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Multivariate assessment of metropolitan sustainability with a focus on demand and supply food aspects: Insights into the metropolitan city of Venice☆

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ABSTRACT

According to the United Nations "World Urbanization Prospects 2018", more than half of the population lives in metropolises and estimates that in 2050 almost 70 % of the world's population will live in urban areas. The unstoppable growth, the complexity, and the challenges in promoting the sustainable growth of metropolitan areas have thus attracted increasing attention from researchers and policy makers in recent years. At the EU level, the relationship between metropolitan cities and food has also become a focus. Despite often being neglected, food has a significant impact on the sustainability of metropolitan cities development. Thus, the aim of this work is to assess the sustainability of metropolitan areas, with a specific focus on the metropolitan city of Venice (Italy), using socio-demographic, economic, and environmental indicators/attributes, as well as local food demand and supply proxies. To achieve this objective a multi-step procedure based on Rough Set Theory and Dominance-Based Rough Set has been implemented. The results show that food attributes seem not to play a major role in shaping the metropolitan area's sustainability. However, when demand and supply food aspects are considered as a decision attribute, their connections with other sustainability indicators become apparent, particularly population density and tourism intensity in the socio-demographic pillar, and land consumption in the environmental one.

1. Introduction

According to the United Nations "World Urbanization Prospects 2018", more than half of the population lives in metropolises and estimates that in 2050 almost 70 % of the world's population will live in urban areas(UN, 2018).

The unstoppable growth, the complexity, and the challenges in promoting the sustainable growth of metropolitan areas have thus attracted increasing attention from researchers and policy makers in recent years. Metropolitan areas are complex and extremely diverse territories that include both urban and rural areas. A commonly accepted definition is that a metropolitan area is a region with a densely populated centre and its surrounding territories share industries, commercial areas, transport network and housing (Moreno-Monroy et al., 2021). In the European Union (EU), in line with the OECD (2012) proposal, Functional Urban Areas (FUAs)[2] are metropolitan areas when they have more than 500,000 inhabitants. Metropolitan areas, metropolitan cities and metropolitan regions are, generally, used interchangeably and so will we.

The metropolitan city is a territorial local authority established in the Italian Constitution[3] (Constitutional law, 2001) and governed by the law n. 56 of 7 April 2014. Italian metropolitan cities are territorial entities of

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[1] Authors, listed in alphabetical order, equally contributed.
[2] Functional Urban Areas are defined as urban area composed of densely inhabited urban core(s) and hinterland.
[3] Municipalities (NUTS5), Provinces (NUTS3), Metropolitan Cities (NUTS3), and Regions (NUTS2) compose Italy.

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a large area. They have the following general institutional purposes: care of the strategic development of the metropolitan territory; promotion and integrated management of services, infrastructure, and communication networks of interest to the metropolitan city; care of institutional relations pertaining to its own level, including those with European cities and metropolitan areas (Law 56/2014). The complexity and interrelation of the social, economic, and environmental metropolitan context make achieving more sustainable, climate resilient, and inclusive agglomerates a daunting, but not impossible, task (Baabou et al., 2017; Boggia and Cortina, 2010; Purvis et al., 2019).

Among the many factors that can influence the sustainability of such complex areas, but so far to a large extent less studied, we find food related aspects. To start exploring this shortfall and to foster a sustainable growth path of metropolitan areas, the Food and Agriculture Organization (FAO), in collaboration with the Resource Centres on Urban Agriculture and Food Security (RUAF) Foundation, has developed the bottom-up concept of City Region Food System (CRFS) (FAO, 2015). The sustainable and resilient CRFSs are envisioned to make affordable, nutritious, and fairly traded foods from local and regional producers more easily available to all the city region consumers from rich to poor, from rural to urban. The two basic blocks of the CRFS are the "City Region" and the "Food System" (Blay-Palmer et al., 2018; Blay-Palmer et al., 2021; Jennings et al., 2015; Van der Gaast et al., 2020). Of particular interest is the definition of City region, which is "a larger urban centre or conglomeration of smaller urban centres and the surrounding and interspersed peri-urban and rural hinterland" (FAO, 2015).

