Multi-criteria decision approach and sustainable territorial subsystems: an Italian rural and mountain area case study

1. Introduction

Worldwide, rural communities share some factors related to livelihoods based on local natural resources, low population density and poor communication. Focusing on agriculture, in developing countries, it is a commonly held belief that farming is a mainstay of most rural economies (Ashley and Maxwell, 2001)[1]. In developed countries, agriculture often plays a marginal role. Land degradation and loss of public services, because of growing depopulation, appear to be the main concerns (Terluin, 2003). Without a doubt, rural area are highly differentiated, and mountain areas are generally characterised by negative climate conditions, low accessibility and population density.

Over past decades, there have been important debates, studies and proposals on the classification of rural areas. Nevertheless, a unanimous and comprehensive definition is still far from being formulated. We believe, however, the crucial problem lies both in methods and in suitable indicators for the selection of rural areas, and in the identification of sustainable development paths capable of solving the problems of these areas. According to Marsden (2003), a deep and detailed understanding of rural space is needed in order to explore the existing conditions for and of rural sustainability. As Knickel and Renting (2000) state, rural development actually includes a number of resources and activities related to the agricultural sector and belonging to an area as a whole. In the development of rural areas, local governments play an important role, but they are not the only actors (Rovai et al., 2016). We believe that their main function is to create or improve a governance system able to establish a cooperative network, social groups, business communities and public and private bodies, limiting the conflicts that regularly arise (Brunori and Rossi, 2007).

Starting from these premises, our goal is the identification of appropriate territorial subsystems in a rural and, at the same time, a mountainous area using Rough Sets Theory (RST) (Pawlak, 1982, 1991) to propose developmental tools combining economic, social and environmental aspects. Recently RST was shown to be very useful in assessing the level of Rural Sustainable Development in a specific area of Italy, the Region of Umbria (Boggia et al., 2014). This study obtained a ranking and an explanation of the main factors able to drive sustainable development and to address decision makers in the process of allocating resources to maintain and improve the level of rural sustainable development. In addition, they highlighted some interesting features of RST applied to Multiple Criteria Decision Making, such as transparency and traceability.

Our case study, Belluno province, Italy, is, according to the EU, a predominantly rural and largely less favoured area due to its mountainous position. Through RST, we identified different areas: in decline, rural at risk of decline, strictly rural, touristic and urban, for the purpose of addressing local public interventions, following a bottom-up approach, and potentially using current European financial opportunities. The commonly shared belief is that support to rural areas needs to be tailored according to the different needs of the territories (Bański et al., 2016), including economic aspects (and agriculture), without underestimating social and environmental components (Saraceno, 1994; Hoggart, 1990; Van der Ploeg et al., 2000; Zolin and Rasi, 2012). For this purpose, RST is a useful and flexible instrument, easy upgradeable and able to capture the fundamental characteristics of a territory, which, due to its characteristics, allows a multi-faceted, i.e., multidimensional, representation (Calleros-Islas, Welsh-Rodriguez, 2015). Through this

[1] In 2014, according to the World Bank (2015) rural populations account for 47 percent of the total population, agricultural land (2013) is 37.7 percent of the world's land area and 70 percent of poverty is concentrated in developing countries' rural areas where agriculture is often the main source of income and employment.

approach, available information is possibly ambiguous or inconsistent given its granulation and different characteristics of the indicators used.

The paper is structured as follows: Section 2 is a synthetic analysis of some main questions arising from characterisation of rural and mountain areas in the EU, both with respect to their definitions and with reference to adopted policies. Section 3 gives a general view of Rough Sets Theory and presents the data sources used in the analysis. Section 4 focuses on the case study. This section is divided into two parts, the first aims at describing condition and decision attributes, the second presents the results in decision rules obtained with reference to different territorial situations: urban, touristic, declining, at risk of decline and rural areas. Conclusions are drawn in the final section. This paper may help local public authorities and private organisations in the appreciation and identification of tailor-made sustainable strategies and/or policies, generally defined as a whole (such as in rural areas) at European, National and Regional levels.

2. EU rural and mountain areas

As far as European Union Policy is concerned, it is worth mentioning that the conceptual framework adopted by the EU for the development of rural areas initially linked agriculture to rural development, without any particular territorial delimitation. European funds financed interventions (until the end of the 1980s), targeted mainly at the modernization of agricultural holdings. With the Structural Funds reform in 1988, EU regional policy included the development of rural areas and vice versa, adopting an integrated approach. In this way, the notion of diversity of rural economies, where agriculture alone was not enough to solve the problems of these areas, was strongly established. Then, with Agenda 2000, a specific fund for rural development (a so-called second pillar), was created (Fonte, 2010; Baldock et al., 2001). The negative aspect of this reform is the separation of rural development policy from regional policy. However, the previous experience was the starting point for sustainable endogenous development models.

The European choice of population density has generated the stratification of the European territory of essentially three groups: predominantly rural, intermediate and predominantly urban[2]. Hence the real nature of the territories that appear homogeneous is therefore ignored, and the classification fails to capture the heterogeneity and complexity of the territories. In this regard, Wandl et al. (2014) focus on the areas in between rural and urban, and propose an alternative classification resulting from the combination of population density and different maps of land cover. As a result, agriculture does not determine the degree of rurality of areas. In actual fact, in a great number of European countries (Italy included), agriculture that is exercised professionally and able to contribute substantially to food security is concentrated in lowland areas often where the industry is most widespread. Moreover, some rural areas fall in the less favoured areas (LAFs) where natural handicaps (such as difficult climatic conditions, steep slopes, low soil productivity) hinder the performance and management of various activities. These conditions affect the production, various costs, and in the long run, the opportunities for farmers or any other rural activity to survive.

According to Council Regulation (EC) 1257/1999, LFAs include three categories: Mountain areas (Article 18), Intermediate/other less-favoured areas (Article 19)[3], Areas affected by specific handicaps (Article 20)[4].

[2] The EU adopted OECD methodology to classify NUTS3 regions. A NUTS3 region is predominantly urban if the share of population living in rural LAU2 is below 15 percent; intermediate, if the share of population living in rural LAU2 is between 15 percent and 50 percent; predominantly rural, if the share of population living in rural LAU2 is higher than 50 percent. In a third step, the size of the urban centres in the region is considered (Eurostat, 2010).

