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Five sector sustainability model: A proposal for assessing sustainability of production systems

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ABSTRACT

The decision-making process towards sustainability is usually based on quantitative indicators, and becomes more complex the more indicators are considered. The lack of a clear criterion (i.e. a conceptual model of sustainability) supporting the choice of one indicator rather than others creates doubts about the real attainments of such studies. The holistic-based approach in choosing indicators to express sustainability claims for a multicriteria perspective. This work proposes a sustainability assessment tool based on the FIVE SEctor SUstainability (5SEnSU) model that is capable to show the relationships between humans and the natural environment, and the use of goal programming as a multicriteria method. 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 an easy-to-understand final indicator: the sustainability synthetic indicator of systems (SSIS). The countries that form Mercosur economic bloc were used as a case study to illustrate the application of the proposed model. Results have shown that Uruguay holds the highest sustainability performance among all Mercosur countries, although still demanding efforts from public policies to improve its national happiness level (K52 indicator), employment rate (K41 indicator) and total emergy flow per capita (K12 indicator). Instead of using a single criterion in choosing indicators, this work provides a scientific-based tool in choosing, calculating, and supporting discussions on the sustainability of production systems under a more holistic perspective.

1. Introduction

Quantifying the sustainability of a given system is important to identify its strengths and weaknesses. From the United Nations Brundtland Report (1987) until the recent sustainable development goals (SDGs; UN, 2019), sustainability assessments are key in supporting more sustainable policies, strategies and action plans towards a sustainable future. Due to its multidisciplinary aspects that include environmental, social and economic aspects (sometimes cultural and value-based elements are also included), the sustainability assessments must rely on scientific rooted bases in establishing definitions, representative conceptual models and indicators.

Different methods aiming to quantify sustainability are available in the scientific literature. Taking as example the sustainability assessments of urban systems, methods based on different definitions, conceptual models and indicators are being considered, including emergy accounting (Sevegnani et al., 2017, 2018; Agostinho et al., 2018), material flow analysis (Barles, 2009), ecological footprint (Barrett et al., 2002), life cycle assessment (Corcelli et al., 2019), and others. Although these studies aim to quantify sustainability, they use different approaches for the same purpose. Is there a right or a wrong method? Is one method better than another? As discussed by Siche et al (2010a), all methods have their advantages in representing sustainability, but the theory supporting them must be clearly provided to allow a better understanding about the meaning of the calculated indicator. Studying the most used representative conceptual models and indicators to quantify sustainability, Giannetti et al. (2010) compared the results obtained from emergy accounting against five sustainability metrics (including ecological footprint, surplus biocapacity, environmental sustainability index, wellbeing index, and the ecosystem

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services product) and highlighted that different metrics provide different interpretations about the sustainability of nations. In a paper that evaluates the reliability of experts' opinions to support the environmental sustainability index named ESI 2005, Giannetti et al. (2009) presented the existence of inherent uncertainties on opinions that lead to inefficiency in measuring and monitoring the natural environment, revealing a lack of a "science of sustainability".

In an attempt to overcome the lack of a scientific-based conceptual model to represent sustainability, several authors have proposed models that have wider or more specific purposes. For instance, Goodland and Daly (1996) presented the types of sustainability including social, economic and environmental, which were merged into the sustainable development term leading to the concepts of strong and weak sustainability as discussed by Ekins et al. (2003). Ulgiati et al. (2006) proposed the sustainability multicriteria multiscale assessment (SUMMA) aiming to overcome the problems related to the use of a single-criteria approach in the life cycle assessments, which can cause partial and often misleading results. Another important contribution comes from the work of Pulselli et al. (2015) that refers to the use of a logical, physical and thermodynamic order to evaluate the sustainability of production systems under an input-state-output (environmental-society-economy) relationship. The proposed input-state-output model might overcome the major drawbacks of common representations of sustainability. Recently, Rockström and Sukhdev (2016) proposed a wider and more integrative view based on the triple bottom line considering the sustainable development goals (SDGs). By separating the SDGs in three rings containing the biosphere in the bottom, society in the middle and economy in the top. Rings are connected by a double arrowed line representing the 17th SDG named "partnership for the goals". In spite of the more broader and integrative models, our literature review indicated a lack of view based on "functions", in which the natural environment and society dimensions should be seen as both donors and receivers of energy, materials, and information flows.

Additionally to the conceptual model issue, there is a large number of indicators that can be used to represent sustainability results in a multicriteria situation. When more and more information from different sources and focuses is available to represent a system, the problem of choosing among alternatives comes up (Kalu, 1999). Decision makers often experience difficulties when selecting between options, and these difficulties are even more evident when the decision involves multicriteria situations. This applies also for the sustainability assessments of production systems, in which a unique indicator hardly is able to represent all aspects embodied in it (Siche et al., 2010a, 2010b; Giannetti et al., 2015). Usually, sustainability issues result in a trade-off between environmental, economic and social dimensions, although some authors insert political or legal and technological concerns. When analyzing projects under a multi-criteria perspective, decision making can be difficult since a "win-win scenario" is hardly achieved. The more criteria translated into indicators are added to each situation, the more holistic and embracing should be the tools for decision-making supported by scientific multi-dimension models (Scott et al., 2012). A decision regarding sustainability based on a multi-criteria view by using data from different sources, under different focuses and that involve several stakeholders can be translated in a term called multi-criteria decision-making (MCDM) or multi-criteria decision analysis (MCDA). According to Kumar et al. (2017), MCDM is defined as a branch of operational research that seeks to achieve optimal results in complex systems where several indicators, multiple and conflicting objectives, and criteria are involved.

Literature is plentiful of papers regarding sustainability assessment using MCDM principles, for instance, Martín-Gamboa et al. (2017) provided a literature review on the application of MCDM to the sustainability assessment of energy systems, while Ibáñez-Forés et al. (2014) have performed a literature review focused on methods, including MCDM, to select options from a sustainability perspective. According to a literature review performed by Scott et al. (2012) focused on papers applying MCDM to the bioenergy sector, authors find that MCDM can be considered a general term where, more specifically, indicators are embedded in several categories and inside the categories different mathematical methods are possible.

Any MCDM demands a multicriteria tool to appropriately integrate, under a quantitative analysis, all the multiples numbers with different units being considered. For this purpose, the goal programming (GP) is an important tool. GP is a mathematical method that was classified by Ibáñez-Forés et al. (2014) as a branch of the multi-objective mathematical programming category. GP was initially introduced by Charnes, Cooper and Ferguson in the 1950s (Charnes et al., 1955) and further developed by other researchers (Ijiri, 1965; Lee, 1972; Ignizio, 1978; Romero, 1985). Currently, GP is one of the most used multi-criteria approaches in business practice and scientific research. According to Jayaraman et al. (2015), GP is a popular and widely used technique to study decision problems in the face of multiple conflicting objectives. Zografidou et al. (2017) stated that GP formulation is a multi-criteria decision-making type of analysis where certain goals are examined in terms of trade-offs. The authors provided an example of renewable energy type's selection, in which a wind farm can provide clean energy and may contribute to the local economy of the region, but it affects the normality of regional ecosystems.