In our work, we identify the metropolitan city of Venice as the city region and we select five indicators of the local food demand and supply as a proxy for the food system. A number of studies have focused their attention on Venice, its lagoon and surroundings (Bertocchi and Visentin, 2019; D'Alpaos and D'Alpaos, 2021; Kılkış, 2019).

The aim of this paper is to assess the sustainability of the metropolitan city of Venice, which is both fragile and home to a priceless natural and cultural heritage threatened by climate change and by a strong tourist pressure.

With our pivotal approach, focused on a broad set of aspects (including food), we propose a wider sustainable perspective of the metropolitan city of Venice having in mind the three pillars of sustainability. Our methodology involves describing territorial reality into three distinct macro categories that represent the pillars of sustainability (social, economic and environmental).

Our final purpose is to identify and suggest opportune policies/tools to the decision makers. To success in this, complex methodologies capable of describing this territory in its multiple distinctive elements are needed.

Thus, the multi-criteria techniques seem the opportune tools to approach and conduct the sustainability assessment of the areas of interest. A growing body of literature has been developed on the subject and many different techniques have been proposed, such as the Analytic Hierarchy Process (AHP) (Carli et al., 2018), the Rough Set Theory (Demartini et al., 2015), the Dominance-based Rough Set Approach (Boggia et al., 2014; Zolin et al., 2020) or the hierarchical SMAA-Promethee method (Corrente et al., 2021). Among them the Rough Set Theory (RST) (Pawlak, 1982) and its evolution, the Dominance-based Rough Set Approach (DRSA) (Greco et al., 1999, 2005) seem to be the most convenient due to their ability to discover hidden patterns in data and their easy-to-read outputs. In this paper we implement a multi-step procedure based on RST and DRSA. The data used are the most recent available at the time of drafting the paper.

The article is organized as follows. Section 2 provides insight on methods and data used, Section 3 presents the case study of the Metropolitan city of Venice, and Section 4 focuses on the results, with an analysis of the decision rules. The last section is devoted to conclusion, further discussion, and possible future developments.

2. Data and methods

2.1. Data

To describe the sustainability of municipalities, we have taken into account eighteen indicators/attributes of which seven are socio-demographic indicators, five are economic indicators related to agriculture and food, and six are environmental indicators (in Table 1 the description and in Appendix A the values).

The first three attributes (S1-S3) of the socio-demographic pillar concern the demographic situation of each municipality of the Metropolitan city of Venice. The attributes S4, S5 and S7 are meant to represent the social aspects (Carli et al., 2018; Corrente et al., 2021; Zolin et al., 2020). The remaining S6 indicator takes into account the pressure of tourists on residents (Tokarchuk et al., 2016). Relevant to the analysis was the inclusion of attributes within the economic dimension related to agriculture and food (ECO1-ECO5). While among the environmental factors both risk factors, such as CO2 emission, wasted water, land consumption and hydrogeological hazard, and potential benefits for the environment (organic UAA and waste separation) were taken into consideration (Carli et al., 2018; Corrente et al., 2021; Ferretti et al., 2020; Hajduk, 2021; Rocha Paz et al., 2021).

2.2. Methods

In order to aid in the planning of sustainability-related policy decisions and to define an integrated approach for assessment and monitoring, authors (such as Boggia et al., 2014; Paolotti et al., 2019) have proposed multicriteria decision analyses for sustainability assessments. Effective modelling must be dynamic and suitable for use as a tool for periodic evaluation in order to support decision makers. This requires producing informative and simple-to-understand outcomes as well as transparent evaluation paths based on updatable indicators. Due to these factors, multicriteria decision analysis techniques combined with group decision making have received a lot of interest in recent years. We set our analysis using the Rough Set Theory (RST), a mathematical technique for analysing imprecise and ambiguous descriptions of objects (activities), this way we can thoroughly examine the data, assess the information content of the under-consideration attributes, and develop decision-making rules that can assist in the evaluation process.

