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Assessing the sustainability of rice production in Brazil and Cuba

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A R T I C L E I N F O

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A B S T R A C T

The objective of this paper is to assess the sustainability of the agricultural production chain of rice (Oryza sativa L.) in Brazil and Cuba, using a conceptual model that considers five sectors of sustainability supported in the Goals Programming philosophy as multicriteria analysis tools. A synthetic sustainability indicator is constructed to support decision-making through the benchmarking process to contribute the environmental, economic and social sustainability of rice farming. As results, Brazil shows a greater sustainability based on better availability of environmental resources for rice cultivation, a lower relative environmental load, better economic and productive performance, poorer employment and wage policies and higher satisfaction of the social demand for rice. On the other hand, Cuba shows a deficit of environmental resources, higher relative environmental load, low economic and productive performance, better employment and wage policies, and unsatisfied social demand for rice.

1. Introduction

The Sustainability has been defined in many ways, with the "triple bottom line approach", which aims to balance the three dimensions of sustainability, being the most widespread. This approach allows for trade-offs between the biophysical, social and economic spheres [1].

In order to assess the sustainability of an agricultural production system, it is necessary to quantify its impact on the environment, economic results and the social benefits it provides. In addition, methods for environmental assessment of agricultural systems have become increasingly complex, integrating the latest available knowledge and scientific tools [2–6].

In this research, the Five Sector Model (5 SEnSU) will be applied which, as its name indicates, is composed of five sectors or quadrants that respond theoretically and methodologically to the three dimensions of sustainable development, with the particularity of subdividing the environmental and social dimensions into two sectors to analyze them independently but causally related [7].

1.1. Then five- sector sustainability as a conceptual model

The Five Sector Model (5 SEnSU) has been developed in the Production and Environment Laboratory of the Paulista University (UNIP), Sao Paulo, Brazil as a conceptual tool to assess sustainability from a comprehensive approach. It is a conceptual methodological abstraction, that are flexible instruments of assessment of the Sustainability that results in synthetic indicators to characterize the performance of a system in terms of sustainability, which contributes to decision making [7].

The 5 SEnSU model is a holistic model that comprises multi-characteristics and considers five sectors of a given system which are: environmental sector as provider, environmental sector as receiver, economic or production unit sector as producer of goods and services, social sector as supplier of labor and inputs and social sector as consumer of goods and services. The purpose of the model is to look for a framework of analysis to achieve the balance between these sectors towards sustainability, which can be done from an analysis perspective based on the achievement of objectives [7].

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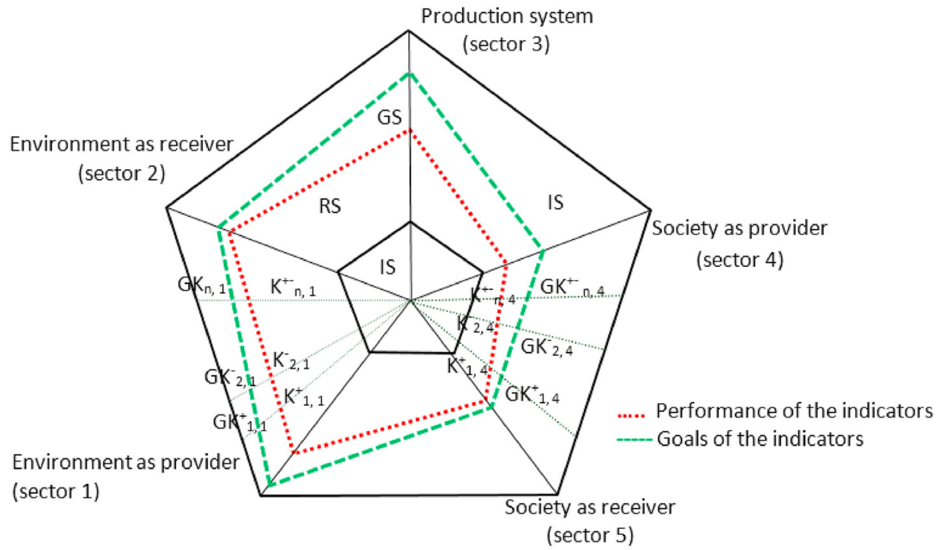

Fig. 1. The Five Sector Sustainability model (5 SenSU) in radar form.

1.2. The sustainability of rice production

Solving the food deficit problem on sustainable basis is one of main challenges to which all countries are called, which creates the need to increase production of basic foods such as cereals, which in many cases contradicts the urgent need of environmental preservation and establishment of sustainable policies of agricultural crops from the economic, social and environmental aspects, consistent with the paradigm of sustainable development of United Nations and the 17 Goals, specifically numbers 12: "Ensure sustainable consumption and production patterns" and 13: " Take urgent action to combat climate change and its impacts" [8–12].

The shortage of basic food for people is the analysis object of international organizations, national governments and researchers, among other actors. From the economic viewpoint, rice is considered, after wheat and corn, the third agricultural commodity, and the second in terms of price variability in market, because it is mainly a highly demanded alimentary product. Its worldwide per capita consumption is more than 50 kg per year [13–18].

Recently, the main rice producing countries have achieved considerable production levels increasing agricultural yield based on some given factors, such as: the extensive cultivation of this cereal combined with intensive farming techniques, the large-scale water use, fertilizers, pesticides and herbicides, along with planting new seed varieties genetically adapted to changing environmental conditions, new cultivation techniques and high levels of mechanization in agriculture and automation of industrial production [19–23].

The Greenhouse Gas emissions from rice farming consist of CH_4 produced during the anaerobic decomposition of organic matter in flooded rice fields, through a process called methanogenesis, where the CH_4, once generated in the soil, diffuses to the atmosphere mainly through the leaves of the rice plant; the type of soil, temperature and the form of rice cultivation also affect CH_4 emissions [24–29].

On the other hand, several authors agree that the greatest short and medium term effect of rice cultivation on the environment is the progressive use of chemical and organic fertilizers, pesticides, fungicides and waste materials with high degrees of toxicity, which are carried away by the water used in the irrigation systems, that infiltrates to the sub-soil high concentrations of these substances which poison the water table, pollute the rivers and seas, degrade the soil, affect the ecosystems and incorporate into the food chains of animals and fish that men consume, negatively affecting their health [30–36].

The main variant of rice farming in the world is flood conditions, which is the main source of GHG emission. In addition great volumes of water are discarded with high concentrations of toxic products [37–40].

In short, due to the relevance of rice (Oryza sativa L.) from the economic, social and environmental points of view as resource of high economic value, basic food for half the population of the planet, and negative impact of intensive cultivation to the environment respectively [33,39], it is necessary to assess the sustainability of this productive chain with an integral approach, to adopt decisions that benefit both the economic, environmental and social aspects in order to achieve necessary sustainability [23].