GP applied to assess the sustainability of the most different production systems is largely found in the literature. San Cristóbal (2012a) applied GP on an environmental input-output linear programming model to the Spanish economy, and studied the capacity expansion-planning for the renewable energy industry using the case study of the north of San Cristóbal (2012b). Jayaraman et al. (2015) proposed a weighted GP model that integrates efficient allocation of resources aiming to simultaneously achieve sustainability-related goals on gross domestic product growth, reduction of electricity consumption and greenhouse gases (GHG) emissions; the model was applied in key economic sectors of the United Arab Emirates to be validated. Yang et al. (2016) studied the application of a MCDM to assess the sustainable development of transport infrastructure projects. Chang (2015) proposed a so-called multi-choice GP model aiming to assess the expansion actions related to the renewable energy industry. Zografidou et al. (2016, 2017) applied GP tools to study the design of a renewable energy map by the allocation of solar plants to each region of Greece. The sustainability performance of European countries was studied by Antanasijević et al. (2017), who applied the differential multi-criteria analysis technique to thirty European countries over 2004 and 2014 aiming to assess their progress in sustainability.

Usually, scientific papers focusing on sustainability assessments that have also applied GP supporting MCDM were developed without a deeper conceptual framework regarding sustainability concepts and definitions. For instance, some papers focus deeply on the technical issues of given activities and develop them under a narrow viewpoint, considering only the technological benefits related to emissions reduction. Other researchers have performed the application of GP in a very comprehensive way, choosing indicators that cover different aspects of sustainability of a given system, but still without establishing a representative conceptual model (Yang et al., 2016; Zografidou et al., 2016, 2017). This aspect is also recognized by Pulselli et al. (2015), who argue that choice of one method or indicator rather than others can be always questioned because all of them have different abilities in representing the multidimensional aspects of sustainability. According to our literature review, we have identified a lack of a conceptual model of sustainability able to assign the multifunctions of each of the three dimensions (environmental, social and economic).

Trying to overcome the lack of a strong conceptual model for sustainability assessments, this paper proposes the FIVE SEctor SUstainability (5SEnSU) model as the first step of an MCDM procedure. The application of the proposed model would support interpretations and decisions based on a more holistic and embracing perspective since it addresses both the provider and receiver functions to environment and society. Here, the 5SEnSU model is used with the goal programming to allow a multicriteria sustainability assessment. The countries that form Mercosur economic union were taken as a case study with the purpose of showing the application of the 5SEnSU, but the procedure can be applied to study the sustainability of different productive systems identified as a MCDM situation.

2. Methods

2.1. FIVE SEctor SUstainability (5SEnSU) model

The conception of the 5SEnSU model is based on six basic axioms. Three (i, ii, and iii) from Goodland (1995) and Goodland and Daly (1996) regarding the limits of natural resources in relation to their exploitation and consumption rates to guarantee the current development patterns and three axioms (iv, v and vi) suggested by the authors of this work:

i No resource should be used at higher rates than its generation rate, e.g., it takes thousand years to form oil reserves that can be explored, and thus the time window of human existence and the formation of oil reserves are not compatible. Fossil oil will never be considered a renewable resource and, in accordance with this axiom, it should never be extracted - except in a scenario as presented by the following axiom iii.
ii No contaminant should be produced at higher rates than their natural recycling process, neutralization and absorption by the natural environment.
iii Non-renewable resource should never be used faster than the necessary time to replace it with a renewable resource.
iv There must be a balance between the environment as a supplier of resources and as receiver of waste and pollutants, which could be achieved by cleaner production practices, environmental care and conservation.
v The production of goods must be limited to the restrictions imposed by the sustainable exploitation of natural resources and by responsible consumption of the society.
vi For human as a social being, its relationship with economic system through providing labor and receiving manufactured products must be balanced.

Considering all these six axioms, as well as the importance of three dimensions in representing sustainability, the five sectors sustainability model (5SEnSU model) was elaborated (Fig. 1). The proposed model is aligned with the input-state-output (environment–society–economy) sustainability model proposed by Pulselli et al. (2015), which postulates sustainability as a matter of relationships among compartments allowing understanding human activity and its physical, social, and economic contexts. According to Bastianoni et al. (2016), human-driven systems are open since they demand energy and matter input flows, and transform resources into goods and services by means of human labor efforts.

The model presented in Fig. 1 addresses to the environment the function of supplier and receiver. The environment in sector 1 has a source function in providing, for instance, raw materials to support the production unit (sector 3) functions. The environment in sector 2 usually has a sink function being the receiver of the wastes and emissions generated by the production unit activities. The same applies to the society that holds the functions of supplier and consumer. Society in sector 4 supplies socio-economic resources to the production unit such as labor, knowledge and know-how, and it receives money for this. The production unit supplies products that will be consumed by the society that pays for them. It is worthy to note that money only circulates on the right side of the diagram in activities that are human-driven, while the exchanges in the left side of the 5SEnSU model only contemplate flows of materials and energy. In other words, the resources provided by the environment are seen as “free resources”, since no one “paid” for them. The same reasoning applies to the waste released to the environment, i.e. there is not a payment from the production unit to the environment as a counterpart of the dilution and decomposition services. The idea of “free resources” hides the fact that the environment actually needs to converge energy either to generate resources and to assimilate or dilute the waste released by humans. These can be understood as environmental services that are very often not taken into account in the traditional accounting practices.

The 5SEnSU model is a holistic model that comprises multi-characteristics. First, the multi-dimension is an important characteristic since it embraces social, environmental and economic dimensions. Second, it can be understood as a multi-view model that may assume the point of view from the natural environment, society as well as from the production unit. Third, the indicators applied to the model are usually multi-metric, including energy, volume, mass, money, labor force, etc. Fourth, its multi-criteria approach can be seen as an important feature of the tools considered within the 5SEnSU model, since an unlimited combination of indicators with several weights and goals can be applied.

2.2. Principles for selecting indicators to feed the 5SEnSU

The selection of indicators is inherent to each sector of the 5SEnSU, for instance, indicators related to environmental constraints must be located in the environmental sector, and so on. Indicators can derive from previous studies or through criteria of experts chosen with non-parametric statistical techniques, among others, the Delphi approach (Dalkey and Helmer, 1963) is a participative approach that can be applied at this stage.

Using the 5SEnSU model does not mean that indicators should be modified from their original rules, algebra and definitions, contrariwise, they must respect their original procedures and meanings. Some general suggestions can be raised when chosing indicators to feed the 5SEnSU: (a) Social, economic and environmental indicators must be considered to preserve the multidimensional characteristics of the model; (b) The more indicators are considered for each sector, the more holistic, detailed, complex, and embracing the model becomes; (c) Indicators should respect as much as possible the same temporal analysis (i.e. time window), in order to have a consistent assessment within that time window; (d) A balance should be sought in terms of the number of indicators selected by each sector in order to avoid "assumed preferences" for a specific sector. Important aspects to be considered, as also suggested by Blanc et al. (2008), are representativeness, relevance, reliability, sensitivity, ease of understanding, comparability and transparency.