The indiscernibility relations and the equivalence of classes are the two key ideas that underpin Pawlak's theory (1982).

Based on the information that is currently accessible, the theory postulates that all objects in a nonempty universe ($\mathscr{U}$) have some characteristics, and that objects with the same characteristics are indistinguishable (similar). An information system $IS = (\mathscr{U}, \mathscr{A})$ can be represented as a matrix, where the rows are objects in $\mathscr{U}$ and the columns are attributes in $\mathscr{A}$ with the appropriate entry values (attribute values). The identification of a decision attribute among the information system's attributes is necessary to conduct the analysis. As a result, the conditional attributes and the decision attributes are split into two separate categories inside the attribute set $\mathscr{A}$. Rules are determined from the decision table in the form

conditions → decisions.

Our subdivision of the target area into territorial classes originates from the official classification adopted by the Rural Development Plan (RDP) of the Veneto Region (2014). The RDP splits the municipalities of the metropolitan city of Venice into 3 categories, urban centre (A); rural areas with intensive agriculture–urbanized rural (B1); rural areas with intensive agriculture–urbanized (B2). The distinction between municipalities in B1 and B2 is a population density threshold set at 400 inhabitants/Km^2, above which the area is classified as B2.

Taking into account the number of tourist presences, our municipalities can also be clustered based on their tourism intensity, which is

Table 1
Indicators (as attributes), meanings and source*.

	Acronym	Dimension/Indicator	Description and reference unit	Source
	S	**Socio-Demographic**		
+	**S1**	**Population density**	Number of inhabitants in a square kilometre (Inhabitants/Km^2)	ISTAT, 2018
-	**S2**	**Aging Index**	Residents aged 65+ over people aged 0–14 (%)	ISTAT, 2018
-	**S3**	**Dependency ratio**	Residents aged over 65 and under 15 over population aged 15–64 (%)	ISTAT, 2018
+	**S4**	**Education**	25–64 residents with tertiary education (ISCED 5 to ISCED 8) (%)	ISTAT, (2019)
+	**S5**	**Cultural institutions**	Number of museums or cultural institutions (Units)	ISTAT, 2018
+	**S6**	**Tourism intensity**	Ratio of tourists' presences over the total resident population of the area	ISTAT, (2019)
+	**S7**	**Active Population Rate**	Population employed or seeking employment over population 15+ (%)	ISTAT, (2019)
	ECO	**Economic (Agriculture and food)**		
+	**ECO1**	**Resident food expenditure**	Total food expenditure by residents in a year (Euro)	Authors Elaboration**
+	**ECO2**	**Tourist food expenditure**	Total food expenditure by tourists in a year (Euro)	Authors Elaboration ***
+	**ECO3**	**Fishing Firms**	Number of firms either involved in fishing or in the retail selling of fish (Number)	CIAA VE RO, (2022)
+	**ECO4**	**Agritourism**	Numbers of agritourism (all kind of agritourism such as restaurants, sleeping, …) (Number)	ISTAT, 2018
+	**ECO5**	**Agri working days**	Number of working days employed in agriculture (Number)	ISTAT, (2011)
	ENV	**Environment**		
-	**ENV1**	**Land consumption**	Portion of natural, semi natural or agricultural land converted to infrastructure, building or industrial sites (%)	ISPRA, (2018)
-	**ENV2**	**Hydrogeological risk**	Area in square kilometres in which there is a medium hydrogeological risk (%)	ISTAT, 2018
+	**ENV3**	**Waste Separation**	Differentiated waste collection (%)	ARPAV, (2018)
-	**ENV4**	**Wasted Water**	Potable water wasted (%)	ISTAT, 2018
-	**ENV5**	**CO2 emissions**	Total CO2 emissions in the year (1000 tons)	ARPAV, (2018)
+	**ENV6**	**Organic Area**	Land used for organic farming with respect to the total municipality area (%)	Authors Elaboration ****