[3] Intermediate/other less-favoured areas (Article 19) are those in danger of abandonment and the conservation of the countryside is necessary. The main characteristics of these areas are: poor productivity of the land usually because of poor soil conditions, a level of production that depends on both the low productivity and the natural environment, a low population density whose predominant activity is agriculture.

[4] Relating to the environment, in which farming should be continued in order to improve the environment.

Mountain areas are characterized by short growing seasons because of either high altitude or steep slopes at a lower altitude. Altitude and slopes also reduce the scope for mechanization. Moreover, Mountain areas include all the areas situated on the northern side of the 62nd parallel. These less-favoured areas benefit from compensatory allowances. Since agricultural production and other activities are more difficult in these territories, the Member States introduced payment schemes to avoid land abandonment. These payment schemes are not compulsory and it is at the discretion of each MS whether to provide support to the areas within the country. The LFA support scheme has been in place since 1975 and it is a long-standing measure of the Common Agricultural Policy (CAP). It belongs to Axis 2 of the 2007-2013 and 2014-2020 Rural Development Policy. The objective is to improve the environment and the countryside through the support of land management in a sustainable way, and the provision of other functions in addition to food protection.

European mountain areas are slowly depopulating. This trend, which has continued for over half a century (and in some Alpine areas for over a century), has meant that mountain areas, which, in Italy, account for almost three-fifths of the total surface, are home to one-fifth of the Italian population. The abandonment of these areas exposes the territories to environmental risks – such as forest fires, landslides and deterioration of the landscape – that affect the entire community. From the social point of view, it makes some essential services for citizens more expensive, from transportation to communications, from health services to schools. Mountain people often suffer from political, social and economic marginalisation, and lack access to public services, such as health, education and leisure. The fragility of mountain areas means that the impact of unsustainable development is more urgent than in other areas, and correcting these issues route is difficult. As noted by Arzeni and Sotte (2013), mountain farming is justified by the undoubted contribution to the protection and exploitation of public goods. Direct payments, however, that absorb a strong share of CAP spending (70 percent) are concentrated in lowland areas and, despite the rural development policy resources in upland areas, are largely insufficient to fill the big gap.

3. Methods and data

With reference to the sustainable development of rural areas, particularly interesting are the assessment and evaluation of some economic, social, environmental and accessibility indicators, such as condition attributes and the information connecting them to different sustainability status, which is a decision attribute of a given municipality (Boggia et al., 2014; Boggia and Cortina, 2010[5]; Ding et al., 2014[6]; Liu, 2007[7]). In the study of regional sustainability, the environment, economy and society represent subsystems that interact and correlate: for this reason, the study of the way the subsystems are planned is of particular interest.

With the aim of discovering the underlying relationships collected by data in an information system through a data mining process, we have considered an artificial intelligence technique, namely Rough Sets Theory (RST), for which inductive decision rules of the type

$$\textit{conditions} \rightarrow \textit{decisions}$$

[5] Boggia and Cortina (2010) analysed social and economic dimensions together so that a set of environmental and socioeconomic indicators have been considered with the aim of defining an integrated methodology of assessment and monitoring. By developing a methodological approach based on MCDM (Multiple Criteria Decision Making), they separately followed two procedures in obtaining two performance indexes: one for socioeconomic profile, the other for environmental performance.
[6] In this field, Ding et al. (2014) proposed a method able to estimate the interrelated promotions of environmental conservation, economic growth and social well-being using the definition of a coordinated development index.
[7] Liu (2007) outlines an evaluation-framework of environmental sustainability, integrating fuzzy logic into MCDM.

can be deduced in order to express informative properties of data. Important benefits are recognised using RST: among them are the lack of any statistical assumption on data distribution, the acceptance of numeric and categorical data, no need for structures collecting data like functions or equations and a simple method of describing patterns exhibited by data (e.g., Celotto et al., 2015).

The definition of condition and decision attributes is the milestone on which it is possible to deduce inductive decision rules (*if, then*). More precisely, we consider a finite nonempty universe $\mathcal{U}$ of elements $\{x_1, x_2, \dots, x_N\}$, that in our case is made up of municipalities, which is related to the finite set $\mathcal{A}$ of k attributes $\{a_1, a_2, \dots, a_k\}$, that in our research are economic, social, environmental, accessibility indicators and sustainability status, by the domain sets V_{a_i} (for each $i = 1, \dots, k$), i.e., the sets of all the values of each attribute a_i. In short, the pair $S = (\mathcal{U}, \mathcal{A})$ represents the information system, also called classification table or condition-decision table.

RST mainly refers to two aspects: approximations and decision rules. Objects characterized by the same information are indiscernible: this represents the main assumption, so that the mathematical structure of the theory is essentially based on the definition of the indiscernibility relation. In other words, each municipality can be described in terms of the condition attributes and consequently can be discerned by means of the values referring to each attribute. In this way, for each set $B \subseteq \mathcal{A}$, universe $\mathcal{U}$ is partitioned into equivalence classes (also called elementary sets) through the indiscernibility relation IND(B). In this way, objects are considered to be indiscernible, that is equivalent, if and only if all the corresponding attributes in set B have the same values. For example, as the results of our case study show, if we consider two municipalities Cortina d'Ampezzo and Lamon, the attribute's values of waste collection and separation, and of forest area extension are the same, while they are different mainly regarding the associations, the economic activity rate and the accessibility to schools, just to name a few factors. When a set $X \subseteq \mathcal{U}$, that is a concept, is made up of objects that are all in elementary sets, then all its objects can be distinguished in terms of the available attributes; otherwise, it is possible to define new sets, called approximations, in such a way that X can be approximated by the related sets.

In more detail, if $[x]_B$ denotes the equivalence class containing x with respect to information assumed in B, then it is possible to set the definition of the B-upper approximation of X

$$\overline{B}(X) = \{x \in \mathcal{U} : [x]_B \cap X \neq \emptyset\} \qquad \text{Eq. (3.1)}$$

which represents the set of all the elementary sets that are not disjoint to X.
Analogously, the B-lower approximation of X is

$$\underline{B}(X) = \{x \in \mathcal{U} : [x]_B \subseteq X\} \qquad \text{Eq. (3.2)}$$

In other words, $\underline{B}(X)$ is made up of all the elementary sets that are included in X in a non-ambiguous way.