When applying the 5SEnSU model, the analyst must have in mind that, besides selecting indicators, it is necessary to determine the minimum and maximum values, goals or targets of each indicator, their desired direction (positive + or negative −) and their weighted values. These parameters are mandatory to be used within the goal programming as explained in the next section. Similar to the indicators establishment, the goals can be set from different approaches: (a) by considering the expertise of analyst according to the case study being evaluated; (b) participative meetings in which experts from different fields of knowledge can obtain a common agreement (for instance, using a non-parametric statistical technique as Delphi); (c) governmental plans and reports; (d) or even considering the threshold of each considered indicator.

2.3. Application of the fundamentals of goal programming to the 5SEnSU model

Goal programming (GP) can be understood as a mathematical method to handle problems with multiple and conflicting objectives that are translated into MCDM situations. GP is one of the possible

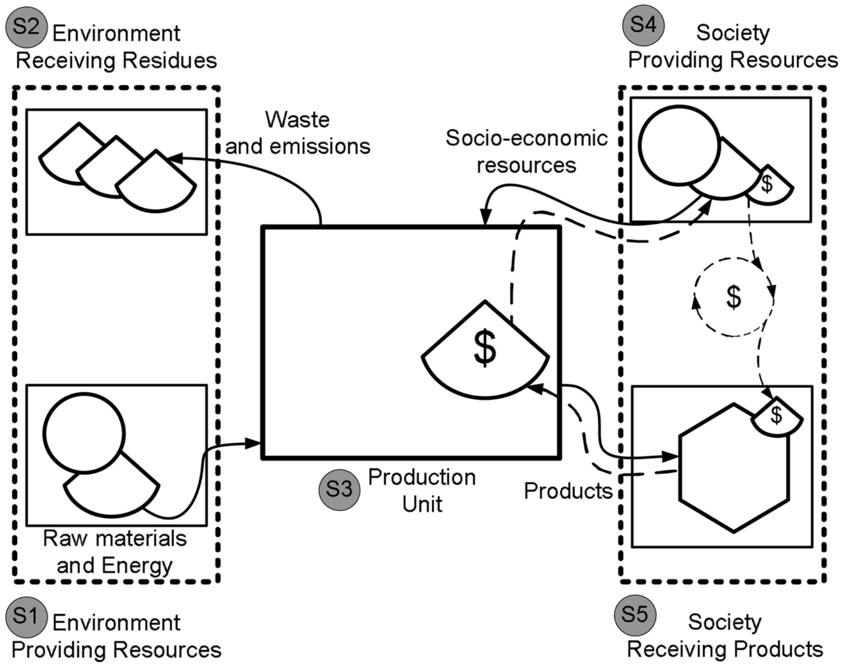

Fig. 1. FIVE SEctor SUstainability (5SEnSU) model. The symbology used here comes from the emergy accounting method as available in Odum (1996), where circles mean energy sources, "water box" means storage, hexagon means consumers, continuous arrows mean material and energy flows and dashed arrows mean money flows. S = sector.

methods to be applied in the MCDM problems, and it is used in this paper for the multicriteria modelling.

One of the most important aspects of GP is Simon's satisfactory logic (Simon, 1955), i.e. the GP is developed within the "satisfactory" paradigm rather than the "optimizer" paradigm. The shift in Simon's situational logic from optimized to satisfactory solutions implies in the search for solutions that are closest as possible to the chosen aspiration level (or goal), however, the found solutions are not obligatorily the optimum ones.

The calculation algebra of the proposed sustainability assessment tool is based on the use of GP philosophy as a multicriteria analysis method to obtain the sustainability indicator. This approach was firstly considered by Goodland (1995) and Goodland and Daly (1996) as discussed by Diaz-Balteiro (2008, 2009) to express the results according to the proximity between the relative values of the indicators and their goals. Fig. 2 shows, in a qualitative way, the philosophy derived from goal programming that is applied in the proposed tool to assess sustainability. The schematic representation shows, as an example, that the objective of the indicator is to be minimized as the CO_2 emissions. Each evaluated system (represented by circles) have a different value for the indicator, consequently, there are different distances or deviations to the established goal for CO_2 emissions. As the objective is to minimize the indicator, those systems with CO_2 emissions above the goal (#2 and #4) will receive higher punishments ($W_{above\text{-}goal}$) than those systems

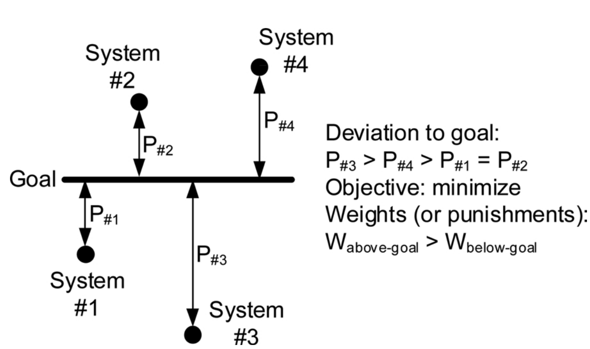

Fig. 2. An example to schematically represent the goal programing philosophy as considered within the proposed tool to assess sustainability. Circles represents the different systems being assessed.

below the goal ($W_{below\text{-}goal}$; #1 and #3), even the deviation of system #3 ($P_{\#3}$) being higher than #2 ($P_{\#2}$) and #4 ($P_{\#4}$), or $P_{\#1}$ being the same as $P_{\#2}$. The final number is obtained by multiplying the deviation by its punishment, resulting in $P_{\#1} * W_{below\text{-}goal}$ for system #1, $P_{\#2} * W_{above\text{-}goal}$ for system #2, $P_{\#3} * W_{below\text{-}goal}$ for system #3, and $P_{\#4} * W_{above\text{-}goal}$ for system #4. The same logic is applied when the objective is to maximize an indicator, for instance, profitability; but in this case, the higher punishments are set for those systems with profit value below the established goal. The closer the indicator is to its established goal, the higher will be the system performance for this indicator, mainly for the indicator that respects the initial objective of minimization and/or maximization (i.e. it is located below or above the goal, respectively).

In this work, modifications have been made in the traditional goal programming in order to allow its application under the 5SEnSU model constraints, which is hereafter explained under a mathematical background. Consider a decisional problem in which G_i goals exist. From the mathematical point of view, the use of the GP philosophy in the 5SEnSU model is based on a linear objective function that aims to minimize the values of the unwanted deviations in the system. Weights are assigned to the indicators representing their relative importance to the system. In this context, the unwanted deviations are those ones that affect the performance of selected indicators, expressed by:

$$\text{Min } Z = \Sigma_i\, W_iN_i + W_iP_i \tag{1}$$

where:Min = minimize;

Z = objective function;

W = weighted value or “aspiration” of the deviation;

N = negative deviation, associated to “higher better” (or maximize) indicator;

P = positive deviation, associated to “lower better” (or minimize) indicator.

