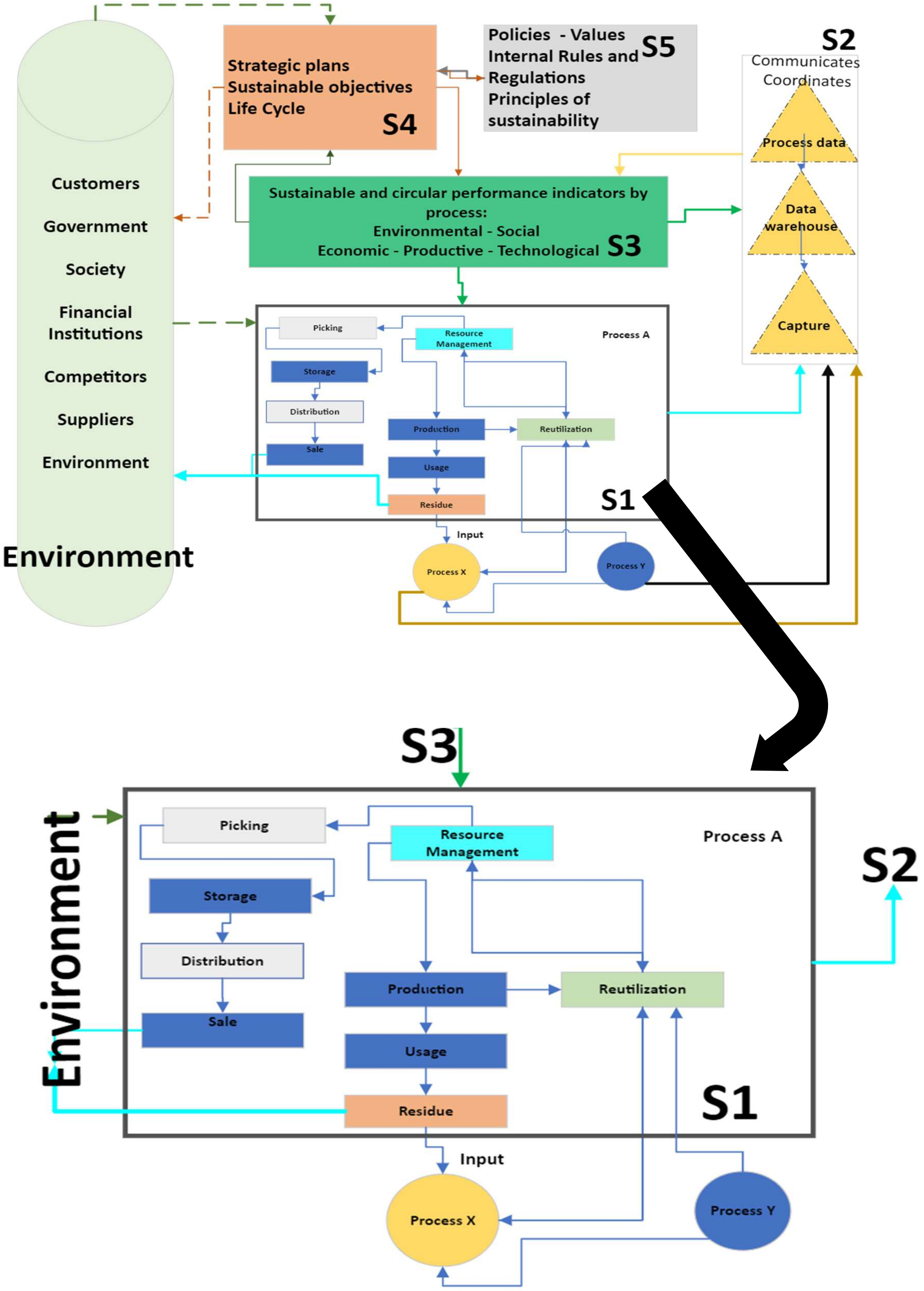

Fig. 5 Model of viable systems based on Stafford Beer (S1= System 1, S2=System 2, etc.)

