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Integrating agricultural sustainability into policy planning: A geo-referenced framework based on Rough Set theory

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ABSTRACT

We propose a geo-referenced framework for agricultural sustainability assessment aimed at supporting policy planning. The framework is based on Rough Set theory and (i) integrates the three pillars of sustainability; (ii) proposes an easy measurement of agricultural systems' ability to resist over time (agricultural resilience); (iii) offers easy-to-read results; and (iv) reduces the gap between researchers' analytical skills and decision-makers' needs. In the paper, a part of the framework, we present essential and practical notion of Rough Set theory and a case study based on Lombardy Region (Italy). Finally, some values and lacks of the method are discussed.

1. Introduction

Policy-makers frequently use the term "sustainability" when declaring their objectives without taking into account the technical limitations this concept implies for the design of public intervention. As already underlined by various researchers, the problem resides in the need for a general and political definition of sustainability in agricultural, scientific, and analytical praxis (Francis et al., 1989; Pretty, 1995; Hansen, 1996). This is because:

1. no unit can directly measure human well-being resulting from agricultural activity;
2. economic profit, social welfare and environmental conservation, the three pillars of sustainability, cannot be maximized contemporaneously due to the trade-offs between them (Brown et al., 2001; Gaviglio et al., 2012);
3. the agricultural system is extremely heterogeneous by nature and includes different scales of analysis (Smit and Smithers, 1993; Gaviglio et al., 2015);
4. today we are studying how to preserve resources for future generations, but today we cannot verify the reliability of our results (Gómez-Limón and Sanchez-Fernandez, 2010); and
5. considering the anthropocentric focus of our studies, the goals of sustainability analysis change according to different stakeholders' points of views, so what is sustainable for one person, might actually be unsustainable for another.

Despite these difficulties, the concept of sustainability is widespread in agricultural science and researchers have developed two main interpretative schemes for it: the goal-prescribing and system-describing models (Hansen, 1996). According to the goal-prescribing model, agricultural sustainability is considered an alternative approach to agriculture; in this case, a scientists' work is focused on techniques that should improve agricultural sustainability. Alternatively, the system-describing model looks at sustainability as a (set of) feature(s) of agricultural activities. This model measures a "state" of sustainability, so it appears useful for identifying strengths and weakness of agricultural systems, helping in decision-making rather than indicating operative solutions. These two frameworks have stimulated the growth of literature on the assessment agricultural sustainability, but further efforts are still required for the development of new interpretive methods for its measurement, especially as regards its integration into policy planning (Gómez-Limón and José, 2009; Gómez-Limón and Sanchez-Fernandez, 2010).

The present paper contributes to the scientific discussion of this issue, proposing a geo-referenced framework for sustainability analysis based on the potential for approximate classification of data and information induction of Rough Set theory (RST, Pawlak, 1982). The initial assumption was that policy-makers cannot

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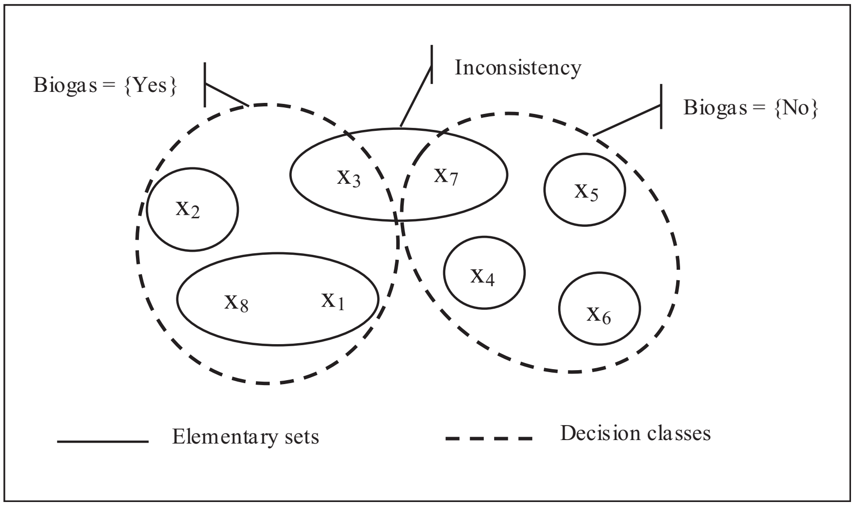

Fig. 1. Elementary sets, decision classes and inconsistency.