Regarding to this rice producing countries should take advantage of international best practices (benchmarking processes) in rice cultivation and adapt them to their agricultural systems in order to improve rice yields and ensure sustainability through an environmentally friendly relationship.

1.3. Characterization of rice agricultural production in Brazil and Cuba

In the last decade, Brazil has evolved from one of the top ten rice importers of the world, to reach the sixth position of exporter countries in 2011; the same source recognizes it as the largest rice producer and consumer out of Asia [14,15,30,41]. According to the National Supply Company of Brazil (CONAB) in the period 2016–2017, 11.506 million tons of rice were harvested in Brazil in 1946.7 million hectares of cultivation area, with a yield of 5911 t/ha. In this period, it exported around 1.1 million tons, and its per capita consumption was of 25 kg per year [42]. The state Rio Grande do Sul produces 95% of the country's total rice although other states such Santa Catarina and Minas Gerais among other, they are important producers of this cereal. Rice production in Brazil shows a decrease in recent years due to marketing issues and problems related to environmental effects in the main producing states, where 75% of the rice is produced under waterlogging conditions, while in Cuba with less water resources availability, the production is of a 95% [17,42,43].

In contrast, Cuba, which is one of the countries with highest per capita consumption of rice (70 kg per year), represents an average per capita consumption of Asian countries (110–140 kg); the national rice production does not satisfy the domestic demand, so that half of the rice consumed (1.2 million tons per year) is imported, being Vietnam, Brazil and other Southeast Asian countries their main suppliers. In the 2016–2017 period, Cuba produced 0.514 million tons of rice in 0.140 million hectares of cultivation area with yields of 3.67 t/ha due to problems with negative impact, such as soil depletion, fertilizers shortage, lack of labor force, the high production costs and progressive drought linked to the effects of climate change. An important and negative aspect to consider is that the main production of rice in Cuba is harvested by the private sector with ancient artisanal techniques of farming, limited resources and yields lower (3.51 t/ha), which represents 78.14 % of the country's total rice production [43].

2. Materials and methods

In order to use model 5 SEnSU and assess the performance of the synthetic sustainability indicator, the radar form proposed by Albo et al. [44] are used to represent the performance of multidimensional composite indicators through the use of information and communication technology (ICT).

Similarly as the classic model of sustainable development, the 5 SEnSU model is based on the balance that must exist between the selected dimensions and the indicators to measure its performance, which are plotted in a pentagon of radar form where the sectors are “clockwise” to from the lower left edge that corresponds with Sector 1 to the lower right edge with Sector 5. See Fig. 1.

The Fig. 1 shows several scenarios according to the performance of the indicators (K+ or K-) of each sector of the 5 SEnSU: An ideal scenario (IS) that corresponds to a perfect balance between the five sectors of the model, a goal scenario (GS) where the objectives of the indicators of each sector are located, and a real scenario (RS) where the real values of each indicator are located, obtained from the measurements of the selected variables.

The advantages of the proposed tool are based on clear criteria in choosing indicators supported by the 5SEnSU model, which recognizes the double functions (as a donor and receiver) of natural environment and society, as well the application of goal programming to obtain the only one sustainability synthetic indicator of systems.

2.1. Composite indicators for sustainability

An indicator is a qualitative or quantitative measure that allows defining a characteristic, identifying a risk, making decisions and/or verifying the results of a certain action or process [5,6]. It is agreed with Albo et al. [44] that “a composite indicator is a measurement and reference tool used to capture multidimensional concepts, such as the use of information and communication technology (ICT)". “A composite indicator is a measuring and benchmark tool used to capture multi-dimensional concepts, such as Information and Communication Technology (ICT) usage” [45,46].

In this context some modifications will be made to the synthetic indicator based on the Programming of Goals (GPSI), which is a non-statistical technique in which synthetic measures are obtained by deviation variables associated with the goals defined for each initial indicator [8]. Other researchers have used this technique to assess sustainability by designing a synthetic indicator [9]. It will be guided by the methodological approach proposed by Blancas et al. [47] to construct indicators based on the relationships between positive and negative indicators to obtain a final indicator of sustainability.

As result of a study to assess the sustainability of rice cultivation in Bangladesh, a composite indicator (CI) was developed, consisting of indicators selected under the four pillars of sustainability (Social, Environmental, Economic and Political), obtained from the calculation of The Rice Farming Sustainability Indexes (RFSI) for different rice varieties [38,48]. Other authors and institutions have proposed composite methodologies and indicators to assess sustainability of agricultural systems taking into account the three dimensions of sustainability: economic, sociocultural and environmental [49].

The calculation of internationally accepted Performance Indicators (PI) based on defined priorities to assess the sustainability of rice cultivation [50]. In this study, performance indicators commonly used to assess the sustainability of rice production will be used to assess the sustainability of rice production.

2.2. The goal programming philosophy in the 5 SEnSU model

Goal Programming (GP) can be understood as a continuous mathematical method to handle multiple and conflicting objectives problems that are translated into Multi-Criteria Decision Analysis (MCDA) situations. GP is one of the possible methodologies to be applied to MCDA problems.

In this context calculation algebra of the 5 SEnSU is based on the use of the GP philosophy as a tool for MCDA to obtain a General System Sustainability Indicator [51–55], to express the results according to the proximity between the relative values of the indicators and its goals. Modifications have been made in order to adapt it to an analysis of the 5 SEnSU Model. Considering a decisional problem in which G_i goals exist.

$$\text{Min } Z = \sum_i (W_i N_i + W_i P_i)$$

Where Z is the objective function to be minimized, N_i and P_i are the unwanted deviation variables (positive and negative) associated to each K_i indicator, W_i are the relative weights of importance of each indicator associated to the deviation variables.

Subject to (ST) the following restrictions associated with the selected indicators: $f_i(K_i)+N_i\text{-}P_i = G_i$, where f_i (K_i) represents the mathematical expression of the i-th indicator; G_i is the aspiration level (Goal), N_i and P_i, the variables of negative and positive deviation, associated to the positive indicators “higher better” and negative “lower better”, respectively, and W_i represents the weighted value or “aspiration” of the deviation variables.

For positive indicators (constraint of type $\geq$), the variable of undesired deviation is the negative N_i, where the objective function would be Min $Z = N_i$; ST $f(K_i) + N_i - P_i \geq G_i$; $N_i = G_i - f(K_i)$. For negative indicators (constraint of type $\leq$), the variable of undesired deviation is the positive P_i, where the objective or achievement function would be Min $Z = P_i$; ST $f(K_i)+N_i-P_i \leq G_i$; $P_i = f(K_i) - G_i$. When it is desired to reach exactly the level of aspiration (=), the undesirable deviation variables are both the positive P_i and the negative N_i, where the objective or achievement function would be Min $Z = N_i + P_i$; ST $f(K_i) + N_i - P_i = G_i$.