Fig. 6 represents the model of viable systems, which is divided into 5 internal systems that are related to each other and to the external environment. From system 5, policies are created for the conservation and improvement of economic, social, productive, technological, and economic aspects as the main categories of the holistic system of integral sustainability. Based on the policies, ethics and values that characterize the sector, based on the work regulations as a regulatory framework for strategies and plans in accordance with the mission and vision, this system has a direct relationship with System 4. System 5 establishes the categories of interest of the scorecard; see Table 2.

Table 2 Balanced scorecard designed from the viable system model of the sector under study.

Category (S5)	Objective (S4)	Indicator (S2)	Meta (S3)	Initiative (S1)
Society				
Environment				
Economy				
Process				
Technology				
Learning:				
Immediate S1 improvements				
Future improvements S4				

System 4 the long-term work plans and the objectives presented in the balanced scorecard are projected considering the entire life cycle, which is necessary to meet the estimated goals considering the aspects that System 5 safeguards. Therefore, each category established in system 5 is supported by several objectives for its conservation and improvement as the fundamental pillars of the system.

System 4 feeds and is fed from two inputs, one internal input determined by system 3 and input external one represented by the environment. From system 3, the information of the deviations or internal performance of the system in general is received; that is, everything that requires future improvement is communicated to system 4 so that it makes the relevant strategic structure for an efficient result. Once it is established, it transfers them again to system 3 so that it lowers them or delivers them of input to system 1, in which the basic procedures and tasks are executed so that the system flows and continues its operation.

From the external environment, system 4 meets all the requirements of the client, government, and environment among others, considering regulations and trends, which allows better preparation to offer answers and adaptation to the changes that the future holds in terms of sustainability variables, thus reducing the levels of uncertainty before the future.

Returning to system 3, this is responsible for the monitoring, control, and measurement of the internal system; in this are the established goals or parameters that must be met to ensure the proper functioning and viability of the system from the regulation of this. The goals are allowed for each objective in each category about the variables of integral sustainability namely, economy, society, environment, process, and technology.

This system is supplied by the flow of information from system two; such information is compared with the value of the estimated goal allowing us to calculate and observe the degree of deviation of the real results of the system from its ideals.

The results of the deviations are averaged by category and plotted according to the Pentagon's sustainability; the categories that in the graph indicate a deviation over 5% will require an analysis for their prompt performance improvement and it will be necessary to make a graph for each category individually. With the graphs of the categories independently you can clearly see the indicator that requires more attention if it is an immediate action for its repair system 3 must be connected to system 1 for its performance, if it is an improvement that needs to be planned for future effect then it will communicate it to system 4. This control exercised by system 3 will reveal the real health of the system compared to its ideals and is of great impact to take the necessary actions so that the system takes the course as planned, which contributes to its self-regulation.

System 2 is the one who transmits the information to system 3 and receives the results of the operations carried out in system 1. Each objective described in system 4 is assigned a metric or calculation formula to know the level of achievement of this, which is established in system 2. The data to activate the formula or indicator correspond to the results of the tasks or activities developed in System 1.

By capturing the information of the executed processes, the data are stored in system 2, where the operation is carried out according to the established indicator or metric whose result allows us to have a real idea of the behavior of the system based on the variables of integral sustainability evaluated. Once captured, stored, and processed through calculations already programmed the real results of the operations already executed are communicated to system 3 to proceed with the comparison according to the goals. The information in system 2 will always be available in up-to-date or historical form for future reference.

For its part, system 1 carries out all the basic operations or implementation of the initiatives necessary for the system to function in general, operations corresponding to the biological and technical processes of the sector given by the supply of raw materials, resource management, production, reuse, collection, distribution, training processes, inclusion between according to the requests or requirements received according to the variables of the integral sustainability of the sector transmitting information of its results to system 2.