consider all the determining factors of sustainability, but they do have a correct basic understanding of it. It would therefore be helpful for them to have a tool that provides a summary of relevant issues in order to support decision-making. The "ideal" solution presented consists of a framework which: (i) integrates the three pillars of sustainability; (ii) proposes a simple measurement of a given agricultural system's ability to resist over time (agricultural resilience); (iii) offers easy-to-read results; and (iv) reduces the gap between the analytical skills of researchers and the needs of decision-makers. In this respect the present paper introduces some novelties into the debate regarding the assessment of agricultural sustainability. The first is the presentation of Rough Set theory as a methodical option to achieve these aims. Secondly, a simple and intuitive definition and interpretation of agricultural sustainability is proposed and discussed. Finally, the work is structured in order to illustrate the basics of RS Theory and develop some practical skills in its use.

The remainder of the text is organized into four sections. Section 2 presents the features of RST and reviews the literature on its applications in agricultural science. Section 3 presents materials and methods for the territorial case study of Lombardy (Italy), while the results and discussion are set out in Section 4. Finally, a concluding paragraph offers a summary of the proposed framework and some reflections on the potentialities and limitations of RST.

2. Rough Set theory for dataset analysis and its application in agricultural science

Scientific models do not always achieve satisfactory solutions for complex problems. Flawed results can easily be generated due to analytical problems like datasets inconsistencies and statistical constraints. In the early 1980s, the Polish professor Zdzisław I. Pawlak proposed a mathematical tool that could deal effectively with these two issues (Pawlak, 1982). He called his model Rough Set theory (RST), because it involves the partition of a set of items under study into subsets according to equalities within them, and an assessment of the overlapping portions (rough sets) which represent the inconsistencies of the database (see Fig. 1 and its description in Section 2.1.2 for further explanations).

Since its original formulation, the RST model has been successfully applied in descriptive and predictive procedures (Stefanowski, 2007). It helps describe regularities within data, uncovering hidden information and suggesting interpretation of dependencies between observed variables. It can be used as a technique for machine learning, knowledge discovery, and inductive inference (Pawlak, 1997) with valuable performance in data reduction, pattern recognition, data significance estimation, cause-effect link detection, automatic classification, and similarity/dissimilarity evaluation (Pawlak et al., 1995).

The basic notions of RS theory and its utility will be discussed in the following paragraphs, with a brief review of applications in agricultural science at the end of the section.

2.1. The Rough Set model

2.1.1. Basic notation and definitions

In Rough Set theory,[1] data are organized in an information system $S = U, Q, V, \rho$ composed of:

- U, the set of x objects described by a Q set of q attributes, that can be divided in *condition* attributes (set $C \neq \emptyset$) and *decision* attributes (set $D \neq \emptyset$), such that $C \cup D = Q$ and $C \cap D = \emptyset$. By definition, decision attributes split objects into sets pertaining to different decision classes $\{K_j : j = 1, \ldots, k\}$
- $V = \bigcup_{q \in Q} V_q$, is the value set of the q attribute;
- $\rho(x, q) : U \times Q \rightarrow V$, a total function such that $\rho(x, q) \in V_q, \forall x \in U$, $q \in Q$, called the *information function*.

RS induces information from this structure applying the *indiscernibility relation*, which states that given a non-empty subset of attributes $A \subseteq Q$, two objects $x_1, x_2 \in U$ and $\rho(x, a)$ defined as the value of attribute a taken by the object x, the objects are indiscernible if $\{(x_1 ; x_2) \in U \times U,\ \rho(x_1, a) = \rho(x_2, a),\ \forall a \in A\}$ and writing xI_Ay. Indiscernible objects for particular values of a create subset of x objects in S; we call each of these subsets an *elementary set* in S or elementary class of equivalence, denoted by $I_A(x)$. Moreover, any finite union of elementary sets is called a *definable set*, and the entire family of equivalence classes of relation constructed over $x \in U$ (i.e. the union of all definable sets) is denoted by $U/I(A)$.

A hypothetical example related to determinants of adoption of biogas technologies by breeding farmers helps to present the

[1] The explanation of Rough Set Theory presented in Sections 3.1.1 and 3.1.2 follows Pawlak et al. (1995), Stefanowski (2007) and Slowinski et al. (2012). Researchers who would like to further investigate the formal characteristics of the method, and its early applications and developments, refer to Pawlak (1982), Kryszkiewicz (1998), Yao (1998), and Pawlak and Skowron (2007).