When assessing the situation of each scenario, the unwanted variables are different depending on the type and desired direction of the indicator (+or -). For positive indicators, the undesired variable is the negative deviation (N^+_{ijk}), with scenarios that reach the aspiration level set as a target or have a higher value of the positive deviation variable (P^+_{ijk}). For negative indicators, the undesirable variable is the positive deviation variable (P^-_{ijk}), with scenarios that reach the target aspiration level or a higher value of the negative deviation variable (N^-_{ijk}) [7,47,56]. The calculation expressions of the deviation variables and sustainability synthetic or composite indicators are shown below.

For the “higher better” positive (+) indicators:

$$N^+_{ijk} = \begin{cases} G^+_{jk} - K_{ijk}, K_{ijk} < G^+_{jk} \\ 0, K_{ijk} \geq G^+_{jk} \end{cases} \quad \forall i \in \{1,2,\ldots,NE\} \forall j \in \{1,2,\ldots,NS\}, \forall k \in \{1,2,\ldots,NI\} \tag{1}$$

$$P^+_{ijk} = \begin{cases} K_{ijk} - G^+_{jk}, K_{ijk} > G^+_{jk} \\ 0, K_{ijk} \leq G^+_{jk} \end{cases} \forall i \in \{1,2,\ldots,NE\} \forall j \in \{1,2,\ldots,NS\}, \forall k \in \{1,2,\ldots,NI\} \tag{2}$$

For the “lower better” negative (−) indicators:

$$P^-_{ijk} = \begin{cases} K_{ijk} - G^-_{jk}, K_{ijk} > G^-_{jk} \\ 0, K_{ijk} \leq G^-_{jk} \end{cases} \forall\ i\ \in \{1, 2, \ldots, NE\} \forall\ j\ \in \{1, 2, \ldots, NS\}, \forall\ k \in \{1, 2, \ldots, NI\} \quad (3)$$

$$N^-_{ijk} = \begin{cases} G^-_{jk} - K_{ijk}, K_{ijk} < G^-_{jk} \\ 0, K_{ijk} \geq G^-_{jk} \end{cases} \forall\ i \in \{1, 2, \ldots, NE\} \forall\ j \in \{1, 2, \ldots, NS\}, \forall\ k \in \{1, 2, \ldots, NI\} \quad (4)$$

$N^{\pm}_{ijk},\ P^{\pm}_{ijk} \geq 0$ and $N^{\pm}_{ijk}.\ P^{\pm}_{ijk} = 0$ where:

NE: quantity of scenarios (countries in this case study); NS: quantity of sectors (1 … 5); NI: quantity of indicators per sector; i: scenario (1 … NE); j: sectors (1 … 5); k: indicators (1 … NI); K_{ijk}: value of the k-th indicator in the j-th sector of the i-th scenario.
$N^+_{ijk}; N^-_{ijk}$: negative deviation variable of the positive or negative indicator respectively.
$P^+_{ijk}; P^-_{ijk}$: positive deviation variable of the positive or negative indicator respectively.
$G^+_{jk}; G^-_{jk}$: goal value for the positive or negative indicator respectively.

The calculation of goals (G^{+-}_{jk}) responds to different situations and that must be selected by the "researcher", determined according to the nature of the indicator, objectives and characteristics of the system. It is necessary to avoid subjective evaluations that affect the final results, in the case that the target values are not known [7,47,56].

The target or reference values of the indicators ($G^+_{jk} y G^-_{jk}$) can be obtained from national or international benchmarking systems or by statistical calculations [1,7,9,55]. In this study for positive (+) indicators, the target value (G^+_{jk}) will be calculated as the mean value of the indicator (K^+_{ijk}) added to the standard deviation of the indicator values ($\sigma(K^+_{ijk})$), according to expression:

$$G^+_{jk} = \overline{K^+_{ijk}} + \sigma\left(K^+_{ijk}\right) \quad (5)$$

For negative type indicators (−), the target value (G^-_{jk}) will be calculated as the minimum value of the indicator $Min(K^-_{ijk})$ added to the standard deviation of the indicator values ($\sigma(K^-_{ijk})$), according to expression:

$$G^-_{jk} = Min\left(K^-_{ijk}\right) + \sigma\left(K^-_{ijk}\right) \quad (6)$$

The corresponding synthetic sustainability indicators will then be calculated for each level of detail (indicators, sectors and scenarios).

Sustainability Goal Indicator (ISG^+_{ijk} and ISG^-_{ijk}), normalized value considering equations (1)–(4).

$$ISG^+_{ijk} = \sum_{ijk} \frac{N^+_{ijk}}{W^+_{jk}.G^+_{jk}} + \sum_{ijk} \frac{P^+_{ijk}}{W^-_{jk}.G^+_{jk}} \forall\ i \in \{1, 2, \ldots, NE\} \forall\ j \in \{1, 2, \ldots, NS\}, \forall\ k \in \{1, 2, \ldots, NI\} \quad (7)$$

$$ISG^-_{ijk} = \sum_{ijk} \frac{N^-_{ijk}}{W^-_{jk}.G^-_{jk}} + \sum_{ijk} \frac{P^-_{ijk}}{W^+_{jk}.G^-_{jk}} \forall\ i \in \{1, 2, \ldots, NE\} \forall\ j \in \{1, 2, \ldots, NS\}, \forall\ k \in \{1, 2, \ldots, NI\} \quad (8)$$

where W^+_{jk} and W^-_{jk} is the weighted value or "aspiration" that the indicator haves. It is recommended that for positive indicators $W^+_{jk} < W^-_{jk}$ and for negative indicators $W^+_{jk} > W^-_{jk}$, where $0 < W^+_{jk}\ ,\ W^-_{jk} \leq 100$.

The Sustainability Sector Indicator (SSI_{ijk}), considering (7) and (8) is calculated as the sum of the difference of the sustainability indexes of the positive indicators and the indexes of sustainability of the negative indicators.

$$SSI_{ijk} = WS_j \sum_i \sum_j \sum_k \left(ISG^+_{ijk} + ISG^-_{ijk}\right) \forall\ i \in \{1, 2, \ldots, NE\}, \forall\ j \in \{1, 2, \ldots, NS, \forall\ k\ \in \{1, 2, \ldots, NI\}\} \quad (9)$$

Following Blancas et al. [47] WS_j are relative weighted, assigned to each sector of the system being.

$$\sum_j WS_j \leq 5 \forall 0 < WS_j \leq 1, \forall\ j\ \in \{1, 2, \ldots, NS\}$$

Table 1
Matrix form to calculate 5 SEnSU's model indicators.