Similarly, it is possible to give the following equivalent definitions: the upper approximation contains those elements that possibly belong to the concept, while the lower approximation contains all elements that necessarily belong to the concept. A concept X is then called *exact with respect to B* if the boundary region

$$BN_B(X) = \overline{B}(X) - \underline{B}(X) \qquad \text{Eq. (3.3)}$$

is empty, otherwise it is said to be *rough with respect to B*.

For instance, if we focus on condition attributes describing social aspects, Valle di Cadore and Domegge have the same description, and so they are included in the same equivalence class with respect to the set of information considered. Nevertheless, Domegge belongs to the class of municipalities in risk of decline, while Valle di Cadore is classified as rural. Consequently, Valle di Cadore belongs to the upper approximation of the set of municipalities in risk of decline, but it does not belong to the lower approximation.

Clearly any object is characterised by condition attributes and decision attributes: this is why the information system is generally called a decision table and is denoted by $\mathrm{S} = (\mathcal{U}, \mathcal{C}, \mathcal{D})$ where $\mathcal{C}$ and $\mathcal{D}$ are, respectively, the disjoint sets of condition and decision attributes, that is $\mathcal{C} \cup \mathcal{D} = \mathcal{A}$. In our study, economic, social, environmental and accessibility indicators are condition attributes, while the index related to corresponding sustainability status plays the role of decision attribute.

Note that the cardinality k of the set $\mathcal{A}$ of all the attributes is $k = n + m$, if there are n condition attributes and m decision attributes.

The decision rule induced by x in S results to be the sequence

$$\mathrm{c}_1(\mathrm{x}), \dots, \mathrm{c}_\mathrm{n}(\mathrm{x}), \mathrm{d}_1(\mathrm{x}) \dots, \mathrm{d}_\mathrm{m}(\mathrm{x}),$$

that is

$$\mathrm{c}_1(\mathrm{x}), \dots, \mathrm{c}_\mathrm{n}(\mathrm{x}) \Rightarrow \mathrm{d}_1(\mathrm{x}) \dots, \mathrm{d}_\mathrm{m}(\mathrm{x}) \quad \text{or in short} \quad \mathcal{C} \rightarrow_\mathrm{x} \mathcal{D}. \qquad \text{Eq. (3.4)}$$

Each decision rule can be measured in different ways.
The *strength* $\sigma_\mathrm{x}(\mathcal{C}, \mathcal{D})$ of the decision rule $\mathcal{C} \rightarrow_\mathrm{x} \mathcal{D}$ is represented by the ratio between the support of the decision rule and the cardinality of $\mathcal{U}$, that is

$$\sigma_\mathrm{x}(\mathcal{C}, \mathcal{D}) = \frac{|\mathcal{C}(\mathrm{x}) \cap \mathcal{D}(\mathrm{x})|}{|\mathcal{U}|} \qquad \text{Eq. (3.5)}$$

Analogously, it is possible to set the definition of *certainty factor* $\mathrm{cer}_\mathrm{x}(\mathcal{C}, \mathcal{D})$ as it follows

$$\mathrm{cer}_\mathrm{x}(\mathcal{C}, \mathcal{D}) = \frac{|\mathcal{C}(\mathrm{x}) \cap \mathcal{D}(\mathrm{x})|}{|\mathcal{C}(\mathrm{x})|} \qquad \text{Eq. (3.6)}$$

representing the conditional probability $\pi_\mathrm{x}(\mathcal{D}|\mathcal{C})$ that $\mathrm{y} \in \mathcal{D}(\mathrm{x})$ conditionally to the assumption that $\mathrm{y} \in \mathcal{C}(\mathrm{x})$.
Finally, the *coverage factor* $\mathrm{cov}_\mathrm{x}(\mathcal{C}, \mathcal{D})$ is defined as

$$\mathrm{cov}_\mathrm{x}(\mathcal{C}, \mathcal{D}) = \frac{|\mathcal{C}(\mathrm{x}) \cap \mathcal{D}(\mathrm{x})|}{|\mathcal{D}(\mathrm{x})|}, \qquad \text{Eq. (3.7)}$$

and it represents the conditional probability $\pi_\mathrm{x}(\mathcal{C}|\mathcal{D})$ that $\mathrm{y} \in \mathcal{C}(\mathrm{x})$ conditionally to the assumption that $\mathrm{y} \in \mathcal{D}(\mathrm{x})$.
In other words, it is possible to rewrite the two measures in the following equivalent ways

$$\mathrm{cer}_\mathrm{x}(\mathcal{C}, \mathcal{D}) = \pi_\mathrm{x}(\mathcal{D}|\mathcal{C}) \qquad \mathrm{cov}_\mathrm{x}(\mathcal{C}, \mathcal{D}) = \pi_\mathrm{x}(\mathcal{C}|\mathcal{D}). \qquad \text{Eq. (3.8)}$$

Simplicity is one of the characteristic features of decision rules induced by an information system in RST: following the goal of discovering patterns in data, it is interesting to consider just those attributes that are “sufficient” to characterise the knowledge in the database. More precisely, it is important to know if it is possible to consider subsets of attributes that are able to define the same equivalence classes as those proposed by the original information system. A *reduct* is a subset of attributes for which the category structure underlying the knowledge induced by a database is the same, and it is minimal, that is, no attribute can be removed from a set without changing the equivalence classes. More precisely, a reduct is a set $RED \subseteq B$, for which it is

$$[\mathrm{x}]_{RED} = [\mathrm{x}]_{\mathrm{B}} \quad \text{Eq. (3.9)}$$

and

$$[\mathrm{x}]_{RED-\{a\}} \neq [\mathrm{x}]_{\mathrm{B}} \quad \text{for each } a \in RED. \quad \text{Eq. (3.10)}$$

The different subsets of attributes can preserve the equivalence-class structure, that is, the knowledge expressed in the information system. Hence, an information system can admit different reducts. The attributes that belong to each reduct constitute the *core*. In other terms, the core represents the set of attributes that cannot be omitted in the information system without changing the equivalence-class structure. When it is empty, no attribute is indispensable, which is necessary in order to represent the category structure in the database.