Eq. (1) is subject to the following constraints associated with the selected attributes or indicators:

$$f_i(K_i) + N_i - P_i = G_i \tag{2}$$

where:f_i (K_i) = mathematical expression for the i-th indicator

G = aspiration level (or goal)

N and P as previously defined

Under the following restrictions:

$$N_i \geq 0,\ P_i \geq 0,\ N_i\, P_i = 0 \tag{3}$$

It is assumed that each sustainability indicator K_i is associated with a linear function $f_i(K_i)$ that characterizes its behavior; this linear function is considered as a weak constraint in the GP.

Before presenting the next deduction steps, a definition of "positive" and "negative" indicators is needed. "Positive" indicators are those in which higher values mean better performance, while the "negative" are those in which higher values represent worse performance. For positive indicators (constraint type $\geq$), the variable of undesired deviation is the negative one (N_i), meaning that $P_i = 0$ and therefore the objective function would be Min Z = N_i subject to $f_i(K_i) \geq G_i - N_i + P_i$ or $f_i(K_i) + N_i - P_i \geq G_i$; $N_i = G_i - f_i(K_i)$. For negative indicators (constraint type $\leq$), the variable of undesired deviation is the positive one (P_i), meaning that $N_i = 0$ and therefore the objective function would be Min Z = P_i subject to $f_i(K_i) \leq G_i - N_i + P_i$ or $f_i(K_i) + N_i - P_i \leq G_i$; $P_i = f_i(K_i) - G_i$. When it is desired to reach exactly the level of aspiration (constraint type =), the undesirable deviation variables are both positive (P_i) and negative (N_i) and therefore the objective function would be Min Z = $N_i + P_i$ subject to $f_i(K_i) = G_i - N_i + P_i$ or $f_i(K_i) + N_i - P_i = G_i$.

When applying the philosophy of goal programming, the unwanted variables depend on the type of indicator (positive + or negative -). For positive indicators, the undesired variable is the negative deviation (N^+_{ijk}), with systems 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 systems that reach the target aspiration level or a higher value of the negative deviation variable N^-_{ijk}.

Thus, for the "higher better" positive (+) indicators we have:

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

$$P^+_{ijk} = \begin{cases} K_{ijk} - G^+_{jk},\ K_{ijk} > G^+_{jk} \\ 0,\ K_{ijk} \leq G^+_{jk} \end{cases} \forall\ i\ \in \{1, 2, ..., NE\}\ \forall\ j \in \{1, 2, ..., NS\},\ \forall\ k\ \in \{1, 2, ..., NI\} \tag{5}$$

And for the "lower better" negative (-) indicators we have:

$$P^-_{ijk} = \begin{cases} K_{ijk} - G^-_{jk},\ K_{ijk} > G^-_{jk} \\ 0,\ K_{ijk} \leq G^-_{jk} \end{cases} \forall\ i\ \in \{1, 2, ..., NE\}\ \forall\ j \in \{1, 2, ..., NS\},\ \forall\ k\ \in \{1, 2, ..., NI\} \tag{6}$$

$$N^-_{ijk} = \begin{cases} G^-_{jk} - K_{ijk},\ K_{ijk} < G^-_{jk} \\ 0,\ K_{ijk} \geq G^-_{jk} \end{cases} \forall\ i\ \in \{1, 2, ..., NE\}\ \forall\ j \in \{1, 2, ..., NS\},\ \forall\ k\ \in \{1, 2, ..., NI\} \tag{7}$$

Being N_{ijk}, $P_{ijk} \geq 0$ and $N_{ijk}.\ P_{ijk} = 0$.

where: NE = quantity of studied systems;

NS = quantity of sectors (1…5);

NI = quantity of indicators per sector;

i = system (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 system;

N^+_{ijk}, N^-_{ijk} = negative deviation variable of the positive or negative indicator;

P^+_{ijk}, P^-_{ijk} = positive deviation variable of the positive or negative indicator;

G^+_{ijk}, G^-_{ijk} = goal value for the positive or negative indicator.

The index of sustainability goal of indicator (ISG^+_{ijk} and ISG^-_{ijk}) is obtained from Eqs. (4), (5), (6) and (7):

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

$$ISG^-_{ijk} = \sum_{ijk} \frac{N^-_{ijk}}{W^-_{jk}.\ G^-_{jk}} + \sum_{ijk} \frac{P^-_{ijk}}{W^+_{jk}.\ G^-_{jk}}\ \forall\ i\ \in \{1, 2, ..., NE\}\ \forall\ j \in \{1, 2, ..., NS\},\ \forall\ k\ \in \{1, 2, ..., NI\} \tag{9}$$

where: W^+_{jk} and W^-_{jk} represent the weighted value of deviation;

G^+_{jk} and G^-_{jk} represent the goal established for the indicator.

Although recognizing all the subjectivity involved, weighting variables is an important and mandatory aspect within a multicriteria approach. By weighting variables, the analysist is able to make final numbers more realistic in representing the real world and useful for policy makers. As usual, the weighting procedure can be based, mainly, on the choice of the analyst who is supposed to be an expert in the case study being evaluated. However, participative approaches based on a common agreement of experts in different fields of knowledge are usually considered more robust and acceptable. For the purposes of this work, the weighting values procedure was based on the expertise of authors, and it is recommended that $W^+_{jk} < W^-_{jk}$ for positive indicators, and $W^+_{jk} > W^-_{jk}$ for negative indicators, where W^+_{jk}, $W^-_{jk} \in \mathbb{R}$, $0 < W^+_{jk}$, $W^-_{jk} \leq 100$. The chosen values applied in our case study were 0.2 and 100.

Considering Eqs. (8) and (9), the sector sustainability indicator (SSI_{ij}) is calculated as the sum of the differences between the positive and negative indicators:

$$SSI_{ij} = \sum_{ijk} (ISG^+_{ijk} - ISG^-_{ijk})\ \forall\ i\ \in \{1, 2, ..., NE\},\ \forall\ j \in \{1, 2, ..., NS\} \tag{10}$$

The sustainability synthetic indicator of each system for each sector ($ISGS_{ij}$) can be obtained:

$$ISGS_{ij} = WS_j \sum_{ij} SSI_{ij}\ \forall\ i\ \in \{1, 2, ..., NE\},\ \forall\ j \in \{1, 2, ..., NS\} \tag{11}$$

where:WSj is the weighted value or relative weight of each sector of the system, being $0 < WSj \leq 1$ and $\sum_j WS_j \leq 5\ \forall\ 0 < WS_j \leq 1$.

Finally, Eq. (12) shows the sustainability synthetic indicator of systems ($SSIS_i$), which represents the overall performance of studied systems when considering the relationship among the indicators, their nature, established objectives and their relative importance.

$$SSIS^i = \sum_j ISGS_{ij}\ \forall\ i\ \in \{1, 2, ..., NE\} \tag{12}$$

2.4. A proposal for establishing levels of sustainability

The sustainability synthetic indicator of systems (SSIS) can be used for two main purposes: a) to define a ranking of sustainability among the sample studied, which allows establishing work priorities and reduce the gaps among the different systems; b) the classification of the studied systems in sustainability levels (SL) based on the criteria presented in Table 1. It is important to emphasize that SL is primarily a

Table 1
Sustainability levels (SL) suggested for the sustainability synthetic indicator of systems (SSIS).