System 1 obeys the activities that were planned in system 4 and transmitted by system 3, in addition to the interventions of the environment that require immediate action. Consequently, the environment has a direct effect on systems 4 and 1 in the same way these systems interact directly with the external environment.

Organic principles of the holistic systemic causal model of integral circular sustainability in the agri-food sector

The sustainable model is given by four principles, as illustrated in Fig. 7, that facilitate the circularity of the materials and inputs used in the production process of the agri-food sector, which allows interaction with other processes and the collaboration of stakeholders in the sector as responsible for the work of minimizing negative impacts to the environment that affect society, the same process and the economy It is recognized that technologies must also be developed for this effect since it is she that affects the variable and not in the opposite way.

Fig. 6 Basic principles of the sustainable model.

Fig. 8 represents a diagram in which the influence of the principles is observed once they are linked to the process, in which it is possible to consider that they create an effect on the categories of environment, economy, society and the process itself. Nevertheless, technology is what affects the principles, so they must be adapted or in favor of them.

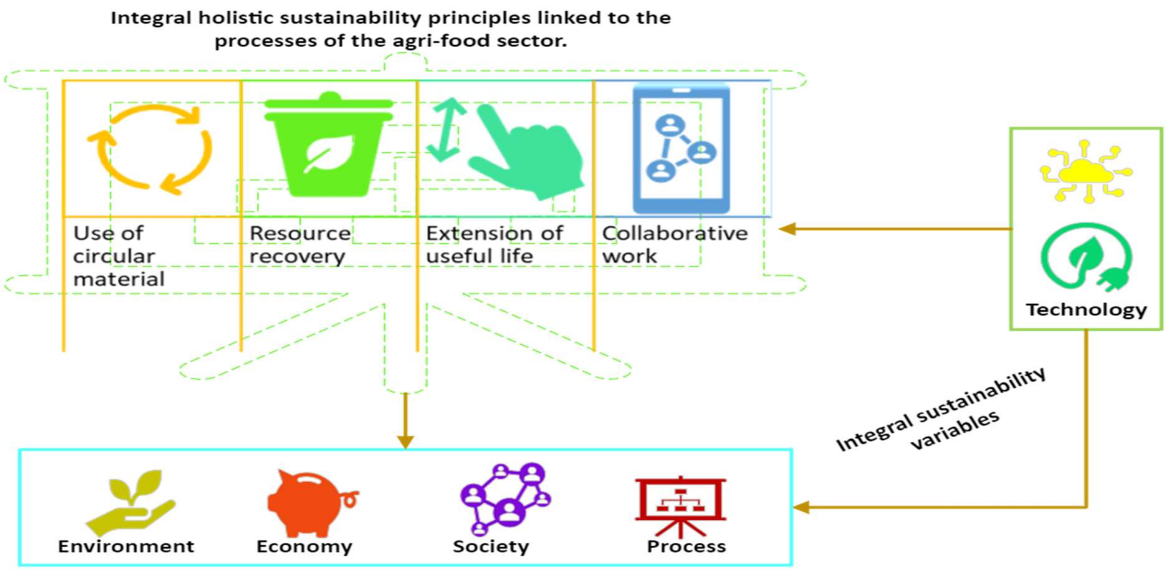

Fig. 7 Basic principles of the sustainable model integrated into the process.

Discussion

The variables environments, society and economy are those that by default are considered before the studies of circularity and sustainability, but currently it is a framework that must expand and integrate other variables that also require equal importance in front of these analyses for which technology and processes are added, considering on the latter the life cycle of the products from the early stages of their creation to the final disposal of the same.

Technology is important [28] due to its implication for the development of activities that will have important consequences in the events that are executed from the sector under study that put their sustainability at risk. Also, the processes leave traces that alter the life cycles within a region if they are not studied in a systemic way considering their effects in the environment where they develop, such a population and the very existence of the process are put at risk.