The results of this research were obtained using ROSE2, modular software that implements basic elements of the RST including rule discovery techniques (Predki et al., 1998, 1999). All computations are based on fundamentals of the RST. ROSE2 interactive system consists of a graphical user interface (GUI) and a set of separate computational modules. The software in the form of a table called an "information table" accepts input data: rows are objects, i.e., observations, cases, etc., columns are attributes that are characteristics or features. Further, attributes are separated into disjoint sets of condition and decision attributes. The first are, for example, results of particular tests or experiments, whereas the second expresses the partition of objects into classes. To induce decision rules the software uses three different algorithms[8], namely the LEM2 algorithm (Grzymala-Busse, 1992), the MODLEM algorithm (Grzymala-Busse et al., 2001) and the algorithm called EXPLORE (Mienko et al., 1996).

LEM2 induces a set of certain and possible set of rules from the lower and the upper approximation: in general, it computes a local covering for each decision concept and then converts it into a rule set. Thus, LEM2 produces the minimum set of rules covering all the examples from the information system (Grzymala-Busse, 1992; Stefanowski, 1998).

The MODLEM algorithm does not require preliminary discretization of numerical attributes, and is able to handle both numerical and qualitative attributes during the rule induction process. In general, the search space for MODLEM is greater than for LEM2, therefore rules generated by MODLEM are simpler and stronger (Grzymala-Busse et al., 2001). EXPLORE algorithm, unlike the others, extracts all decision rules satisfying users' needs regarding strength, length of rules and discrimination level. Since it discovers all possible rules satisfying users' requirements, a much greater number of rules are generated with respect to the other two algorithms (Bal, 2013).

In this study, we used data collected on the website of the National Institute for Statistics (ISTAT, 2010, 2011) based on the census data referring to 2010 for agriculture and 2011 for population, industry and services. Regarding accessibility information, the sources are the Dolomiti Bus and Trenitalia websites. Six public upper secondary schools were analysed, including vocational education schools. The time, in minutes, is calculated for each municipality to the closest upper secondary school by available public transport (bus, train)[9].

[8] It is important to underline that this study is not intended to compare these three different discretization methods for rule induction.

[9] High schools are in Belluno, Feltre, Longarone, Agordo, Pieve di Cadore and Cortina d'Ampezzo.

The maps were obtained using the software ArcGIS. The values assumed by all the condition attributes give a meaningful graphical representation. This confirms the goodness in the (RST) methodology used which is able to characterise situations even with conflictual data.

4. Case Study

The province of Belluno, our case study, differs from any other Italian and European NUTS3 regions for several reasons. Firstly, the total surface is classified (OECD approach, based on population density) as predominantly rural, and at the same time, as completely mountainous. Then, Belluno shares land borders with two provinces and region with a legal special status. For the larger autonomous power neighbouring villages enjoy, social unrest especially in the populating living in municipalities located near the administrative border (political instability) is a great concern. In actual fact, individual municipalities within the province have promoted several referendums to join the provinces and/or border regions that, thanks to their autonomy, can offer citizens and businesses more favourable economic conditions. As a result, the population is expressing a profound uneasiness, which creates geopolitical instability.

The province is home of a great part of Dolomites chain (recognised as a UNESCO world heritage site), among the most attractive mountain landscapes in the world. The province includes a large part of a national park (Dolomites national park), several Nature 2000 sites, and vast ancient forests (such as the Cansiglio).

Last, but not least, the province is also home of the most important eyewear district in the world characterized by the production of luxury eyewear. The eyewear district is located in Agordino and has its origins in the 1960s from the crisis resulting from the closure of local mines, which in turn gave rise to a severe level of unemployment. At that time, the municipality of Agordo bought land from private and offered it to local entrepreneurs[10]. The province contributes 80 percent to the national production of eyewear. The legal sites of the four leading companies in the world market are located in Belluno province. The globalisation of markets and the competitiveness based on cost of production have given rise to an accentuated process of relocation in other countries for the more labour-intensive phases, reducing the labour demand.

Moreover, Belluno is the most widespread of all the provinces of the region measuring 3,678 square km, together with the lowest population of about 210,000 inhabitants. The total population of Belluno Province has undergone a continuous decrease during the last decades. Population loss was particularly high between the 1950s and the 1970s mainly due to the increasing emigration flows fuelled by scarce job opportunities. Currently, the decrease in residents seems to be the result of the declining birth rate, rather than the weaknesses of the labour market. The municipalities of Belluno Province are generally small villages. Around 60 communes have fewer than 5,000 inhabitants (ISTAT, 2011). The climate generally ranges from continental to alpine in the internal areas, whereas in the most southern pre-alpine valleys the vicinity with the Adriatic Sea creates some warmer influences. The capital town is Belluno (about 36,000 residents). 67 municipalities, the most important being Feltre, Cortina d'Ampezzo, and Longarone further compose the Province. There are nine Mountain Communities that bring together several municipalities with the purpose of a common management of resources. The economy of Belluno Province relies mainly on SMEs and on tourism, particularly in the winter season. Specialized agriculture and forestry activities have a great importance in maintaining the delicate balance of the mountain ecosystems, with, however, a decreasing trend.

[10] A recognised executive is Luxottica's leading entrepreneur who never hesitated, in times of economic growth, to provide bonuses and guarantees for its own employees. In the business world he is considered an enlightened entrepreneur.

The total agricultural land, including forests, has strongly decreased from 310,000 hectares in 1950 to 105,000hectares in 2010 as has the number and average size of farms (ISTAT, 2011). On the one hand, this is due to the general expansion of urbanization, infrastructure and industrial settlements, and on the other hand, to the abandonment of agriculture for negative climate conditions and for the inability to compete with lowland productions. Forest area has increased in the region with an average estimate of 300 hectares per year (ISTAT, 2011). Large portions of forest cover are currently included in networks of protected areas. Forests have an important role in land-use dynamics in Belluno province, covering a large portion of the territory and representing a crucial natural resource for landscape, biodiversity and recreation. Moreover, forests can provide timber for local activities. However, natural reforestation occupies areas previously farmed, contributing to an increase in the total forest area, while increasing environmental damages and risks. Grazing land and old pastures have showed the highest replacement degree.