I	K_{ijk}	Sceneries, Sectors, Indicators $\forall\ \mathbf{i} \in \{1, 2, \ldots, \mathbf{NE}\}, \forall \mathbf{j} \in \{1, 2, \ldots, \mathbf{NS}\}, \forall\ \mathbf{k} \in \{1, 2, \ldots, \mathbf{NI}\}$								Sustainability synthetics indicators		
		$G^{+,-}_{jk}$	To positive Indicators (+)			To negative Indicators (−)						
			N^+_{ijk}	P^+_{ijk}	ISG^+_{ijk}	P^-_{ijk}	N^-_{ijk}	ISG^-_{ijk}		SSI_{ijk}	SIS_{ij}	$SGIS_i$
1	$K_{1,1,1}$	$G^{+,-}_{1,1}$	$N^+_{1,1,1}$	$P^+_{1,1,1}$	$ISG^+_{1,1,1}$	$P^-_{1,1,1}$	$N^-_{1,1,1}$	$ISG^-_{1,1,1}$	…	$SSI_{1,j,k}$	$SIS_{1,NS}$	$SGIS_1$
2	$K_{2,1,1}$	$G^{+,-}_{2,1}$	$N^+_{2,1,1}$	$P^+_{2,1,1}$	$ISG^+_{2,1,1}$	$P^-_{2,1,1}$	$N^-_{2,1,1}$	$ISG^-_{2,1,1}$	…	$SSI_{2,j,k}$	$SIS_{2,NS}$	$SGIS_2$
3	$K_{3,1,1}$	$G^{+,-}_{2,1}$	$N^+_{3,1,1}$	$P^+_{3,1,1}$	$ISG^+_{3,1,1}$	$P^-_{3,1,1}$	$N^-_{3,1,1}$	$ISG^-_{3,1,1}$	…	$SSI_{3,j,k}$	$SIS_{3,NS}$	$SGIS_3$
…	…		…	…	…	…	…	…	…	…	…	…
NE	$K_{NE,NS,NI}$	$G^{+,-}_{NS,NI}$	$N^+_{NE,NS,NI}$	$P^+_{NE,NS,NI}$	$ISG^+_{NE,NS,NI}$	$P^-_{NE,NS,NI}$	$N^-_{NE,NS,NI}$	$ISG^-_{NE,NS,NI}$		$SSI_{NE,NS,NI}$	$SIS_{NE,NS}$	$SGIS_{NE}$

Sources: Adapted from Giannetti et al. [7].
Where.
NE: quantity of scenarios (countries); NS: quantity of sectors (1 … 5); NI: quantity of indicators per sector.
i: scenario (1 … NE); j: sectors (1 … 5); k: indicators (1 … NI); K_{ijk}: value of the k-th indicator in the j-th sector of the i-th scenario.
The calculation of values the variables and indicators will be done by the expressions (1–11).
$N^+_{ijk}; N^-_{ijk}$: negative deviation variable of the positive or negative indicator respectively.
$P^+_{ijk}; P^-_{ijk}$: positive deviation variable of the positive or negative indicator respectively.
$G^{+,-}_{jk}$: goal value for the positive or negative indicator respectively.
ISG^+_{ijk};ISG^-_{ijk}: sustainability goal Indicator for the positive or negative indicator respectively.
SSI_{ijk}: sustainability sector Indicator.
SIS_{ij}: sustainability indicator by sector for scenario.
$SGIS_i$: sustainability goal Indicator by scenarios.

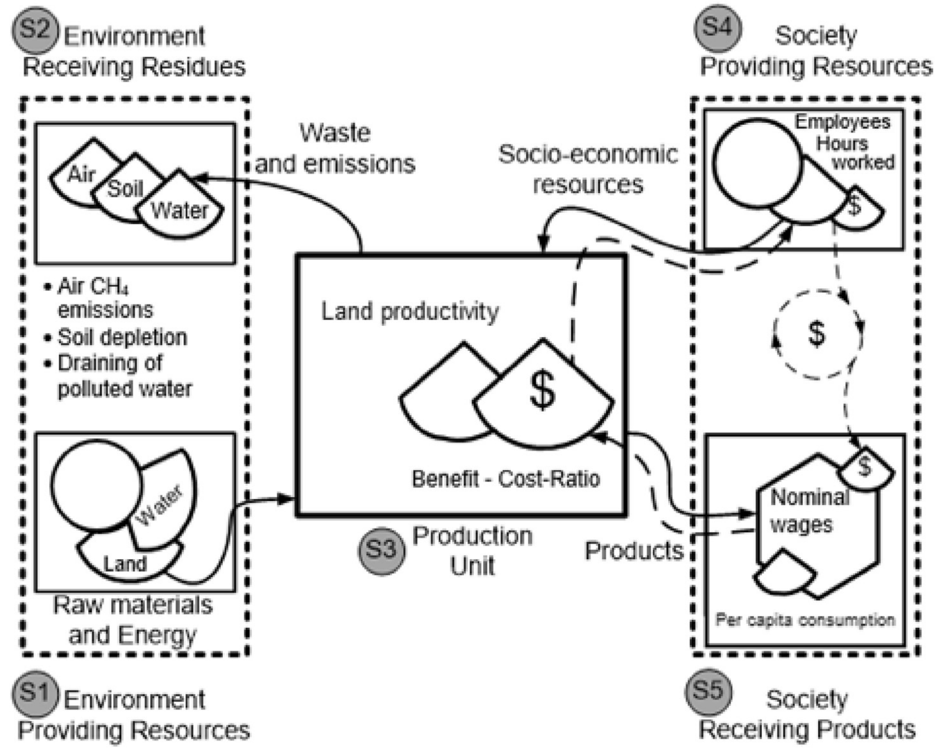

Fig. 2. Rice production farming in the 5 SenSU model. **Source:** Adapted from Giannetti et al. [7]. License Number 4830481117917, provided by Elsevier and Copyright Clearance Center.

To establish the indicator (K_{ijk}) of a better or worse contribution to the sustainability of a sector or system, the lower or higher value of (SSI_{ij}), would be determined, which depends on the positive or negative nature of the indicator respectively. It is also possible to determine the value of the indicator that changes the position of the scenario in the system for a certain sector.

The Sustainability Indicator by Sector for scenario (SIS_{ij}), considering (9), allows comparing the performance of the system scenarios when comparing different sectors or combinations of these in particular.

$$SIS_{ij} = \sum_i \sum_j \sum_k SSI_{ijk} \forall\ i \in \{1, 2, \ldots, NE\}, \forall\ j \in \{1, 2, \ldots, NS\} \tag{10}$$

The Sustainability Goal Indicator by Scenarios ($SGIS_i$), considering (10), shows the performance of the scenarios when considering the relationship between the value of the indicators, their nature, objectives and relative importance in the system.

$$SGIS_i = \sum_j SIS_{ij} \forall\ i \in \{1, 2, \ldots, NE\} \tag{11}$$

In order to assess the performance of several scenarios, an ascending ranking of the values of ($SGIS_i$) would be sufficient, being better located, the scenarios that occupy the first positions.