* in the first column, "+" means that higher values are better, whereas "-" means that higher values are worse

** ECO1=yearly mean income*0.1575*residents: income of each municipality is based on personal income tax data (IRPEF) from the Ministry of Economy and Finance; 15.75 %: ISTAT estimation on how much is spent on food and beverages (excluding alcohol) by a resident in the Veneto region; MEF, 2018 and ISTAT, 2018

*** ECO2=presences*30: 30 as a result of the daily amount spent by a tourist (in average 130 euros) and the percentage of it devoted to food and beverage expenses (23 %) according to Veneto Region 2018; ISTAT, 2018

**** ISTAT, (2011)

an expression of the pressure exerted by tourism demand on the resident population in a given area (e Silvia et al., 2018). In particular, our municipalities can be grouped as follows: municipalities with tourism intensity values from 0 to 6 (i.e. with a ratio of the number of annual presences to the resident population between 0 and 6) are considered Non-Touristic (NT), while municipalities with values above 20 (i.e. with a ratio of the number of annual presences to the resident population over 20) are considered Touristic (T). It should be noted that no municipality has values between 6 and 20. The municipalities were therefore classified into 4 areas:

- A-T: Urban and tourist intensive
- B1-T: Rural with intensive agriculture – urbanized rural and tourist intensive
- B1-NT: Rural with intensive agriculture – urbanized rural and not tourist intensive
- B2-NT Rural with intensive agriculture – urbanized and not tourist intensive.

These four classes are not ordered, i.e., municipalities in one class are not considered better than the municipalities of another class. For this reason, no inconsistency could be generated by violations of the dominance principle (Greco et al., 2001, 2002).

In order to examine the relationship between the metropolitan city and food, we propose a new information system, $IS = (\mathscr{U}, \mathscr{A})$, in which the agri-food sector, represented by the ECO_i attributes, is described by a composite index that serves as decision attribute.

Let $\overline{ECO}_i$ be the normalized attributes so computed:

$$\overline{ECO}_i = \frac{ECO_i - \min_i}{\max_i - \min_i}$$

where $\min_i = \min_k\{f(x_k, ECO_i)\}$ and $\max_i = \max_k\{f(x_k, ECO_i)\}$ are the minimum and maximum values assumed by each condition attribute ECO_i.

Let n and m be the total number of agriculture and food attributes related to demand and to supply aspects. The *Food Attribute* (FA) is defined as follows

$$FA = \frac{1}{2n}\left(\sum_{i=1}^{n}\overline{ECO}_i\right) + \frac{1}{2m}\left(\sum_{j=1}^{m}\overline{ECO}_j\right)$$

In our case study, ECO_1 and ECO_2 refer to demand side, while ECO_3, ECO_4 and ECO_5 to supply, so the *Food Attribute* is

$$FA = \frac{1}{2}\left(\frac{1}{2}\overline{ECO}_1 + \frac{1}{2}\overline{ECO}_2\right) + \frac{1}{2}\left(\frac{1}{3}\overline{ECO}_3 + \frac{1}{3}\overline{ECO}_4 + \frac{1}{3}\overline{ECO}_5\right).$$

In the updated information system $IS = (\mathscr{U}, \mathscr{A})$, the new condition criterion is represented by FA, so that the domain V_{FA} is completely preordered by the new outranking relation $\succsim_{FA}$ with the following meaning: $x \succsim_{FA} y$ when municipality x is at least as good as municipality y with respect to criterion FA.

If in RST, objects characterized by the same information were considered as indiscernible, the appealing idea of a partitioned universe $\mathscr{U}$ is not sufficient when objects are described by attributes with domains that are preference orders: in fact, violations of the dominance principle could generate inconsistencies. For this reason, it is necessary to refer to DRSA, so that we can consider each municipality assigned to one class Cl_t ($t \in \mathbb{N}$) such that the classes are preference-ordered and upward and downward unions of classes can be related to each Cl_t.