4.1 Condition and decision attributes

The starting point of our approach is to define an information system table where the columns are labelled by attributes, called condition and decision attributes, and the rows by objects (which in our study represent the municipalities).

Condition attributes were selected on the base of the main characteristics of the analysed mountain area and, only partially, influenced by the availability of homogeneous and comparable information. The selection process has considered the environmental characteristics of a mountain area, which needs protection, and, at the same time, to be valued. That is why the choice (on environment indicators) fell on the question of waste and availability of green spaces (in our case forest areas). On the other hand, depopulation, resulting from poor economic opportunities and leisure facilities and difficult accessibility, is the crux of the matter: abandonment has a heavy negative impact on the environment. In this way, economic, social and accessibility indicators can also be traced, in a wide sense, to environmental indicators.

Even if, in the final phase and before data processing, a distinguished local expert validated the selection of the indicators, our research was preceded by active participation in conferences and working groups (supported by industrial and agricultural associations, non-governmental organizations, local public service representatives) dedicated to the development processes of the Belluno area.

Thus, 14 (condition attributes) variables were selected. More precisely, five indicators were used for the social aspects (population density, birth rate, accessibility to free time places, associations), two for environment (waste collection and available per capita forest area), four for economic activity (economic activity rate, tourism intensity, business activity index, unemployment rate), and finally three for accessibility (internet, schools, financial services). Large companies and research centres are absent, given that they are mostly concentrated in Belluno city.

The ranges for each attribute were determined with the help of a regional expert, taking into account the general features of the province of Belluno. At the end, the chosen attribute classes, generally, are the following: very low (VL), low (L), medium (M), medium-high (MH), high (H) and very high (VH) according to the different municipality situations compared to the province average (Table 1).

The condition attributes describing social aspects (Fig. 1) are as follows.

S1 **Population density:** following OECD methodology, the threshold of 150 inhabitants per square kilometre was adopted. However, considering that the average density of the province accounts for 58.61 inhabitants per square kilometre, the proposed classification refers to four classes.
S2 **Birth rate** (or nativity): this is an essential issue in rural areas, since many of these areas show a serious depopulation trend. In 2011, the average birth rate of the province is 7.2 (the national average birth rate is 9.2). In this case, three categories have been detected.
S3 and S4 **Cinemas and theatres within 20 km and Sport facilities within 20 km**: the possibility of accounting for entertainment is crucial in rural areas as the absence of such facilities can provoke serious social problems, such as migration of younger generations, alcoholism, depression, etc. In this case, three categories have been designated.
S5 **Associations**: they refer to social cooperatives, recognized foundations, unrecognized associations and other non-profit institutes related to sport, culture, civil protection, environmental protection, political activity, philanthropy and promotion of volunteering, etc. They represent the level of population cohesion as a background of common objectives, common ground and idea sharing. Three classes were defined.

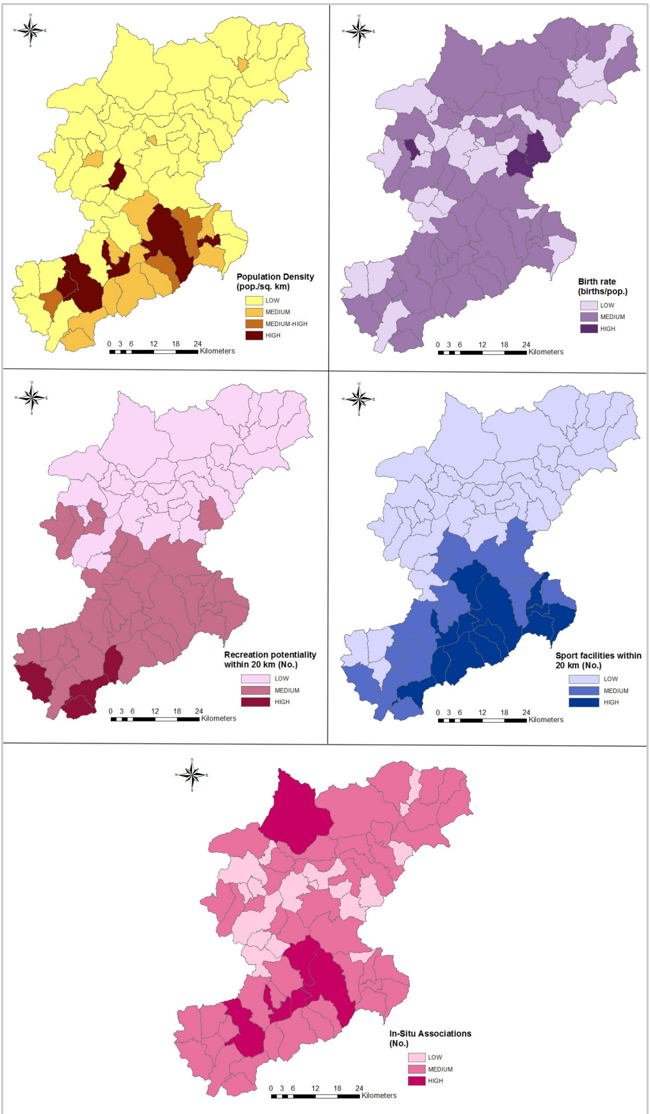

Fig. 1. Social aspects, Belluno province.

As far as the environment is concerned, two condition attributes (Fig. 2) were selected:

ENV1 **Waste collection and separation**: waste collection and separation are essential for the environment and for local leaders who seek to manage it in a more efficient and sustainable way. Three classes were selected considering that 70 percent of waste is collected separately in the province analysed.
ENV2 **Forest area extension**: forest area is the land under natural or planted stands of trees of at least 5 meters in situ, measured in ha per capita. The categorization of the forest area per inhabitants is a difficult task. Considering the average forest area per residents in Italy (0.172 ha/inhabitant), almost all Belluno's municipalities are strongly above the national average (2.02 ha/inhabitant). Starting from this premise, four classes have been utilised.