	Sustainability levels
$Min_{SSIS} \leq SSIS_i \leq \bar{SSIS} - \sigma_{SSIS}$	High
$\bar{SSIS} - \sigma_{SSIS} < SSIS_i \leq \bar{SSIS} + \sigma_{SSIS}$	Medium
$\bar{SSIS} + \sigma_{SSIS} < SSIS_i \leq Max_{SSIS}$	Low

Legend: Min_{SSIS} = minimum value of $SSIS_i$; Max_{SSIS} = maximum value of $SSIS_i$; $\bar{SSIS}$ = average for $SSIS_i$; σ_{SSIS} = standard deviation for $SSIS_i$ values.

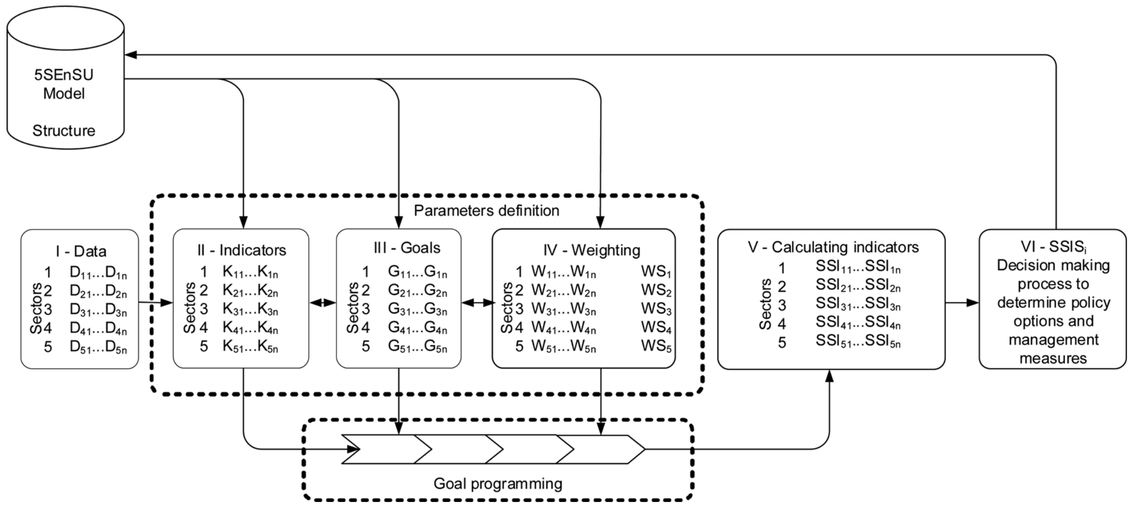

Fig. 3. Calculation procedures for the 5SEnSU model. Legend: D = data; K = indicator, G = goal; W and WS are the relative weights for each indicator or sector of the system, respectively; SSI = sector sustainability indicator; SSIS = Sustainability synthetic indicator of systems; Roman numerals indicate the sequential stages for procedures.

proposition in classifying or labelling the evaluated systems in different sustainability levels. Rather than mandatory, this step can be applied by those ones who desire this kind of classification for their ultimate purposes. Although establishing SLs could be considered important depending on the political purposes, it can be applied only when a large sample is being studied due to the demanded statistical inferences on the obtained SSIS, as maximum and minimum values, average, and standard deviation. All these statistical parameters are used in establishing the confidence intervals for the SSIS sample.

2.5. Guidelines for the application of 5SEnSU model

Fig. 3 presents a general framework for applying the proposed sustainability assessment tool driven by the 5SEnSU model. Data (stage I) for each sector are gathered with the concern of being representative and having as much as possible the same temporal basis. For the parameters definitions, the indicators (stage II) for sectors are chosen and calculated, each one with its own original definitions, meanings, rules and algebra. Goals (stage III) are established for each indicator previously chosen and then settled to be maximized or minimized. The weighting stage (IV) demands the establishment of weights for each indicator, representing a "punishment" for those ones that are more distant from the fixed goals. By means of the goal programming algebra as presented in the previous sections, the sector sustainability indicator (SSI_i) and sustainability synthetic indicator of each system for each sector (ISGS) is calculated (stage V). Finally, the final stage (VI) is the interpretation of the sustainability synthetic indicator of systems ($SSIS_i$) to support discussions and public policies. Appendix C shows all procedures of Fig. 3 automatized in a computer application. It can be developed in different computational languages, including a spreadsheet using the Excel® software.

3. Results and discussion

The Mercosur countries (named from here as "systems") were used as a case study to illustrate the application of the proposed tool in assessing sustainability. The Mercosur is formed by full member countries and associate countries, where Argentina, Brazil, Paraguay and Uruguay are full member countries; Venezuela was a full member but it was suspended in 2016. As associate countries, there are Bolivia, Chile, Colombia, Ecuador, Peru and Suriname. Suriname even being an associate country was not included in this work due to the lack of data.

Primary data were gathered from several sources as individually presented in the next sections. The ideal situation would be having all data from the same year, but this was not possible at this moment. Although from different years, the used data do not impair the application of the proposed tool in assessing sustainability.

3.1. Establishing indicators, goals and weight values to feed the 5SEnSU

Rather than choosing indicators and goals through a participatory meeting with experts, they were chosen according to authors experience and data availability with the main purpose to illustrate the proposed approach. Two indicators per sector were chosen to feed the 5SEnSU model, totalizing ten indicators. Details and the reasons in choosing indicators and goals are hereafter presented. Indicators are represented by the letter "K", followed by the number of the sector "i" and by its number in the sector "j", or kij. The time window considered for all indicators is one year.

3.1.1. Sector 1 – environment as a provider

K11 - Biocapacity per capita 2012. According to the Global Footprint Network (2017), biocapacity indicates the ecosystems' capacity to produce resources used by people and to absorb waste generated by humans, under current management schemes and extraction technologies. Thus, K11 is an indicator that should be maximized. The mean value added to the standard deviation was set as goal considering our expertise in the subject and due to data availability. Other authors (Wackernagel et al., 2017; Lewan and Simmons, 2001; Moran et al., 2008; Liu et al., 2017) have used this indicator to access the sustainability of countries.

K12 - Total emergy flow per capita 2008. Emergy is defined as the sum of all inputs of energy directly or indirectly needed to make any product or service (Odum, 1996). Specifically, the empower (i.e. emergy per year) is used. This indicator must be maximized since the higher the empower per capita, the more real wealth the nation holds. The established goal was based on the same criteria as for K11. Emergy flow per capita has been used by several authors (Fan et al., 2018; Liu et al., 2017; Viglia et al., 2018; Giannetti et al., 2013, 2018) in evaluating the sustainability of nations.

3.1.2. Sector 2 – environment as a receiver

K21 – Amount of CO_2/capita 2012 emissions. According to The World Bank (2017) data, carbon dioxide emissions are those stemming from fossil fuels burn. This indicator must be minimized to avoid global warming. As the CO_2 emissions is a current issue that deserves strong

Table 2
Description of indicators and their goals as established in this work to study the Mercosur countries.

