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Assessing Sustainability of local production systems: A proposal based on socio-ecological resilience and collaboration

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Sustainability and resilience are considered the base for reaching a balanced functioning of socio-ecological systems, facing internal conditions and external shocks. However, there is no agreement on how to get a good measure of both concepts to allow for managing local production systems in that sense. In this *Brief* a methodology for assessing sustainability of production systems as result of a two-year research is presented. The possibility for applying this methodology rests on a collaborative process between science and policy to improve resilience, and therefore sustainability of local production systems.

Introduction

An interdisciplinary research group from seven universities in the Centre-West of Argentina, have developed an analytic-methodological proposal to assess **sustainability of local production systems, based on the concept of resilience of socio-ecological systems** (RA, 2010). Sustainability is considered not as a stable state condition but, as a daily construction process based on past experiences and projections about the future; a set of ideal situations that are constantly redefined as a result of changes in the natural and social environments in which a production system evolves (Kates *et al*, 2001). And from resilience, defined as the response capacity to disturbance, the approach of sustainability includes a perspective of open and dynamic systems instead of one related to an exposed unit (Chapin et al, 2004).

Sustainability analysis should rest on two main interconnected components, the natural and the social. However, the complexity of the interactions in a system makes more favorable for the analysis to break them in four dimensions as the ecological, the economic, the social, and the institutional. The **ecological** dimension refers to the need to restore the natural environment and preserving ecosystems' functioning by disconnecting economic progress and social inequities from environmental damage. The **economic** dimension based on a notion of prosperity, excludes *per se*-economic growth but includes ending poverty and to secure food, education, and basic infrastructure. The **social** dimension pursues social inclusion by enhancing human, cultural and social capital. The **institutional** dimension here refers to those more formal and organizational aspects (e.g. knowledge about the system, legislation) concerning to human-human and human-nature interactions conveying to the functioning of the socio-ecological system. Interactions among these dimensions generate synergies and tradeoffs arising from the *demands* that each dimension poses over the others, and on the extent to which these demands are being satisfied, namely *contributions*. Results of these interactions are at the core of sustainability performance for a particular socio-ecological system (SDSN, 2013) (Figure 1).

The analytical approach

Since each dimension *demands* actions to itself and to the others to enhance human wellbeing, **Aggregated Demand** corresponds to all of the dimensions based on four particular criteria. Under the criterion of **preservation** the Ecological dimension demands restoration and conservation of ecosystems. This implies to maintain ecosystems' functioning and ecosystems' capacity to satisfy basic human needs. The Economic dimension bases its demands on the criterion of **efficiency** for the optimal allocation of natural resources to secure economic progress and ecosystems' functioning. The Social dimension under the criterion of **equity** demands social participation towards a just distribution of natural and economic resources and to avoid any type of social exclusion. Finally, the Institutional dimension, under the criterion of **management capacity**, demands to the rest of dimensions the ability to manage tasks and processes in a rapid and reliable manner, to be able to respond to the current risks and future uncertainties through adaptive management.

At the same time, each dimension related to a production system *contributes* to a different degree to **Human Wellbeing.** The Ecological dimension should provide a healthy and natural productive environment; the Economic dimension should contribute to economic progress in the sense of prosperity; the Social dimension should provide for prosperity and equitable social opportunities; and, the Institutional dimension should contribute through participative governance for conducting socio-ecological systems towards sustainability (IRF 2015, 2013).

Assessment Methodology

Analytical indicators of sustainability will be developed from collaboration between policy and other decision makers, together with scientific experts of each of the dimensions and through the establishment of a **bridging organization.** This type of an organization refers to those organizations in charge of collaboration and co-production of knowledge among diverse stakeholders (Crona & Parker, 2012) to produce sounded decision and policy making. Main challenges for a bridging organization rest on the reconciliation of individual or group's needs visions of current and future outcomes, and to promote a continuous learning process to be able to reach a **plural desired** state of a system.

In order to evaluate (qualitatively and quantitatively) the sustainability performance of a production system a **Sustainability Matrix** was developed (Figure 1). The matrix is based on the intended and unintended outcomes from actions taken within the assessed production system, and on the implications for the resilience of the socio-ecological system. The sustainability matrix helps to organize the four dimensions of the sustainability and shows the relationships between the Aggregated Demands from each dimension with the others, and the actual contributions to Human Wellbeing. Within the matrix, a number of **components** (e.g. water, soil, air, and biodiversity, for the ecological dimension) need to be defined in relation to the established criteria and for each of the dimensions. These components are to be related to the rest of components in the Matrix aiming at identifying synergies and trade-offs. One or more indicators may be constructed for each component (e.g. for "water", indicators of quality, quantity and source would be needed).