To facilitate the application of the 5 SEnSU model these five steps should be followed:

Step 1 Diagnosis and characterization of the productive or service system in terms of sustainability, specifically in its environmental, economic and social performance. In addition to identifying and characterizing the areas or places where the study will be conducted.

Step 2 Selection of the sustainability indicators for each sector depending on their function in the system and the philosophy of the 5 SEnSU model; In this step, it is important to select the variables or indicators to construct the synthetic indicators of sustainability, which must respond to each of the five sectors of the 5 SEnSU model. These can be selected by previous studies, through criteria of experts chosen with non-parametric statistical techniques or DELPHI method among other selection techniques and must meet the criteria of representativeness, relevance, reliability, sensitivity, ease of understanding, comparability and transparency [7, 57].

Step 3 Classification of the sustainability indicators depending on their function in the five sectors and determine the minimum, maximum and target levels of each indicator, their desired direction (positive + or negative -) and the weight or weighted values of each indicator and sector.

Step 4 Application of the methodology and expressions of calculation to determine the synthetic indicators of sustainability. To facilitate the calculation of the indicators, Table 1 can be used, showing a matrix form that can be used for automation in a computer application.

Step 5 Interpretation of the results and decision making to application of corrective measures to improve the performance of variables and sustainability indicators.

2.3. Study location in Brazil and Cuba

The agricultural production of rice in both countries was previously characterized with a focus on sustainability. To assess the sustainability of rice production, companies were selected in the main rice areas of both countries. The research in Cuba was carried out in the rice Company Agro-Industry (CAI) Fernando Echenique located in the Province of Granma, where 70% of the rice production of the country is concentrated, and the climate is hot and humid, with an average annual temperature of 28 °C. The annual rainfall levels exceed 750 mm per year (Coordinates 20° 18′19.7 “N 76° 58′04.0″ W) [43]. In Brazil, the research was carried out in 148 municipalities in NATES region of the Rio Grande do Sul State, located at coordinates 29° 47′29.4 “S 55° 47′15.9″ W and 70 m of altitude. The municipality has an average annual temperature of

Table 2
Values and goals of the selected performance indicators.

Names of the indicators	Acronym	Desired Direction	Units	Values		*Goal(G)
				Brazil	Cuba	
Sector 1 (environment as provider)						
Water for irrigation	K11	–	Mm^3/t-year	1.525	2.689	$Min(K_{11}) + \sigma(K_{11})$
Land for farming	K12	–	Mha/t-year	0.135	0.272	$Min(K_{12}) + \sigma(K_{12})$
Sector 2 (environment as receiver)						
Methane emission (CH_4)	K21	–	kg CO_2 Eq/t-year	0.230	1.602	$Min(K_{21}) + \sigma(K_{21})$
Water drained	K22	–	Mm^3/t-year	0.154	0.272	$Min(K_{22}) + \sigma(K_{22})$
Sector 3 (production unit)						
Benefit - Cost-Ratio	K31	+	–	1.25	1.30	$\overline{K_{32}} + \sigma(K_{32})$
Land productivity	K32	+	t/ha-year	7.430	3.671	$\overline{K_{32}} + \sigma(K_{32})$
Sector 4 (society as provider)						
Number of employees	K41	+	Employees/t-year	2.6	3.6	$\overline{K_{41}} + \sigma(K_{41})$
Hours worked by employees	K42	+	Hours/t-year	550	650	$\overline{K_{42}} + \sigma(K_{42})$
Sector 5 (society as receiver)						
Per capita consumption percent	K51	+	%	101.24	42.87	100
Nominal wages	K52	+	$/t-year	323.83	237.41	$Min(K_{52}) + \sigma(K_{52})$

(*) The goal values of the indicators were calculated using the expressions (4, 5). For positive (+) indicators, the target value (G^+_{jk}) will be calculated as the mean value of the indicator (K^+_{ijk}) added to the standard deviation of the indicator values ($\sigma(K^+_{ijk})$). For negative type indicators (−), the target value (G^-_{jk}) will be calculated as the minimum value of the indicator $Min(K^-_{ijk})$ added to the standard deviation of the indicator values ($\sigma(K^-_{ijk})$).

27,5 °C and a rainfall between 500 and 1000 mm per year [58,59].

3. Results and discussion

As previously discussed, the SEnSU model will be used to assess the sustainability of the agricultural production chain of rice in Brazil and Cuba, which will be carried out following the five steps mentioned above.

3.1. Selection of the sustainability indicators for each sector

In this context, the sustainability of the productive chain of rice farming, based on the balance of the five sectors of the 5 SEnSU model defined above will be considered: the environmental sector as provider of resource land for farming, water for irrigation and biocapacity (sector 1), the environmental sector as receiver of water drained and methane emissions as Greenhouse Gases (sector 2), the production sector as producer of rice for human consumption (sector 3), the social sector as supplier of labor force and services to the productive sector (sector 4) and the social sector as consumer of rice (sector 5).

The sustainability indicators of the productive chain of rice farming were selected from previous studies assessing the sustainability and diverse data sources, which were classified according to the criteria of 5 SEnSU model: Water for irrigation [40,50,60,61]; Land for farming [38,48,62]; Methane emission [29,38,40,48,50,63]; Water drained [36,38,48,64]; Benefit-Cost-Ratio [38,48,60,62] and Land productivity bib38 [38,39,48,50,60,62]; Number of employees, Hours worked by employees, Per capita percent, Nominal wages [38, 48, 50, 60. 64].

The Fig. 2 shows the selected sustainability indicators of rice production, represented in the conceptual diagram of the 5 SenSU model.

The figure above shows the material, energy and financial flows of rice production related to the selected indicators, represented in the dynamics and structure of 5 SenSU model with the symbols of the Emergy methodology [7].

The data sources are Rio Grande Rice Institute (IRGA); Brazilian Agricultural Research Corporation (EMBRAPA); National Supply Company of Brazil (CONAB); Ministry of Agriculture of Cuba (MINAGRI); National Office of Statistics and Information of Cuba (ONEI); The Statistics Division of Food and Agriculture Organization of the United Nations (FAOEST), Sustainable Rice Platform (SRP) and data obtained, calculated or estimated of the farms selected in both countries.

In order to homogenize the indicators values declared in different measure units, all units were expressed in relation to a functional unit, in this case, the tons of rice produced in a one-year period (units/t-year). The tables are appended with the general calculations for each indicator and the computer tool designed to automate the application in this study case. Table 4 in Appendix 1 shows the data sources and the calculations of the sustainability indicators for both countries.

Two indicators per sector were selected, totalizing ten indicators represented by the letter K, followed by the sector's number and by the sector's number indicator. Some indicators have values that are desired to be maximized and others that are desired to be minimized, the goals established for each one can be found as well, as presented in Table 2, showing the average values of the selected indicators and their goals, from which the calculations of the sustainability indicators were made, which were automated in a Microsoft Excel Book (supplementary material), tables and graphics were developed for calculation purposes and presentation of results.