Sector	Indicators	Objective	Goal (G)
1	K11 – Biocapacity per capita 2012 (gha/capita). Source: Global Footprint Network (2017)	Max	$\bar{K}_{11} + \sigma(K_{11})$
	K12 – Total emergy flow per capita 2008 (sej/capita yr). Source: NEAD (2017)	Max	$\bar{K}_{12} + \sigma(K_{12})$
2	K21 - Emissions of CO_2/capita 2012 (tons/cap yr). Source: World Bank (2017)	Min	Min (K_{21}) + $\sigma(K_{21})$
	K22 – Municipal Solid Waste per capita 2012 (kg/capita yr). Source: The World Bank (2012)	Min	401.5 (goal for Latin America)
3	K31 – GDP PPP/cap 2012. Source: The World Bank (2017)	Max	Max (K_{31})
	K32 – GINI 2013. Source: The World Bank (2017)	Min	Min (K_{32})
4	K41 – Employment rate 2012 (% population). Source: The World Bank (2017)	Max	100%
	K42 – Expected years of schooling (years). Source: UNDP (2017)	Max	16
5	K51 – Human Development Index (HDI) 2012. Source: UNDP (2017)	Max	0.8
	K52 – National Happiness Level 2013. Source: UNSDSN (2013)	Max	$\bar{K}_{52} + \sigma(K_{52})$

Legend: kij, "i" indicator of "j" sector; σ = standard deviation.

action to be minimized, its goal was pushed as the minimum value on the evaluated sample of Mercosur countries added to its standard deviation; these statistical parameters were set according to authors´ expertise and data availability. Similar uses of this indicator in assessing the sustainability of nations have been made by Liu et al. (2017) and Bekun et al. (2019).

K22 - Municipal Solid Waste per capita 2012. According to the Pan American Health Organization (PAHO), the definition of Municipal Solid Waste presented in The World Bank's (2012) report "What a Waste: A Global Review of Solid Waste Management" is: Solid or semi-solid waste generated in population centers including domestic, commercial wastes, as well as those originated by the small-scale industries and institutions (including hospital and clinics). Market street sweeping and from public cleansing are included. This indicator should be minimized to align with circular economy concepts and its goal was set as 1.1 kg/capita day, which is the average for Latin America according to the PAHO report. Other authors used this indicator in similar assessments (Tomić and Schneider, 2017; Cremiato et al., 2018).

3.1.3. Sector 3 – production unit

K31 – GDP per capita based on purchasing power parity (GDP PPP) per capita 2012. According to The World Bank (2017) data, GDP PPP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. This indicator must be maximized since it reflects the economic power of the nation. The goal set for this indicator was pushed as the maximum value found in the evaluated sample of Mercosur countries since the country that presents this level could be seen as a reference for the other ones. Similar uses of this indicator have been made by Menegaki and Tiwari (2017) and Kurniawan and Managi (2018).

K32 - GINI 2013. GINI index is a general measure of economic inequality. According to the World Bank data, this index measures the extent to which the distribution of income among individuals or households within an economy deviates from an equal distribution. An index of 0 represents perfect equality, while an index of 100 implies perfect inequality, thus GINI must be minimized. The goal set for this indicator was the minimum value existent in the sample of evaluated Mercosur countries, again, because it could be considered as a reference to the others in achieving similar economic (in)equality level. Among several others, examples of GINI index usage can be found in Menegaki and Tiwari (2017); Armiento (2018); Neri et al. (2017) and Pulselli et al. (2015).

3.1.4. Sector 4 – society as a provider

K41 – Employment rate 2012. According to The World Bank (2017) data, this indicator represents the proportion of a country's population that is employed, thus it should be maximized. Since a job represents more than exclusively a source of economic resources in exchange of a delivered service (among others, a job also represents a social acceptance of a human being in its societal environment), the established goal was pushed to 100%. Example of employment rate use can be found in Antanasijević et al. (2017) and Ge et al. (2017).

K42 – Expected years of schooling. According to the UNPD (2017), this indicator represents the number of years of schooling that a child of school entrance age can expect to receive if the prevailing patterns of age-specific enrolment rates persist throughout the child's life. This indicator must be maximized, meaning that more years spent in school, higher educational level the population holds. The goal was set as 16 years since this is the approximate value observed for countries with a high human development index as presented by the UNPD database. Example of its usage can be found in the work of Shen et al. (2017).

3.1.5. Sector 5 – society as a receiver

K51 – Human Development Index (HDI) 2012. UNPD (2017) defines HDI as an aggregated measure of the achievements in key dimensions of human development, including long and healthy life, being knowledgeable, and have a decent standard of living. HDI values range from 0 (worst scenario) to 1 (best scenario), thus it must be maximized. The value 0.8 was set as a goal since this is the lowest value of HDI to label a country as high level as shown by UNPD database. Among other users, Shaker (2018) have used HDI in studying countries.

K52 – National Happiness Level 2013. This indicator is available in the World Happiness Report published by the United Nations Sustainable Development Solutions Network (UNSDSN, 2013). It reflects the level of happiness of a given society. This indicator is to be maximized, which means higher happiness levels, and the criteria to set the goal were the same as for K11 and K12. Examples of its use can be found in Verma (2017) and Laczniak and Santos (2018).

Table 2 summarizes all the chosen indicators for each sector, as well as the goals set for each of them. The values of each indicator for each country are shown in Table 3. All the calculation procedures of Fig. 3 (and Appendix C) were inserted into an Excel spreadsheet, where the GP mathematics fundamentals were set. An application was designed in Visual Basic language for calculation purposes and then tabulated in a Microsoft Excel sheet (Supplementary Material), which applies the GP philosophy to classify the countries based on the 5SEnSU model.

3.2. Performance on sustainability for the Mercosur countries: intervals, hierarchy, and policy implications

The sustainability of the Mercosur bloc depends on the performance of each nation translated by their different indicators within the sectors of the 5SEnSU model. As exposed in the calculation procedure modelling, countries with lower $SSIS_i$ values are more sustainable, since their overall performance is closer to the established goals. The level of sustainability is determined by the intervals as shown in Table 4, which indicates a high sustainability level for Uruguay and Chile. Colombia

Table 3
Indicators for the evaluated Mercosur countries[a].

Countries	Sector 1		Sector 2		Sector 3		Sector 4		Sector 5	
	Indicators									
	K11	K12[b]	K21	K22	K31	K32	K41	K42	K51	K52
Argentina	6.64	5.09	4.60	445.30	12969.7	42.3	92.80	17.3	0.823	6.562
Brazil	8.86	2.80	2.30	375.95	12291.5	52.9	92.60	14.2	0.734	6.849
Paraguay	10.90	1.50	0.80	76.65	3855.5	48.3	95.20	12.3	0.679	5.779
Uruguay	10.21	3.10	2.60	40.15	15092.1	41.9	93.60	15.5	0.788	6.355
Venezuela	2.77	5.70	6.60	416.10	12755.0	44.8	92.60	14.2	0.770	7.039
Bolivia	17.18	3.70	1.80	120.45	2645.2	48.1	97.70	13.8	0.661	5.857
Chile	3.62	8.60	4.70	394.20	15431.9	50.5	93.60	15.6	0.831	6.587
Colombia	3.65	2.20	1.70	346.75	7885.0	53.5	89.60	13.3	0.712	6.416
Ecuador	2.19	2.30	2.50	412.45	5702.1	47.3	95.90	13.3	0.725	5.865
Peru	3.93	5.30	1.80	365.00	6387.8	44.7	96.40	13.4	0.731	5.776

[a] Please refer to Table 2 for indicators meanings, their units, and data source.
[b] Numbers in E + 16 sej/capita yr.