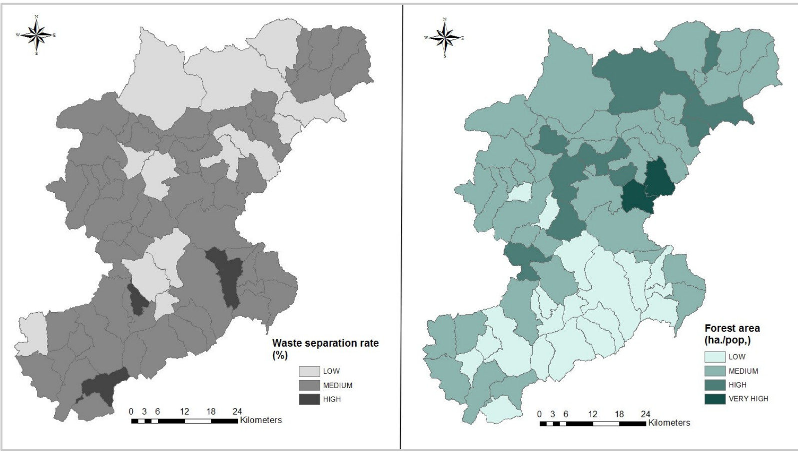

Fig. 2. Environmental aspects, Belluno province.

The condition attributes for the economic aspects (Fig. 3) are described below:

ECO1 **Economic activity rate**: as is well-known, the percentage of active persons (employed and unemployed) of the total population of working age is a meaningful economic indicator in rural development policies. Three different classes have been considered.
ECO2 **Tourism intensity**: it measures the number of visitors. Considering tourism flow in previous years, four classes have been created.
ECO3 **Business activities index:** this ratio, between the total number of active businesses or local units and the residents, represents how, and how much, SMEs are widespread in our case study. Three categories according to the number of active businesses per inhabitants can be used.
ECO4 **Unemployment rate:** in rural areas, job opportunities are often lower compared with urban areas, and the unemployment rate is a determinant index in describing local economic situations. With respect to the unemployment rate, three categories have been selected.

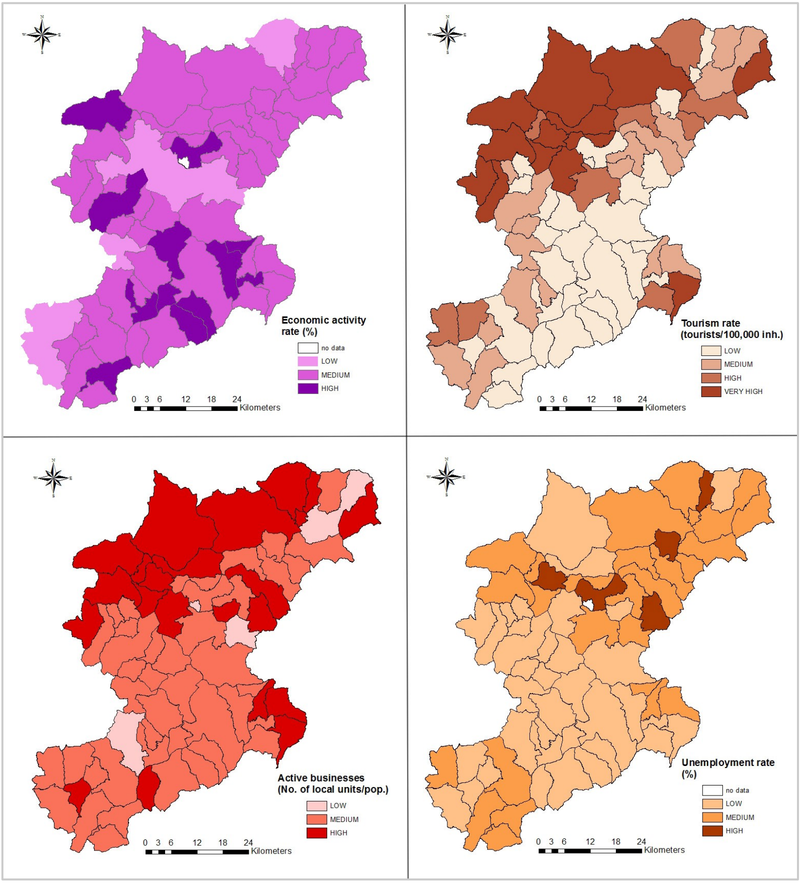

Fig. 3. Economics aspects, Belluno province.

Finally, accessibility (Fig. 4) is pictured by three condition attributes:

ACC1 **Internet access**: the identified index measures immaterial accessibility, and it is the result of the percentage of residents having broadband internet access at home. Four classes have been identified.

ACC2 **Accessibility to schools**: this indicator measures the material connection to public services, expressed by the time spent (minutes) to travel to the most accessible school by public transport. Four classes have been chosen.

ACC3 **Banks**: even if the number of financial institutions could be an economic indicator, in our case study the number of bank branches and cash machines available in each municipality is for us expression of accessibility to financial services. In this case, three classes have been detected.