Figure 1. Sustainability Matrix for a Production System

		HUMAN WELLBEING				AGGREGATED DEMANDS
		ECOLOGICAL (Preservation)	ECONOMIC (Efficiency)	SOCIAL (Equity)	INSTITUTIONAL (Management Capacity)	
DEMANDS FROM THE VARIOUS DIMENSIONS	ECOLOGICAL	WATER SOIL AIR BIODIVERSITY	ACCESS (to production resources)	ACCESS (to resources for life)	CURRENT STATUS AND NEW SCENARIOS (of environmental resources)	ECOSYSTEM SERVICES
	ECONOMIC	PRO ENVIRONMENT PRACTICES PRODUCTION OF LOW ENVIRONMENTAL IMPACT PRODUCT LIFECYCLE	PRODUCTIVITY INDEPENDENCE OF EXTERNAL INPUTS COMPETITIVENESS	LIVELIHOOD CORPORATE SOCIAL RESPONSIBILITY SOCIAL MOBILITY	ENTREPRENEUR TRAINING RULES COMPLIANCE PARTICIPATION	ECONOMIC RESOURCES
	SOCIAL	PERCEPTION AND AWARENESS OF ENVIRONMENTAL PROBLEMS RESPONSIBLE USE OF ENVIRONMENTAL RESOURCES	EDUCATION LABOR	CULTURAL, HUMAN & SOCIAL CAPITAL	SOCIAL ORGANIZATION	SOCIAL PARTICIPATION
	INSTITUTIONAL	LEGISLATION PARTICIPATION OF SOCIAL GROUPS EDUCATION TOWARDS SUSTAINABILITY	LEGISLATION SOCIAL CAPITAL ORGANIZATION SERVICES	ACCESS CITIZENSHIP PARTICIPATION	LEGISLATION ENFORCEMENT MONITORING	ADAPTIVE MANAGEMENT
CONTRIBUTIONS TO HUMAN WELLBEING		HEALTHY AND PRODUCTIVE ENVIRONMENT	ECONOMIC PROGRESS	EQUAL OPPORTUNITIES AND SOCIAL PROSPERITY	PARTICIPATORY GOVERNANCE	*SYSTEM'S SUSTAINABILITY TREND*

Each space within the Matrix shows examples of components determining the relationships between dimensions and based on the established criteria for each dimension.

Source: Translated from Seiler & Vianco, 2014

The components in the Matrix are not fixed; they depend on the characteristics of the production system or of the region being analyzed. The Principal Diagonal informs on the state or baseline of each dimension through a set of components which respond to the stated criteria. The rest of the Matrix establishes relationships among dimensions and their components. As a way of exemplification, it is possible to think about the demand of a production system in terms of the availability of particular natural resources to develop the production process. The existence and specificities of natural resources spatially distributed determine not only the characteristics of an ecosystem but also the possibilities for the production system to develop as well as the limits to such a development. The same method applies for all the relationships among dimensions.

Each *component* is determined by a set of indicators defined through specific variables. For example, the ecosystem baseline may have four components: water, air, soil and biodiversity. Based on the need for preserving the ecosystem from where the production system under evaluation depends on, the Water component may be represented by indicators such as quality, quantity and source of freshwater; and, each of these indicators uses different variables to make the valuation –e.g. for freshwater quality it would be useful to measure the amount of dissolved nitrates and salt as milligrams per liter; in terms of quantity, runoff volume or recharge capacity of aquifers. The aggregation of components gives place to Relationship Indicators within and among the four dimensions (Figure 2). Then, the Sustainability of a production system (SPS) arises from the aggregation of actual contributions to the demands, representing a "quantification" of the Wellbeing state for a resilient socio-ecological system, based on the sustainability of a particular production system which is one of its most representative systems.

Since production systems are not homogeneous in terms of its integrating units (e.g. different stakeholder holding different power, therefore differently affecting the production system), this methodology also allows to analyze these various groups separately, by disaggregating components in various strata among the units of analysis based on the "best" criteria representing such heterogeneities.