Table 4
Sustainability levels for the Mercosur countries.

Country	Sustainability Intervals[a]	Sustainability level
Uruguay	$4.17 \leq 4.17 \leq 5.93$	High
Chile	$4.17 \leq 5.08 \leq 5.93$	High
Venezuela	$5.93 < 6.98 \leq 13.59$	Medium
Brazil	$5.93 < 8.28 \leq 13.59$	Medium
Argentina	$5.93 < 8.32 \leq 13.59$	Medium
Bolivia	$5.93 < 10.75 \leq 13.59$	Medium
Peru	$5.93 < 11.02 \leq 13.59$	Medium
Ecuador	$5.93 < 13.54 \leq 13.59$	Medium
Colombia	$13.59 < 14.39 \leq 15.11$	Low
Paraguay	$13.59 < 15.11 \leq 15.11$	Low

[a] Estimated by using the following statistical values obtained for SSISs results (Appendix D): $\bar{SSIS} = 9.76$; $Min_{SSIS} = 4.17$; $Max_{SSIS} = 15.11$; $\sigma_{SSIS} = 3.83$; $\bar{SSIS} - \sigma_{SSIS} = 5.93$; $\bar{SSIS} + \sigma_{SSIS} = 13.59$.

and Paraguay achieved low sustainability levels, while all other countries are within the medium level. It is worth to note that sustainability levels, as presented in Table 4, are valid exclusively for the sample (10 Mercosur countries) used in this work. Anyhow, the focus here is the approach used in establishing the sustainability levels that can be replicated in other studies.

Regarding a visual form on the hierarchy of sustainability based on numbers presented at Appendix D, Fig. 4 was developed to provide an easier and faster interpretation of the results. This figure is the representation of the sustainability synthetic indicator of systems ($SSIS_i$), which locates the countries depending on their performance, that is, the most sustainable countries would be those with the lowest $SSIS_i$ value. The first column presents the sustainability final ranked countries according to their $SSIS_i$. When all indicators of all sectors are simultaneously considered, the country that shows the highest degree of sustainability is Uruguay, reaching a total SSIS of 4.17. Although Uruguay is the most sustainable country under an overall perspective, in some sectors it is not the most sustainable one, for instance, it holds 3rd, 2nd, 3rd and 4th positions in sectors 1, 2, 4 and 5 respectively. Paraguay showed the lowest degree of sustainability when all indicators are considered, which is evidenced by its SSIS of 15.11. It is interesting to note that in sector 4, Brazil and Venezuela are overlapped because they have the same value of $SSIS_i$ for that sector.

Although Fig. 4 shows easily understandable results, it comes from deep previous complex calculating procedures as provided by the framework presented in Fig. 3. Without a mathematical method, it would be a hard task to consider all the indicators under a multicriteria perspective that result in a single number as expressed by the $SSIS_i$. As already recognized by Bastianoni et al. (2016), the aggregation of a large number of specific indicators into a single one could be considered as positive due to its easy interpretation by a decision maker thinking towards a macro view; on the other hand the extreme concentration of information into a single number could lead to loss of information, hindering more specific public policies. In this sense, besides providing an aggregated result, Fig. 4 highlights information on each sector evaluated and shows evidences to establish priorities among sectors.

Regarding specific public policies, the decision maker can use the proposed tool to verify in which sector a particular system has low performance. In this case, the analyst can go back in the calculations to verify which indicators are driving the low performance in that sector. Taking Chile as an example, the country holds the 4th position in sector 1, which is represented by indicators K11 (Biocapacity per capita) and K12 (Total emergy flow per capita). Observing the data presented in Appendix D, indicator K12 generated a $SSIS_{12}$ that is the best one among all countries, on the other hand, indicator K11 generated a $SSIS_{11}$ that pulled down the position in the overall analysis of sector 1 for Chile. In this way, indicator K11 would be a focus for improvements. Another example is Uruguay that could make efforts to increase its total emergy flow per capita (K12), increase the employment rate (K41) and increase its National Happiness Index (K52). The same analysis can be done for all other countries evaluated in this study.

4. Conclusions

The 5SEnSU model is proposed to support a sustainability assessment based on a more holistic perspective of a system when compared to the existing approaches found in the scientific literature. It considers the environment either as a supplier of resources and/or as a receiver of waste and emissions. The society is also seen as a provider of labor force and as a receiver of goods. The model drives the analyst and policymakers to seek a balance among the 5SEnSU sectors towards sustainability.

The application of the GP philosophy supporting the calculation algebra within the proposed tool works as a multicriteria analysis, allowing the sustainability performance evaluation of the different sectors considering the goals of the selected indicators. The approach allows measuring the system's sustainability performance in order to rank and classify them in levels of sustainability.

The 5SEnSU model brings some advantages such as the holistic view of the system, the recognition of the double functions for the environment and society, and the importance of using a multi-criteria approach when dealing with sustainability. On the other hand, the main limitation, which is also shared with all other multicriteria-based assessment methods, is related to the need for a larger amount of primary data for calculating the indicators, as well as establishing goals and weights.

The case study allowed ranking the sustainability of the Mercosur

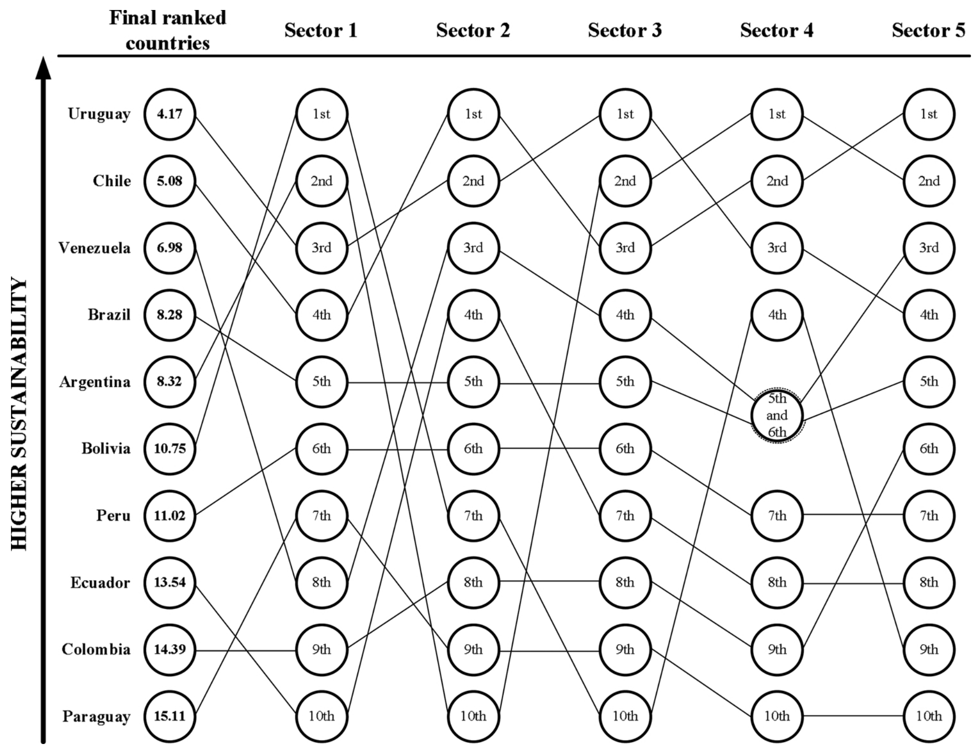

Fig. 4. Sustainability ranking for the Mercosur countries. Numbers within the circles on the first column represents the $SSIS_i$ for each country. Numbers within the circles in the sectors columns represents the position of that country in that sector.