Table 3 shows the results of the Sustainability Goal Indicator calculation for each one of the selected indicators (K_{ijk}), which considers the desired direction of the indicator, with the lowest value being the best result. In this case Brazil shows a greater behavior in the indicators (K_{11}, K_{21}, K_{22}, K_{31}, K_{32}, K_{51} and K_{52}) than Cuba in the remaining indicators

Table 3
Sustainability Goal Indicator ($\mathbf{ISG^+_{ijk}}$ and $\mathbf{ISG^-_{ijk}}$).

Names of sceneries (Countries)	Sector 1 (environment as provider)		Sector 2 (environment as receiver)		Sector 3 (production unit)		Sector 4 (society as provider)		Sector 5 (society as receiver)	
	ISG^-_{K11}	ISG^-_{K12}	ISG^-_{K21}	ISG^-_{K22}	ISG^+_{K31}	ISG^+_{K32}	ISG^-_{K41}	ISG^+_{K42}	ISG^+_{K51}	ISG^+_{K52}
Brazil	1.525	0.097	0.620	0.083	0.060	0.779	1.207	120.711	0.571	17.898
Cuba	2.689	0.040	0.752	0.035	0.010	4.538	0.207	20.711	0.012	104.318

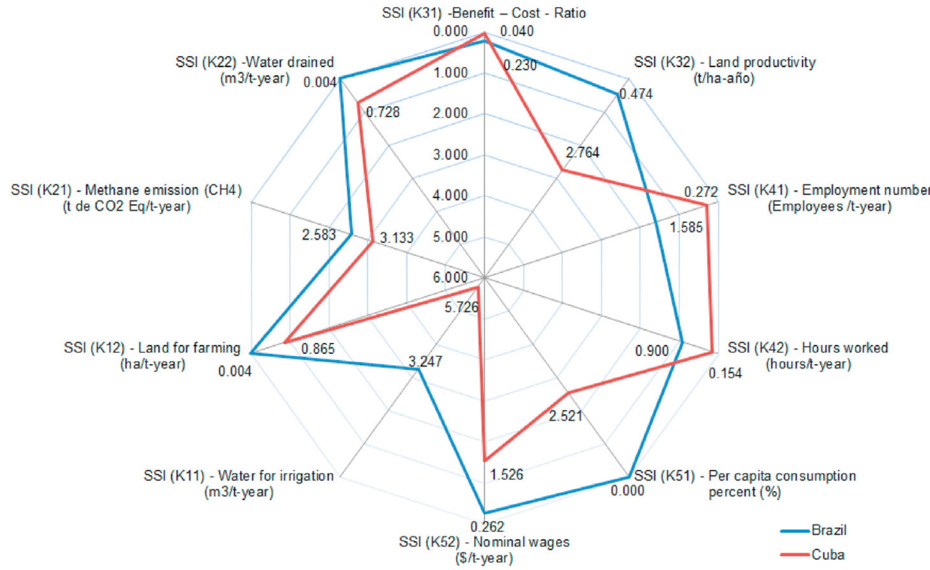

Fig. 3. Performance of rice farming in terms of the indicators' behavior concerning to goals.

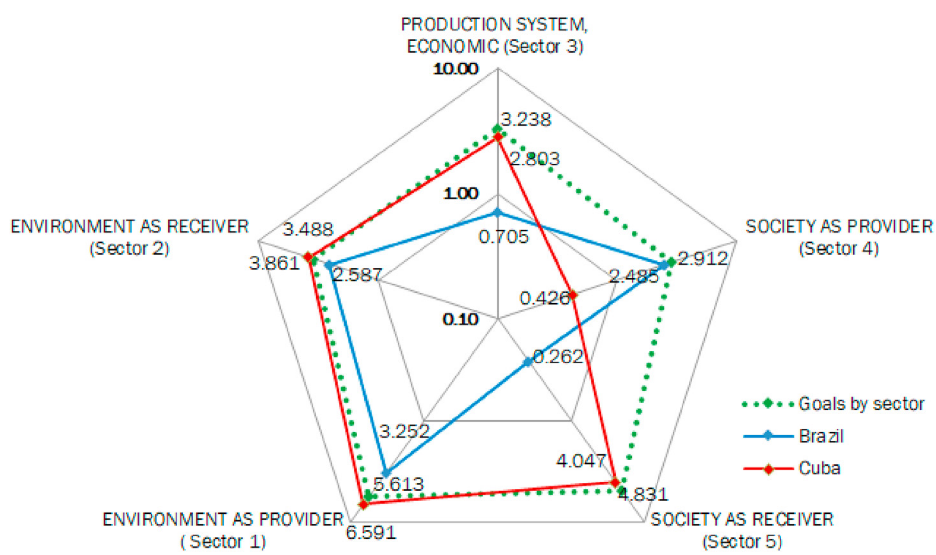

Fig. 4. Sustainable productive chain of rice farming according 5 SEnSU model.

(K_{12}, K_{41} and K_{42}), which does not mean that its performance is better due to the nature and desired direction of the indicator. This is *considered* in the results shown in Table 4 in Appendix 1 and the analysis of the graph shown in Fig. 3.

Fig. 3 shows in radar form the performance of selected indicators, normalized to the target value used as reference of each indicator. The values are situated and shown on a scale in reverse order, where the lower values represent a greater proximity to target value and therefore greater sustainability.

The previous Fig. shows an analysis of each sustainability indicator Sector Sustainability Indicator (SSI_{ijk}), of the rice production chains of both countries, where it is observed that Brazil has a better performance than Cuba in the indicators (K_{11}, K_{12}, K_{21}, K_{22}, K_{32}, K_{51} and K_{52}). On the other hand in indicators (K_{31}, K_{41} and K_{42}) Cuba has a better performance, when comparing with goals and desired direction of the indicators selected. However, considering all the indicators together (multi-criteria analysis), it is still not possible to say in which country rice cultivation is more sustainable.

Brazil has a better performance in the indicators: water for irrigation, land for farming, methane emission, and water drained, land productivity, nominal wages and per capita consumption percent. On the other hand, in the indicators Benefit-Cost-Ratio, number of employees and hours worked by employees, Cuba has a better performance when comparing with the goals selected. Brazil takes a better place when considering the environment as provider of resources (sector 1) and as receiver of waste and pollutants (sector 2), in the production of rice (sector 3), and society as receiver of goods and services (sector 5), instead Cuba shows better as provider of services and labor force from the society to the productive or economic sector (sector 4).

One important aspect to consider about rice cultivation is the significant difference in the agricultural yield between both countries. In Cuba, it is mainly due to soil depletion, scarcity of human, material and financial resources, high production costs, the progressive drought related to the effects of climate change and the use ancient artisanal techniques of farming.