Knowing the variables and how they affect each other allows us to have a broad knowledge of the sector detecting which is one that requires more attention after proceeding with the study can be a voice of help to maintain the balance and not expose the integral sustainability of the sector.

The processes of the agri-food sector require attention from their nature, being some biological necessary for planting and cultivation and the technicians who contribute to the advanced operations of the same, it is pertinent to know how they flow and how these two variables of the process are integrated, knowing that they have influences from the external environment from policies, regulations, trends, markets and the environment itself but also the impacts to which they are exposed and are able to exert on the internal media must also be considered, considering the internal policies given by the mission, vision, values and internal regulations that regulate the relationship with other internal processes [31].

This dynamic facilitates the analysis of the operations that need to be restructured and evidence their incidence against the internal or external processes with which they have direct and indirect links, which will help a better coexistence between them from the homeostasis of the system in general

[59]. Recognizing the effects on other processes allows the creation of awareness [25] that contributes to the competitive and productive permanence of achieving objectives, remembering to be a teleological process, that is, it has purpose and determination since it is not random, but planned and premeditated [59], also with great impact on the economy, environment, interest groups, the technological means to be used and on the same processes.

Holistic and adaptive dynamics of the agro-industrial sector based on Beer's viable model, integrating the balanced scorecard as an iterative process that contributes to learning and continuous improvement of the agro-industrial sector. Knowing the holistic dynamics is an increase in the adaptability, viability and therefore the sustainability of the sector making it more economically, technologically, socially, and environmentally responsible, preserving its integrity for future generations and with good results that can be improved with the reasonable practices of the resources available, being increasingly productive and efficient [14].

The fusion of systems analysis through the viable model of Beer and the balanced scorecard allows us to conclude the strategic structure in a systemic way relevant for a better operation and achievement of the established objectives. Considering the mission and vision of the system under study integrated in system 5 of the model, in addition to this work items of interest that contribute to sustainability are added, such as the learning that is generated, especially when an objective has indicators below the established goal, which helps the approach of new and timely proposals for improvement to develop in the short or long term.

The balanced scorecard designed from the viable system model of the sector under study allows the evaluation of the variables of integral sustainability as an iterative process that contributes to the learning and continuous improvement of the agro-industrial sector [60]. This interaction leads to the creation of strategies [61] that should be included in the design from its link to the systemic process. To go beyond determining low performance rates and proposing improvements is to recognize the learning about what could not be achieved with the resources that were available.

The organic principles described for this model, such as use of circular material, recovery of resources, extension of the useful life of the product, and collaborative work, are perceived as necessary to guarantee the quality of the integral holistic sustainability of the system, so that its integration is of value and in which its interaction with the main sustainability variables must be considered, recognizing which affect the principles, but which in turn are affected by them [31,44,62].

In this opportunity, technology is key to compliance with the principles, and the use of artificial intelligence is of great contribution to more efficient operations and results [38]; therefore, they are also considered a restriction for the selection of this, since the application of the principles in the model has a direct effect on the performance of this creating impact on the other categories of the sustainable pentagon namely the environmental, social, economic and process, which are also affected by technology. These last four do not affect the principles, but rather, they are affected if they are not executed rationally and consciously.

Conclusion

This characterization the sector through causal map systemic, based on the determination of the critical variables in terms of integral holistic sustainability, leads to creating a strategic structure from the improvement and continuous learning of the sector as a complex adaptive system. Its value focuses on permitting its location in the sustainable plane as a contribution to current global problems from the systemic use of viable models that allows us to know three fundamental points:

- Knowing where the system is today by analyzing systems 1 (basic operations for normal operation) and 2 (historical, current, and actual system information system) of the viable systems model these systems are critical because they are part of the starting point to know the path of improvement that the sector requires according to its objectives.
- Knowing where you want to go is another aspect of value that is estimated in system 3 (control system, audits where the ideal parameters and goals are established) the clarity of

the goals is important because they direct the processes of self-regulation of the system in general.