countries, where the performance in the different sectors is clearly presented. Furthermore, countries were classified into high (Uruguay and Chile), medium (Venezuela, Brazil, Argentina, Bolivia, Peru and Ecuador) and low (Colombia and Paraguay) sustainability levels. Although the sustainability levels classification is specific for the sample under study, it can be considered important in a macro analysis where clusters are essential to highlight differences. While the macro analysis reveals what spots (or sectors) must be primarily focused, for specific public policies the analyst may go back in the calculations to verify which indicators should be improved for achieving higher sustainability. In this sense, results showed that Uruguay holds the best position when all indicators of all sectors are considered, however, improvements are demanded on specific indicators in sectors 5, 4 and 1, precisely the national happiness level (K52), employment rate (K41) and total emergy flow per capita (K12).

The 5SEnSU model provides a strong scientific basis to evaluate the sustainability of production systems at any scale, including regional analysis. By organizing the sectors as donors and receivers, the model also provides a holistic view of how a given system may improve or balance its relationship among the components (sectors). The 5SEnSU model can be applied to other case studies to validate its use, as well as a subsidy method for decision making towards sustainable development.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ecolmodel.2019.06.004.

Appendix C. Matrix form of procedures presented in Fig. 3 to calculate the sustainability synthetic indicator of systems (SSIS)

i	Systems, Sectors, Indicators ∀ i∈ {1,2,...,NE}, ∀ j∈{1,2,...,NS}, ∀ k∈{1,2,...,NI}						
	K_{ijk}	Positive Indicators (+)			Negative Indicators (-)		
		N^{+}_{ijk}	P^{+}_{ijk}	ISG^{+}_{ijk}	P^{-}_{ijk}	N^{-}_{ijk}	ISG^{-}_{ijk}
1	$K_{1,1,1}$	$N^{+}_{1,1,1}$	$P^{+}_{1,1,1}$	$ISG^{+}_{1,1,1}$	$P^{-}_{1,1,1}$	$N^{-}_{1,1,1}$	$ISG^{-}_{1,1,1}$
2	$K_{2,1,1}$	$N^{+}_{2,1,1}$	$P^{+}_{2,1,1}$	$ISG^{+}_{2,1,1}$	$P^{-}_{2,1,1}$	$N^{-}_{2,1,1}$	$ISG^{-}_{2,1,1}$
3	$K_{3,1,1}$	$N^{+}_{3,1,1}$	$P^{+}_{3,1,1}$	$ISG^{+}_{3,1,1}$	$P^{-}_{3,1,1}$	$N^{-}_{3,1,1}$	$ISG^{-}_{3,1,1}$
NE	$K_{NE,1,1}$	$N^{+}_{NE,1,1}$	$P^{+}_{NE,1,1}$	$ISG^{+}_{NE,1,1}$	$P^{-}_{NE,1,1}$	$N^{-}_{NE,1,1}$	$ISG^{-}_{NE,1,1}$

Sustainability Indicators		
SSI_{ij}	$ISGS_{ij}$	$SSIS_i$
$SSI_{1,(1..5)}$	$ISGS_{1,(1..5)}$	$SSIS_1$
$SSI_{2,(1..5)}$	$ISGS_{2,(1..5)}$	$SSIS_2$
$SSI_{3,(1..5)}$	$ISGS_{3,(1..5)}$	$SSIS_3$
$SSI_{NE,(1..5)}$	$ISGS_{NE,(1..5)}$	$SSIS_{NE}$

Appendix D. Calculation spreadsheet to obtain the sustainability synthetic indicator of systems (SSIS)

Country	Sector 1			Sector 2			Sector 3			Sector 4			Sector 5			$SSIS_{country}$ [(b)]
	Indicators		Sector[(a)]	Indicators		Sector[(a)]	Indicators		Sector[(a)]	Indicators		Sector[(a)]	Indicators		Sector[(a)]	
	SSI_{11}	SSI_{12}	$ISGS_1$	SSI_{21}	SSI_{22}	$ISGS_2$	SSI_{31}	SSI_{32}	$ISGS_3$	SSI_{41}	SSI_{42}	$ISGS_4$	SSI_{51}	SSI_{52}	$ISGS_5$	
Argentina	2.18	0.33	2.51	3.90	0.55	4.44	0.80	0.05	0.85	0.36	0.00	0.36	0.00	0.16	0.16	8.32
Brazil	1.24	2.78	4.02	0.55	0.00	0.55	1.02	1.31	2.33	0.37	0.56	0.93	0.44	0.00	0.44	8.28
Paraguay	0.37	3.81	4.19	3.45	0.01	3.46	3.75	0.76	4.51	0.24	1.16	1.40	0.82	0.73	1.55	15.11
Uruguay	0.67	2.55	3.21	0.00	0.01	0.01	0.11	0.00	0.11	0.32	0.16	0.48	0.05	0.31	0.36	4.17
Venezuela	3.82	0.49	4.31	0.02	0.18	0.20	0.87	0.35	1.21	0.37	0.56	0.93	0.33	0.00	0.33	6.98
Bolivia	0.00	2.07	2.08	1.52	0.01	1.53	4.14	0.74	4.88	0.12	0.69	0.80	0.78	0.68	1.46	10.75
Chile	3.46	0.00	3.47	0.01	0.00	0.01	0.00	1.03	1.03	0.32	0.13	0.45	0.00	0.14	0.14	5.08
Colombia	3.45	3.26	6.71	1.71	0.00	1.71	2.45	1.38	3.83	0.52	0.84	1.36	0.51	0.26	0.77	14.39
Ecuador	4.07	3.18	7.25	0.16	0.14	0.30	3.15	0.64	3.80	0.21	0.84	1.05	0.48	0.67	1.15	13.54
Peru	3.33	0.81	4.14	1.52	0.00	1.52	2.93	0.33	3.26	0.18	0.81	0.99	0.37	0.74	1.10	11.02

Legend: SSI = Sector sustainability indicator; ISGS = Sustainability synthetic indicator of each system for each sector.
[(a)] Value obtained by adding both individual indicators (SSI), according to Eq. (11).
[(b)] Value obtained by adding the ISGS of each sector, according to Eq. (12).

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