The previous aspects are evidenced if a sustainability analysis per sector for each country using the Sustainability Indicator by Sector for scenario or countries (SIS_{ij}), Fig. 4 shows the performance of this

Fig. 5. Ranking of Sustainability Goal Indicator by Scenarios' performance by sectors of the productive chain of rice farming.

indicator, the scale of presentation of the radar graph is logarithmic with base 10, so the lower the values (below the target), the better the sustainability of the sector.

The previous Fig shows that the SIS_{ij} of Brazil (blue line) shows a lower performance value with respect to the target (green line) in sectors 1,2, 3 and 5; which means that it consumes fewer resources from the environment, pollutes it less and its economic and consumption results from society are better. In contrast, Cuba (red line) shows a lower value of SIS_{ij} in sector 4, which means that it makes better use of the resources provided by society.

3.2. Decision making for the application of corrective measures

Based on the results evidenced in this study and considering the high per capita consumption of rice as a staple food of the Cuban population, in addition to the low volumes of production and agricultural yields, as well as the poor performance of the cereal sustainability indicators in comparison with Brazil.

The ranking results of Brazil in terms of the performance of the sustainability indicators are mainly due to the high agricultural yields of rice productive chains farming and the lower emission of polluting waste into the environment, which make its rice production chain more sustainable. Fig. 5 shows a ranking of Sustainability based on the Sustainability Goal Indicator by Scenarios ($SGIS_i$). Brazil is represented in green color with an indicator value of 9.290, which means greater sustainability; Cuba is represented in yellow color with a value of 17.729, which means less sustainability.

Fig. 5 show that Brazil exhibits an improved performance in sectors 1, 2, 3 and 5, which means, it behaves better for a negative impact for the GHG emission and disposal of residues on the environment, and it has better outcomes in the economical aspect and it satisfies superiorly the social needs as for resources coming from the rice production chain. Yet, Cuba shows a better performance in sector 4, which means that it is a better provider of resources from society to the productive sector.

The above results show, in the case of Cuba, a deficit of environmental resources for rice cultivation, higher relative environmental load, low economic and productive performance, better employment and wage policy, together with a dissatisfaction of the social demand for rice. In contrast, Brazil shows a better availability of environmental resources, lower relative environmental load, better economic and productive performance, worse employment policy and salary, in addition to a higher satisfaction of the social demand for rice.

The main decisions that Cuba must take to improve the sustainability of rice production farming chain should be focused on establishing public policies to adopt the best agricultural practices based on benchmarking processes of rice cultivation used in Brazil, Vietnam or other producing countries. In addition, Cuba should consider hiring technical assistance in these countries.

Specifically in replacing the old artisan cultivation techniques, use the best of irrigation and drainage techniques to optimize the use of water, access sources of financial resources to improve the quality of the soil, the best use of human resources and improve the quality of resistant seeds to mitigate the effects of climate change on rice agriculture, with the objective of increasing the agricultural yields of rice and therefore the better performance of the other sustainability indicators. These measures would improve the per capita consumption of the country with a diet based on high rice consumption.

4. Conclusions

All these analyses allows assuring that Brazil's performance is superior than Cuba as for sustainability of the rice farming chain, based on a better environmental, economic and social balance that is evaluated according to 5 SEnSu model and the Goal Programming (GP) philosophy as multi-criteria analysis tools.

This is demonstrated when analyzing the Sustainability Goal Indicator for both countries. The above performances mean a greater balance and sustainability in the rice production chain in Brazil than in Cuba.

Cuba should take up the best international agricultural practices in rice farming, used by major producing countries such as Brazil to improve the performance of sustainability indicators.

The results confirm the possibility of using 5 SEnSu model as tool to assess the sustainability of the rice production chain in different scenarios to facilitate decision making regarding the implementation of policies based on benchmarking to improve the sustainability of this important farming. The model provides an innovative tool for assessing the sustainability of agricultural food production.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2021.100152.

Appendix 1

Table 4
Data source and calculations of sustainability indicators for rice cultivation in Brazil and Cuba

Indicator		Unit	Expression	Brazil	Cuba
A	Land for rice farming[a]	Ha	–	2.16E+06	1.40E+05
B	Rice production[b]	Ton	–	1.60E+07	5.14E+05
C	Rice productivity	ton/ha	B/A	7.43E+00	3.67E+00
D	Land for farming/Rice production	ha/ton	A/B	1.35E-01	2.72E-01
E	Water for irrigation/Land for rice farming[c]	m^3/ha	–	1.13E+04	9.87E+03
F	Water for irrigation/Rice production[c]	m^3/ton	E*(1/C)	1.52E+03	2.69E+03
G	Rice production for countries[b]	Ton	–	1.15E+01	5.14E-01
H	Methane emission for rice farming by countries	ton CO_2-Eq.	–	2.65E+03	8.23E+02
I	Methane emission/Rice production[d]	ton $CO_{2\text{-Eq.}}$/ton	H/B	2.30E-01	1.60E+00
J	Water drained (10.1% Water for irrigation)[e]	m^3/ton	0,101*F	1.54E-01	2.72E-01
K	Benefit - Cost- Ratio[f]	–	–	1.25E+00	1.30E+00
L	Number of employees[h]	Employees/ton	–	2.60E+00	3.60E+00
M	Hours worked by employees[h]	h/Employees	–	5.50E+02	6.50E+02
N	Industrial Yield Index[g]	–	–	7.20E-01	6.70E-01
O	Quantity of population[g]	people	–	2.08E+08	1.15E+07
P	Per capita consumption[g]	Kg	–	2.50E+01	7.00E+01
Q	Per capita consumption percent[g]	%	(B/O*1000 *N)/P	1.01E+02	4.29E+01
R	Nominal wages[i]	$/ton	–	3.24E+02	2.37E+02

Sources.
(a) Land dedicated to rice production in NATES region, State of Rio Grande do Sul, Brazil [58,59] and municipalities of Granma Province in Cuba [43].
(b) Rice production in NATES region, State of Rio Grande do Sul, Brazil [58,59] and Granma Province in Cuba [43].
(c) Water for irrigation IWton (m^3/ton).

$$\text{IWton} = \text{IWha}\ \ (\text{m}^3/\text{ha}) \cdot \frac{1}{\text{RP}\ \ (\text{ton/ha})} = \text{m}^3/\text{ton}$$

Where.
IWton: Water for irrigation (m^3/ton).
RP: Rice productivity (ton/ha).
IWha: Water for irrigation (m^3/ha).
Substituting values for Brazil.
RP = 7.430 ton/ha.
IWha = 11.329 Mil m^3/ha. Average volume of water used in conventional irrigation [21,58,59,65,66].