- Knowing what is needed to reach that desired goal regarding the integral sustainable performance of the sector so that it works internally and has a positive impact and adapts to the external environment this is achieved in system 4 (system that allows future strategic planning to better respond to the environment) considering the conditions or constraints of system 5 (policy system, values, mission, vision that direct the system).

As an iterative process, it allows performance within the systemic approach of continuous improvement and learning.

Limitations and future research

It is necessary to validate the integration model, in general, to identify with more solid criteria the level of the contribution in the sector since it is a valuable contribution for policy management to implement tools from the development of instruments in favor of the creation of comprehensive strategies to reduce the negative impacts of certain economic and industrial activities, which represent a critical issue for today's nations [63,64].

Respect to new research, the study of the synergy between and compensation between the economic well-being of farmers, agricultural production and ecological preservation is considered [11], as well as the lack of tools, methodologies, and frameworks to manage the increased complexity of agri-food sustainability as a complex adaptive system [21]. Finally, the development of a model that quantifies the level of depletion of resources due to their excessive use.

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Contributions

L.L.R: conceptualization, investigation, data curation, formal analysis, writing, and editing.

F.P.Z: conceptualization, funding acquisition, formal analysis, and critical revisions.

A.L.S: conceptualization, funding acquisition, formal analysis, and revisions.

M.A.F: methodology, formal analysis, review, and supervision.

M.F.M: formal analysis, and critical revisions.

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Supporting information

S1 Appendix. Interaction and influence between the main variables of integral sustainability in the agri-food sector

Characterization and Causal Model of the Holistic Dynamics of the Integral Sustainability of the Agrifood System

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APPENDIX S1

Interaction and influence between the main variables of integral sustainability in the agri-food sector

The present document is intended to explain the methodology used, which is the authors' own, within the framework of the review of the literature consulted mainly on the Web of Science and Scopus.

The table 1 shows the dynamic hypotheses used in the study, starting from an initial one traditionally known in the sustainability cycle given by the linkage of economic, social and environmental variables cycle 1.

Cycle 2 represents dynamic hypothesis 1 where process variables are integrated into the traditional ones.

Cycle 3 represents dynamic hypothesis 2 where technology variables are integrated into the traditional ones.

Finally, cycle 4 integrates both process and technology variables to the traditional ones, having a more integral interaction in the system under study.

Table 1 Dynamic Hypotheses and system interactions

Dynamic Hypotheses	Parameter	System Interaction
Cicle 1	Traditional model (Economy + environment + society)	-Creation of strategies to strengthen economic, social, and environmental links to guarantee future resources.
Cicle 2	Process + traditional model	-Specific controls on waste generating organizations. -Qualified procurement for efficient operations. -Reduction of costs and establishment of competitive market prices. -Selection of raw materials suitable for the process and the environment. -Generation of jobs with quality guarantees. [1,2]
Cicle 3	Technology + traditional model	-Encourages innovation. -Encourages the development of society. -Facilitates mechanisms that reduce environmental impacts. -Data and information management to support decisions. -Effort reduction. [3–5]
Cicle 4	Process + Technplogy + traditional model	-Improved transactions. -Security in processes. -Continuous monitoring of operations. -Reliable information for decision-making. -Use of eco-friendly and user-friendly tools, materials, and

		methods. -Improved process flexibility and performance. -Trained staff to address issues [6–9]

Level of interaction and influence between the main variables of integral sustainability in the agri-food sector

The most commonly used sustainability variables or dimensions represent economy, environment and society, as evidenced in [9–17]. However, using this study, the following is annexed to this model: production and technology, therefore creating the so-called Pentagon of sustainability, as represented in Fig. 1.