Figure 2. Values of the Sustainability Matrix

Relationships		HUMAN WELLBEING				AGGREGATED DEMANDS
		ECOLOGICAL (Preservation)	ECONOMIC (Eficiency)	SOCIAL (Equity)	INSTITUTIONAL (Management Capacity)	
DEMANDS FROM THE VARIOUS DIMENSIONS	ECOLOGICAL	RI_{11}	RI_{12}	RI_{13}	RI_{14}	D_1
	ECONOMIC	RI_{21}	RI_{22}	RI_{23}	RI_{24}	D_2
	SOCIAL	RI_{31}	RI_{32}	RI_{33}	RI_{34}	D_3
	INSTITUTIONAL	RI_{41}	RI_{42}	RI_{43}	RI_{44}	D_4
CONTRIBUTIONS TO HUMAN WELLBEING		B_1	B_2	B_3	B_4	SPS

The Figure shows the valuation of the Sustainability Matrix (SPS) for a production system within a socio-ecological system, from a system of relationship indicators among the four dimensions (RIij). For more details see Annex A. Source: Translated from Seiler & Vianco, 2014

The true value and sensitivity of the methodology rests in that it requires an exhaustive knowledge of the productive systems under analysis and of their functioning. Scientific interdisciplinary groups as well as all stakeholders, from citizens, firms, NGOs, the state, are required to participate to establish proper relationships between dimensions, the components of the systems and the variables/indicators for accurately assessing each component.

Finally, the sustainability indicator (*SPS*) is a relative measure to its potential value and indicates the current position of the system in terms of its desired state. However, it is the inter-temporal regular comparisons which will determine an accurate evaluation of a system's trajectory towards sustainability.

Even though the methodology was developed for assessing agriculture production systems, it is applicable to any production system whenever specific indicators are generated. It is expected that being extensively applied for can contribute with **global sustainability assessment** and to promote behavioral changes to avoid tensions among divergent aspirations from different actors (SDSN, 2013; Cumming et al 2005; Moreno-Pires and Fidélis, 2012).

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Annex: Calculation of a Sustainability Matrix

Sustainability Matrix: Calculation

The calculation begins with the collection of information in primary units. Survey responses or census data are organized into a data table, where data retains its original unit of measure. As a way of comparison, the procedure continues by relating the actual value -observed for each variable (or indicator) used to give value to a component in each dimension - with a selected reference measure, by

$$X_{g,lm} = \frac{x_{g,lm}real - x_{g,l}mín}{x_{g,l}máx - x_{g,l}mín}$$

Where, $X_{g,lm}$ is the standardized value of the variable l, in the component g, observed in a primary unit m. The resulting value is between 0 and 1. $x_{g,l}mín$ y $x_{g,l}máx$ are the reference values for the variable l of component g; the minimum and maximum reference values are determined for each variable, for each component and for each unit of analysis; for example, according to references $x_{g,lm}real$ is the response value (i.e. observed value) of observation m in a survey, for the variable l of component g. The range of m is from 1 to n, the total number of analyzed units within a territory under study; the range of g is 1 to K, the total amount of components in the dimension ij; and, the range of l is from 1 to L and shows the number of indicators or variables accounted for in each component.

Standardization of all observed attributes allows the balancing calculation of each component. With homogeneous observations of n units, for L variables of the component g, an Index for each component is calculated as follows:

$$I_g = \frac{1}{n}\sum_{m=1}^{n} X_{g,m} = \frac{1}{n}\frac{1}{L}\sum_{l=1}^{L} X_{g,lm}$$

Where, I_g is the homogeneous value of component g; $X_{g,m}$ is the average value of the homogeneous variables (of component g) observed from m units of analysis.

From the calculation of all components for each dimension ij the Relation Index (IR_{ij}) is obtained. The RI index is the average value of the components:

$$RI_{ij} = \frac{1}{K}\sum_{g=1}^{K} I_g$$

The Aggregation of all IR leads to the calculation of final demand D_i and wellbeing W_j for each dimension of sustainability; and D_i and W_j assuming values between 0 and 4.

The sustainability of a production system (SPS) arises from adding the final demand or wellbeing achieved by the four dimensions, and varies between 0 and 16. The value of SPS represents a quantification of the wellbeing state and sustainability of a particular production system. The Production System Sustainability Indicator (SPSI) of a system relates the value reached by the SPS with respect to the optimum of 16; The SPSI varies between 0 and 1 and its closeness to 1 indicates greater sustainability of a production system.

A simulation case

To illustrate the method, the responses from five hundred units of observation were simulated for a primary production system. The Ecological dimension integrates Water, Soil, Air and Biodiversity components; and, the water component includes indicators or variables related to quality, amount and sources of freshwater. The Component Water Quality was built considering the presence of nitrates and dissolved salts, which after a certain level freshwater becomes unacceptable for human consumption By simulating with random values (for these variables) and the subsequent standardization the following values were obtained:

$$X_{CAL,N} = 0.0828 \quad X_{CAL,S} = 0.0915$$

Where, $X_{CAL,N}$ and $X_{CAL,S}$ are the average value for the homogeneous measures of the Nitrates and Salt content Variables respectively, both pertaining to the Water Quality Indicator (CAL).