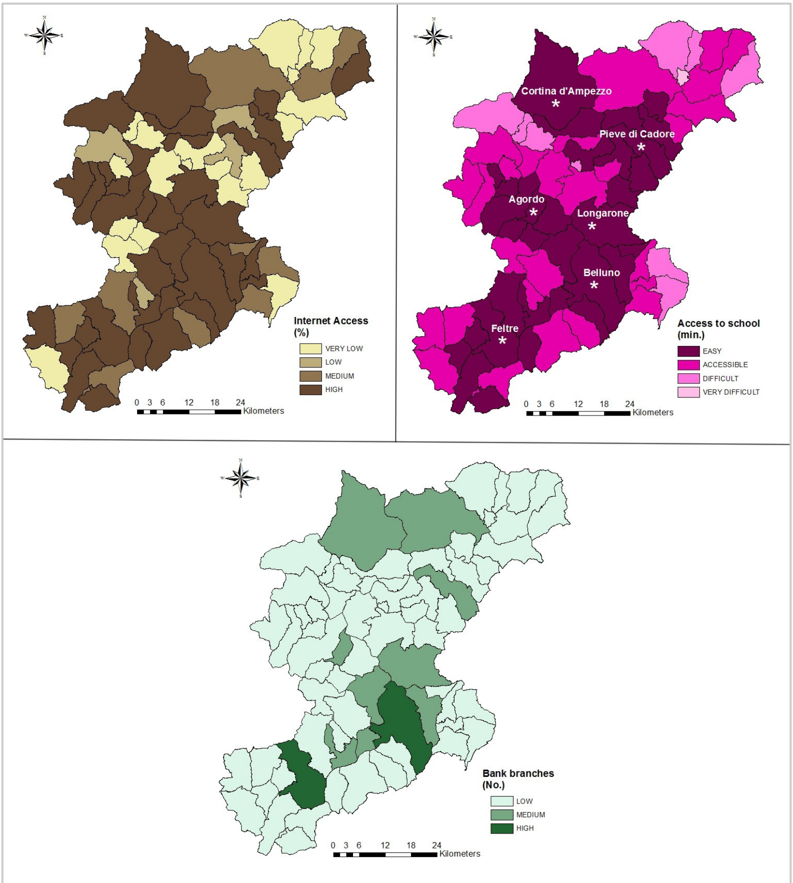

Fig. 4. Accessibility aspects, Belluno province.

At the end, the chosen attribute classes are summarised in Table 1:

Table 1 Condition attributes and classes.

	Very Low (VL)	***Low (L)***	***Medium (M)***	***Medium-High (MH)***	***High (H)***	***Very High (VH)***
S1		$S1 < 60$	$60 \leq S1 < 120$	$120 \leq S1 < 150$		$S1 \geq 150$
S2		$S2 < 6$	$6 \leq S2 < 12$		$S2 \geq 12$	
S=S3 or S=S4		$S < 6$	$6 \leq S < 15$		$S \geq 15$	
S5		$S5 < 10$	$10 \leq S5 < 50$		$S5 \geq 50$	
ENV1		$ENV1 < 60\%$	$60\% \leq ENV1 < 80\%$		$ENV1 \geq 80\%$	
ENV2		$ENV2 < 1$	$1 \leq ENV2 < 3$		$3 \leq ENV2 < 5$	$ENV2 \geq 5$
ECO1		$ECO1 < 50\%$	$50\% \leq ECO1 < 55\%$		$ECO1 \geq 55\%$	
ECO2		$ECO2 < 5\ 10^5$	$5\ 10^5 \leq ECO2 < 1.5\ 10^6$		$1.5\ 10^6 \leq ECO2 < 3\ 10^6$	$ECO2 \geq 3\ 10^6$
ECO3		$ECO3 < 0.05$	$0.05 \leq ECO3 < 0.10$		$ECO3 \geq 0.10$	
ECO4		$ECO4 < 5.5\%$	$5.5\% \leq ECO4 < 8.4\%$		$ECO4 \geq 8.4\%$	
ACC1	$ACC1 < 25\%$	$25\% \leq ACC1 < 50\%$	$50\% \leq ACC1 < 75\%$		$ACC1 \geq 75\%$	
ACC2	$ACC2 \geq 75$	$50 \leq ACC2 < 75$	$25 \leq ACC2 < 50$		$ACC2 < 25$	
ACC3		$ACC3 < 5$	$5 \leq ACC3 < 10$		$ACC3 \geq 10$	

Source: Authors' elaboration

According to RST, it is indispensable to define the decision attribute to complete the decision table. For this purpose, five different categories were identified considering different balanced, less balanced or not balanced sustainability status of a given municipality. There is no exact order among them, but it can be noted that the category “rural” is a desired, or a relative “best” status regarding sustainability for municipalities. Besides, we can also state that the category “in decline” is the least desired or the “worst”.

The assigned categories are the following:
City (C): Municipalities are characterised by higher population density, a good level of infrastructure of leisure for free time and higher job opportunities, compared with the province average. Further, the unemployment rate is below the average and the entertainment facilities are present and easily accessible. Nevertheless, from an environmental point of view (green area per capita), they are below the province average, so they are not well-balanced with respect to sustainability. Since municipalities belonging to this category are rather urban and need specific urban policies or tools for sustainable development.
Touristic municipality (T): They are normally characterized by lower population density but with high seasonal tourism intensity. A great pressure coming from tourism if not controlled can lead to a less balanced sustainability status.
Rural municipality (R): Municipalities that rely on the combined effect of economic, social and environmental activities with a broader concept of sustainability belong to this class. It does not imply that these municipalities are by far the best regarding a given attribute.
Municipality at risk of decline (RD): These are rural municipalities between “rural” and “declining” status. With declining municipalities, they generally share a low population density, low participation in the phenomena related to associations and fewer economic activities. In this situation, if specific instruments are ignored there is a high risk of falling into the last category.
Declining Municipality (D): These are municipalities with low population density, little economic activity and little accessibility. There is also an absence of possibilities of free time activities. These municipalities are also completely unbalanced regarding sustainability (namely for social and economic aspects).

4.2 Results and discussion

A crucial question in the context of data mining is whether there are attributes that are more important to represent knowledge in the equivalence classes than others. In the same way, it is important to know if a subset of attributes could (by itself) characterize the database (reduct). A reduct can be thought of as a sufficient set of attributes that represents the category structure. In our case, we have 81 reducts. The core, the collection of the most significant attributes, is given by the intersection of all reducts. This gives us all the necessary subsets of attributes for the category structure to be represented. In our case, the intersection of reducts is empty: this means that no single indicator is completely indispensable for the perfect approximation of the decision classes. It shows also how complex and difficult is the assessment of sustainability.

The most important element of our analysis is the rule generation: 19 decision rules were obtained through the algorithm LEM2 (basic minimal covering), 27 through MODLEM-entropy (extended minimal covering) and 83 through the algorithm EXPLORE (satisfactory description) with a minimum coverage factor level of 30 percent. In this section, some decision rules obtained from the analysis corresponding to the decision are presented. Not all the obtained rules will be introduced in the section, since the software extracted a total of 120 decision rules, and we selected only those resulting from each algorithm with the highest certainty value. As can be observed, some attributes included in our selection characterise only specific territorial subsystem. That is the case of S2 (birth rate) finds only in municipalities at risk of decline and ECO4 (unemployment rate) detected only in rural areas. By contrast, in our selection, Eco 1 never appears.