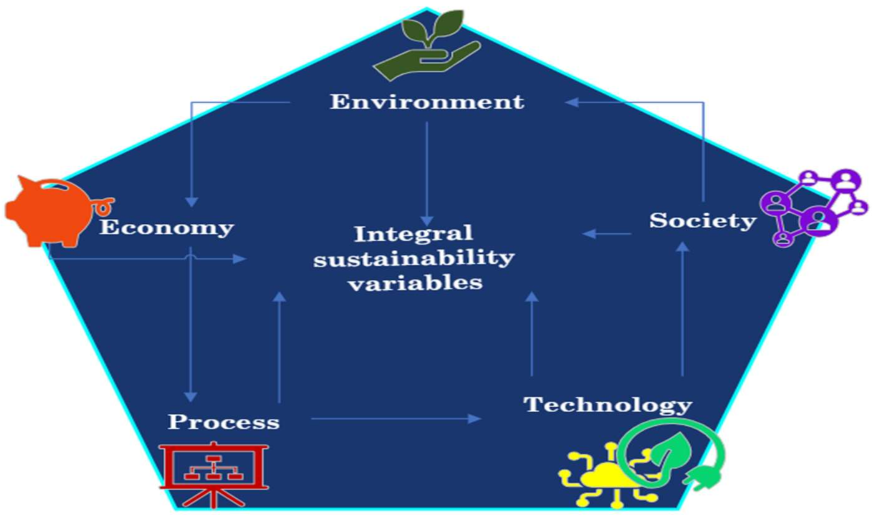

Fig. 1 Integral sustainability pentagon

Consider some internal variables, as shown in Fig. 2.

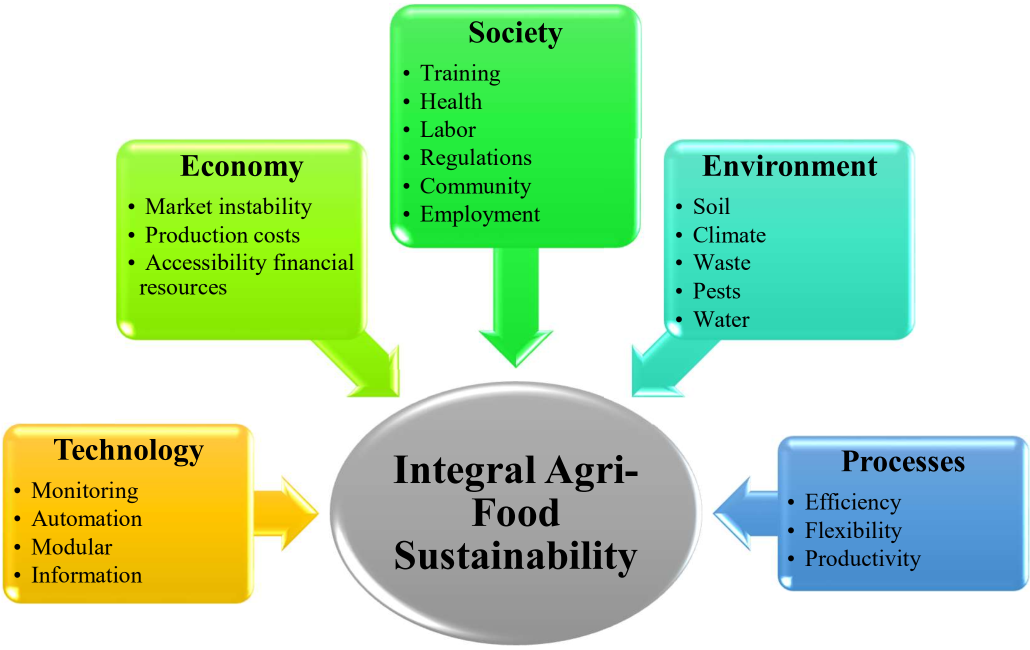

Fig. 2 Variables of the integral sustainability of the agro-industrial sector

Objective

Reinforce the sustainable structure by integrating variables that guarantee the supremacy and optimization of the use of resources, recognizing their importance and impact by the current economic and environmental crisis.