With this information the Water Quality indicator was calculated as:

$$In_{CAL} = \frac{X_{CAL,N} + X_{CAL,S}}{2} = \frac{0.0828 + 0.0915}{2} = 0.0871$$

Repeating the procedure for other variables and indicators, the Water Quantity (In_{CAN}) and the Water Sources (In_F) indicators were calculated as to compose the Water component of the Ecological dimension. The achieved results are shown in Table A.1.

Table A.1. Water component indicators

Indicator	Index
Quality	0.0871
Quantity	0.8126
Source	0.5163

The next step was to calculate a single indicator for the Water component (I_A):

$$I_A = \frac{In_{CAL} + In_{CAN} + In_g}{L} = \frac{0.0871 + 0.8126 + 0.5163}{3} = 0.4720$$

With the same procedure, the Ecological dimension components Soil (I_S), Air (I_{AI}) and Biodiversity (I_B) were obtained. Together with the Water component, the Ecological-Ecological relationships are shown in Table A.2.

Table A.2 Value of the components of the Ecological-Ecological relationship

Component	Index
Water	0.4720
Soil	0.2811
Air	0.9619
Biodiversity	0.5617

The Relationship Index (RIij, where i=J) was obtained as follows:

$$RI_{11} = \frac{1}{4}\sum_{g=1}^{4} I_g = \frac{I_A + I_S + I_{AI} + I_B}{4}$$
$$= \frac{0.4720+0.2811+0.9619+0.5617}{4} = 0.5692$$

The Sustainability Matrix values (Table A.3.) were obtained by repeating the procedure for the rest of Relationship Indexes (RIij).

Table A.3. Sustainability Matrix

Relationships		DEMANDS				AGGREGATED DEMANDS
		ECOLOGICAL (Preservation)	ECONOMIC (Eficiency)	SOCIAL (Equity)	INSTITUTIONAL (Management Capacity)	
CONTRIBUTIONS	ECOLOGICAL	0.5692	0.5560	0.6957	0.2575	2.08
	ECONOMIC	0.8438	0.8984	0.3792	0.9842	3.11
	SOCIAL	0.8761	0.4139	0.8409	0.2998	2.43
	INSTITUTIONAL	0.4916	0.0157	0.8705	0.2961	1.67
CONTRIBUTIONS TO HUMAN WELLBEING		2.78	1.88	2.79	1.84	**9.29**

For the assessment of the demand side to and of the wellbeing from each dimension of sustainability, exemplified by the Ecological dimension, both demands and wellbeing were added as follows:

$$D_i = \sum_{j=1}^{4} IR_{ij} \quad W_i = \sum_{i=1}^{4} IR_{ij}$$

$$D_1 = 0.5692 + 0.5560 + 0.6957 + 0.2575 = 2.08$$
$$W_1 = 0.5692 + 0.8438 + 0.8761 + 0.4916 = 2.78$$

Where, D_1 represents contributions to the demand for ecosystem's functioning and services and W_1 represents contributions to wellbeing provided by all dimensions for a healthy and productive environment. The sustainability of a production system (SPS) is obtained by adding the demands and contributions to wellbeing from all sustainability dimensions, as follows:

$$SPS = \sum_{i=1}^{4} D_i = \sum_{i=1}^{4} W_i$$

As for the example, the aggregated demands and to human wellbeing contributions set the level of sustainability at a value equal to 9.29 as shown below:

$$SPS = 2.08 + 3.11 + 2.43 + 1.67$$
$$= 2.78 + 1.88 + 2.79 + 1.84 = 9.29$$

And the Production System Sustainability Indicator (SPSI) is obtained for this particular case as:

$$SPSI = \frac{SPS}{16} = \frac{9.29}{16} = 0.5805$$

The values in Table A.3 show for each dimension favorable or unfavorable conditions between dimensions.

The above simulated case has not included any type of weighting procedure; however, it is certainly possible to incorporate weights to the measurements at any stage of the process of constructing the Sustainability Matrix with the objective of underscore particular aims. Yet, manipulation of data through this sort of procedure should be collectively validated under the proposed Methodology.

The application of this methodology has effects in the short and long term. In the short term, it may identify the strengths and weaknesses of a production system; and in the long term and through periodic temporal measurements it may show the dynamic or evolution of the productive system towards sustainability.