Table 2 Cities: Decision rules

CITY	S1	S5	ECO3	ACC3	Certainty
LEM2 MODLEM EXPLORE				H	100
EXPLORE	H	H	M		100

In the case of urban areas (represented by only two cities in the province) algorithms (LEM2, MODLEM and EXPLORE) show that decision rule is the presence of financial institutions (high). EXPLORE instead detects the density of the population (high), the number of associations (high) and business activity (medium), and the environmental attributes are absent (Table 2).

Table 3 Touristic municipalities: Decision rules

TOURISTIC	S3	ECO2	ECO3	Certainty
LEM2 MODLEM EXPLORE		VH	H	57.89
EXPLORE	L	VH		52.63

In the field of tourist areas, algorithms LEM2, MODLEM and EXPLORE show the tourism intensity (very high) combined with business activity (high) as decision rule. These two attributes explain 58 percent of the tourist municipalities. EXPLORE detected in 53 percent of cases, as a decision rule, the low presence of cinemas and theaters within 20 km, combined with the very high tourism rate. In addition, in this case, the environmental and accessibility attributes are absent (Table 3).

Rural municipalities[11] have been disaggregated into three categories: municipalities in decline, municipalities at risk of decline and rural municipalities, according to the level of attributes.

In rural municipalities in decline, algorithms LEM2 and EXPLORE highlight the role of the low density of population, the low number of associations, the medium waste collection (and a very low accessibility to the Internet). In this decision rule falls more than 55 percent of municipalities. EXPLORE confirms the role of Internet access (very low) combined with business activities (medium), with the previous same level of certainty. MODLEM focuses on population density (low), tourism intensity (low), and internet access (very low). The three attributes explain 33 percent of the municipalities defined *a priori* as decline. Independently from the chosen algorithms, all decision rules share low internet access, highlighting the role of this attribute in defining declining municipalities.

Municipalities at risk of decline, characterized by several condition attributes suggesting a more complex and articulated territorial subsystem, have attributes that generally lie at an average level. Common attributes, whatever the algorithm chosen, are those explaining environmental conditions: waste collection and forest extension area, generally absent in the previous categories. LEM2 with birth rate, waste collection, forest extension area and business activity rate collects more than 62 percent of the municipalities. With the same percentage are represented the municipalities in EXPLORE algorithm, which adds to the previous attributes the high internet access. A second decision rule originated by EXPLORE

[11] All the municipalities excluding cities and tourist centers.

emphasizes the low incidence of waste collection, the low forest area extension and, for the first time, the medium level of structures devoted to cultural free time activities. (Table 4)

Table 4 Decline, at risk of decline, rural municipalities: Decision rules

Algorithm	S1	S2	S4	S5	Env1	Env2	ECO2	ECO3	ECO4	ACC1	ACC2	ACC3	Certainty
Decline													
LEM2 EXPLORE	L			L	M					VL			55.56
EXPLORE								M		VL			55.56
MODLEM	L						L			VL			33.33
Risk Decline													
LEM2		M			M	M		M					62.50
EXPLORE													
Explore 1		M			M	M		M		H			62.50
Explore 2			M		L	L							52.63
MODLEM		M			M	M	M				H		37.50
Rural													
LEM2				M			L		L			L	47.37
MODLEM	M			M			L						31.58
EXPLORE													
Explore 1				M		L	L						52.63
Explore 2				M			L		L			L	47.37

Finally, municipalities classified as rural underline the importance of the number of associations (medium) and of the tourism intensity (low). These attributes are included in all decision rules obtained through the different algorithms. The decision rule that represents the largest number of cases is defined by EXPLORE, which explains more than 50 percent of cases and attributes are associations (medium), forest extension area (low) and tourism intensity (low). The rural municipalities at risk of decline still appear more diversified subsystems including attributes belonging to the different sustainability aspects (social, economic, environmental and accessibility).

5. Concluding remarks

As is well-known, rural areas are complex territorial systems, and it is extremely difficult to evaluate their sustainability. In our research, RST was applied in order to assess the different levels of sustainability in a specific rural and mountain area. The first result of the RST application was the evidence of this complexity. The town and tourist centres are easy to describe: few attributes are sufficient and the rules identified prove to be unambiguous. In contrast, our analysis confirms the great heterogeneity of places identified as rural. Fourteen indicators, defined as conditioning attributes and a decision attribute characterized by different sustainability statuses, allowed us to highlight different territorial subsystems.

A family of generated decision rules is the final result of this study. Decision rules may be suitable for arranging rural municipalities into sustainability classes and, thereby, identifying the current situation of a specific territory, indispensable for the preparation of territorial development programmes. Decision rules are appropriate tools to reveal the simultaneous presence of certain characteristics, which lead to a different sustainability status. In addition, they are able to uncover factors causing disadvantage or risk, and at the same time, to disclose several important features aiming at reaching the desired level of sustainability in a given rural area.

Decision rules may moreover provide private and public leaders with information about possible development strategies and policies that may improve the sustainability of their territories. Even though they can suggest developmental proposals, which cannot be improved in the short run (such as to fight negative demographic trends), local decision makers may benefit from the results of the analysis in the medium to long run. Other dynamics affecting the territory need to be considered by local leaders as external/upper-level policies or global economic and social trends that may deeply modify the analysed framework.

We additionally demonstrate that the RST has several properties and a high potential in this context of study. One of the most important characteristics of RST is traceability. It means that for each decision rule we can say exactly which municipality supports it. The other important property of the theory is that it is based on ordinal properties. Finally, another relevant characteristic of this approach is that no weights are needed for the analysis compared with other techniques. We can conclude that RST is a suitable methodology for territorial analysis of rural sustainability. However, the results depend substantially on the indicators used in the analysis, and therefore, selected indicators should be reconsidered and improved in their information typology. Another possible development includes the application of the DRSA (Dominance Based Rough Set Approach), which is a recent extension of the RST for multi-criteria decision analysis, dealing with preference ordered decision classes.

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