Justification

The methods and productive actions implemented, as well as the use and level of technologies applied, considerably affect the patterns of ecosystems according to their management, depleting resources or prolonging their useful life, which is of interest to explore since the aim is to avoid or slow down the extinction processes of certain reserves; therefore, it is necessary to incorporate variables that directly influence these dynamics [18–24].

Methodology

Phase 1: listing of system variables, Phase 2: description of relationships between system variables, and Phase 3: identification of key variables and their categories and interpretation.

Results

Table 2 List of variables to study

Environment	Society	Process	Technology	Economy

Table 3 Qualitative effect between variables

Integral Sustainability Variables	Process	Technology	Environment	Society	Economy
Process	Efficiency Productivity Performance.	It requires technology and encourages innovation for its development to contribute to efficient performance.	Emission of greenhouse gases, better use of water resources, soil degradation (extinguishes resources, rendering them worthless for future events) [15,25–32]	Provide opportunities for integration through interdisciplinarity within the framework of employability with quality. (direct-indirect/local or external contracting) [12,15,29,30,33]	Fair and affordable prices Investor-friendly profits investment level according to performance integration of productive sectors [5,15,34]

Technology	Generate agility in the processes. Optimal use of resources Avoid waste [9,31,35–41]	Ease of integration and achievement of goals.	Promote the consumption and rational use of resources, avoiding their deterioration or extinction [9,31]	Facilitates communications and relationships [9,37,38]	Streamlines transactions [9,31,36]
Environment	Soil and water quality interfere with the yield and efficiency. Availability of naturally occurring renewable and nonrenewable resources [34,42]	Need for mechanisms to clean, purify, and guarantee safe extractions.	Quality: air, water, land, availability of renewable and nonrenewable resources.	Air quality, water quality, safe disease-free environment [10,12,32,43,44]	Need for investment to remain stable and favorable [42,45]
Society	Professionalization for the optimal development of activities, sociocultural influence, and scale of consumption of goods and services produced [32,34,46]	Need for technology readiness [24,38]	Adequate use of resources to ensure their future availability [32,35]	Integration and participation, inclusive and resilient.	Opportunities for accessibility to services and products [12,44]
Economy	Cost of inputs, acquisition of credit, cost of taxes and tariffs, licenses, international stock exchange movements [47]	Procurement for development [48]	Grant investments for improvement and maintenance [31,35,47,49,50]	Enable resources to purchase goods and services (drives the economy itself)[34,44,48]	Development opportunities for everyone.

Very low	**Low**	**Medium**	**High**	**Very high**
1	**2**	**3**	**4**	**5**

Table 4 Quantitative effect between variables

Integral Sustainability Variables	Process	Technology	Environment	Society	Economy	Variable that most affects
Process	5	4	5	4	4	**22**
Technology	5	5	4	4	4	**22**
Environment	5	2	5	3	2	**17**
Society	4	3	3	5	4	**19**
Economy	4	4	2	3	5	**18**
Variable that is most affected	**23**	**18**	**19**	**19**	**19**	

Conclusion

Establishing need in a variable indicates the level of dependence on the other variable, requiring contributions from it but not providing them. Put differently, it is critical for that variable to advance or evolve but does not promote a significant effect for the other variable. For example, it is important to have a healthy environment so as not to affect the quality of life or the health of society. However, the environment does not need highly specialized practices and society for its conservation because it requires more than the participation of society; other sectors would have to be linked since society uniquely would not cause a significant effect.

The matrix is filled in according to the answer to the question: is variable X (yellow column) important for the progress or development of variable Y (blue row)?

The oblique line provides a qualifier of five, extensively corresponding to intersections between the same variables.

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