$$\text{IWton}_{\text{Brazil}} = 11.329\ \ \text{Mil}\ \ \text{m}^3/\text{ha}\ \ \cdot\frac{1}{7.430(\text{ton/ha})} = 1.524764\ \ \text{Mil}\ \ \text{m}^3/\text{ton}$$

$$\text{IWton}_{\text{Brazil}} = 1524764\ \ \text{m}^3/\text{ton}$$
$$\text{IWton}_{\text{Brazil}} = 1.52\text{E}+03\ \ \text{m}^3/\text{ton}$$

Substituting values for Cuba.
RP = 3.671 ton/ha.
IWha = 9.872 207 Mil m^3/ha. Average value of water for rice irrigation in spring agricultural campaign of 9266 Mm^3/ha and 10 478 Mm^3/ha for winter agricultural campaign [67,68].

$$\text{IWton}_{Cuba} = 9.872207\ \ \text{Mil}\ \ \text{m}^3/\text{ha}\ \ \cdot\frac{1}{3.671(\text{ton/ha})} = 2.689241\ \ \text{Mil}\ \ \text{m}^3/\text{ton}$$

$$\text{IWton}_{Cuba} = 2689.241\ \ \text{m}^3/\text{ton}\text{IWton}_{\text{Cuba}} = 2.69\text{E}+03\ \ \text{m}^3/\text{ton}$$

(d) Methane emissions (ton CO_2-Eq.) of rice farming.

$$\text{ME} = \frac{\text{MERFC}\ \ (\text{tonCO}_{2-\text{Eq}}/\text{yr})}{\text{RPC}\ \ (\text{ton/yr})} = \text{tonCO}_{2-\text{eq}}/\text{ton} - \text{yr Where,}$$

ME: Methane Emission (ton CO_2-Eq.).
MERFC: Methane Emission for Rice Farming by Countries ($\text{tonCO}_{2-\text{eq}}$).
RPC: Rice Production (ton/yr).

$$\text{ME} = \frac{\text{MERFC}\ \ (\text{ton}\ \ \text{CO}_{2-\text{Eq}}/\text{yr})}{\text{RPC}\ \ (\text{ton/yr})} = \text{tonCO}_{2-\text{Eq}}/\text{ton} - \text{yrME} = \frac{\text{MERFC}\ \ (\text{ton}\ \ \text{CO}_{2-\text{eq}}/\text{yr})}{\text{RPC}\ \ (\text{ton/yr})} = \text{tonCO}_{2-\text{Eq}}/\text{ton} - \text{yr}1\ \text{Gg} = 1\,000\,000\ \text{Kg} = 1000\ \text{ton.}$$

Substituting values for Brazil.
MERFC = 2 651 842.500 ton CO_{2-Eq} Methane emissions (CO_2 Eq) of rice farming [30].
RPC = 16 046 287.000.ton/yr

$$\text{ME}_{Brazil} = \frac{2651842.500\ \ \text{ton}\ \ \text{CO}_{2-\text{Eq}}/\text{yr}}{16046287\ \ \text{ton/yr}} = 0.230\ \text{tonCO}_{2-\text{Eq}}/\text{ton} - \text{yr}$$

$$\text{ME}_{\text{Brazil}} = 2.30\text{E} - 01\ \text{tonCO}_{2-\text{Eq}}/\text{ton} - \text{yr}$$

Substituting values for Cuba.
823.2941 Gg = 823 294 100 Kg = 823294.100 ton/yr.
MERFC = 823 294.100 $\text{tonCO}_{2-\text{Eq}}$ Methane emissions (CO_2 Eq) of rice farming [30].
RPC = 514 045 ton/yr.

$$\text{ME}_{Cuba} = \frac{823294.100\ \ \text{ton}\ \ \text{CO}_{2-\text{Eq}}/\text{yr}}{514045\ \ \text{ton/yr}} = 1.602\ \ \text{ton}\ \ \text{CO}_{2-\text{Eq}}/\text{ton} - \text{yr}$$

$$\text{ME}_{\text{Cuba}} = 1.60\text{E}+00\ \ \text{ton}\ \ \text{CO2} - \text{Eq/ton}\ \ \text{Rice} - \text{yr}$$

(e) Water drained. Calculated based on 10.1% of water for irrigation in both countries [42,58,59,65–69].
(f) Benefit - Cost- Ratio. Calculating and comparing benefits and costs of rice farming. BCR = total revenue (benefit)/cost in this case, if a rice farming scenario has a BCR that is greater than 1, it indicates that the scenario benefits outweigh the costs. Therefore, the farming should be considered. If the BCR is equal to 1, the ratio indicates that the profits equal the costs. If a scenario's BCR is less than 1, the rice farming costs outweigh the benefits and it should not be considered. Due to the monetary inequality between both countries, this indicator refers to US dollar monetary units [13,42,67,70].

(g) Per Capita Rice Consumption percent (%).

$$PCR = \frac{\left(\frac{\text{Rice production (ton)} \cdot \text{Industrial yield}}{\text{Total of population persons}} \cdot 1000 \text{ kg/ton}\right)}{\text{Per capita consumption (kg/persons)}} *100$$

$$PCR = \frac{\left(\frac{\text{RPC(ton)} \cdot (1000 \text{ kg/ton}) \cdot \text{IYIR}}{\text{TPP (persons)}}\right)}{\text{PCC(kg/persons)}} *100$$

Where.
PCR: Per Capita Rice Consumption percent (%).
RPC: Rice Production (ton/yr).
IYIR: Industrial Yield Index (−).
TPP: Total of Population people (persons).
PCC: Per Capita Consumption (kg/persons).
Only national rice productions are considered in both countries (not imports). Industrial yields in Cuba and Brazil are considered to be 67% and 72 % respectively [42,70,71]. The data of quantity of population of both countries in 2016 of the World Bank [72].
Substituting values for Brasil.

$$PCR_{Brazil} = \frac{\left(\frac{1.60E+07 \text{ ton} \cdot 0.72}{2.08E+08 \text{ persons}} \cdot 1000\text{kg/ton}\right)}{25 \text{ kg/persons}} \cdot 100 = 101.24\%$$

It is possible to observe the national production of rice in Brazil satisfies the per capita demand of the population of this country in a 101.24%.
Substituting values for Cuba.

$$PCR_{Cuba} = \frac{\left(\frac{5.14E+05 \text{ ton} \cdot 0.67}{1.15E+07 \text{ persons}} \cdot 1000 \text{ kg/ton}\right)}{70 \text{ kg/persons}} \cdot 100 = 42.87\%$$

It can be observed that the national production of rice in Cuba only satisfies 42% of the per capita demand of the population of this country, so to satisfy all the demand, Cuba must import rice from other countries, including Brazil.
(h) Values of estimated and calculated indicators from data on the agricultural production chain of rice in Brazil and Cuba [14,15,17,18,43–45,66,68,41,42].
Based on data from companies of the rice productive farming chains in Brazil and Cuba, the average values of the indicators for each country where calculated.
(i) Nominal wages: Due to the monetary inequality between both countries, the nominal wage will be expressed in US dollars.

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