For each condition criterion in $P \subseteq \mathscr{C}$, in fact, it is possible to define a partial preordering D_P so that each municipality is related to two sets: the *P*-dominating set and the *P*-dominated set, representing the basis of knowledge approximated by the upward and downward unions of decision classes.

A decision rule in the form of if… then… manifestly expresses the characteristic information and the related decision class with the intention of identifying potential links, similarities, and differences between the characteristics of the information (conditions) and the adopted decision: decision rule, in DRSA, can be formalised as $D_{\leq}$–decision rule, $D_{\geq}$–decision rules, or $D_{\geq\leq}$–decision rule.

This way, the method we propose combining RST and DRSA consists of nine steps of which six pertain to RST, one step (the seventh) defines and computes the Food Attribute, and the last two steps refer to DRSA. It can be summarized as follows:

1. Definition of the information system $IS = (\mathscr{U}, \mathscr{A})$, where $\mathscr{U}$ is the (Universe) set of all considered municipalities and $\mathscr{A} = \cup_{i=1}^{3} A_i$ is the set of all gathered information, more precisely it is: $A_1 = \cup_{i=1}^{7} S_i$, $A_2 = \cup_{i=1}^{5} ECO_i$ and $A_3 = \bigcup_{i=1}^{6} ENV_i$.
2. Definition of the disjoint sets of the condition and decision attributes $\mathscr{C}$ and $\mathscr{D}$, respectively, so that the set of all information $\mathscr{A}$ is partitioned: $\mathscr{A} = \mathscr{C} \cup \mathscr{D}$. An information can be considered as a condition attribute (i.e. an attribute characterising the sample) or as a decision attribute (i.e. information marking the category of sample).
3. Definition of the coefficient matrix with reference to the partition of $\mathscr{A}$ under consideration: $f(x_i, a_j) \in V_{a_j}$ denotes the value assumed by *i*-municipality ($i = 1, \ldots, 44$) with reference to *j*-information ($j = 1, \ldots, 18$). The set V_{a_j} is called domain set and contains all the values assumed by each attribute a_j.
4. Partitioning of each municipality under the Rural Development Plan (RDP) classification. In addition, further subgroup the municipalities based on the value tourist intensity.
5. Extraction of RST decision rules with decision attribute the Rural Development Plan (RDP) classification: in the form of if … then … sentences, the conditions that characterise the rule and the resulting decision class assignment can be explicitly displayed.
6. Sensitivity analysis: by explicitly representing the dependence between condition and decision criteria (conditions → decision), search for any characteristics (by presence or absence of information relating to the pillars) in order to update the information system.
7. Introduction of the Food Attribute, *FA*, to understand the relationships of the economic indicators related to food with other sustainability attributes.
8. Updating of the information system $IS = (\mathscr{U}, \mathscr{A})$ and of $\mathscr{A} = \mathscr{C} \cup \mathscr{D}$ into new condition $\mathscr{C}$ and decision $\mathscr{D}$ attributes.
9. Extraction of new DRSA decision rules with decision attribute *FA*, due to the presence in data of inconsistencies generated by violations of the Dominance Principle (Greco et al., 2001, 2002).

3. Case study

In Italy, there are 15 metropolitan cities (NUTS 3 classification), ten of them, located in ordinary regions, are defined by a national law and they are: Turin, Milan, Venice, Genoa, Bologna, Florence, Bari, Naples, Reggio Calabria, plus the metropolitan city of Rome, the capital.

To the autonomous regions/provinces, with a higher autonomy, is reserved the right to individuate in their territory metropolitan cities and they are Cagliari, Catania, Messina, Palermo e Sassari.

The Metropolitan City of Venice is the subject of this case study, located in the Veneto region of northeast Italy. It covers an area of 2472 km2 and includes 44 municipalities. It is a flat area, interspersed with rivers and canals, bathed by the Adriatic Sea, with Venice as its capital.

The province as a whole is a popular tourist destination, renowned not just for the city of Venice but also for its numerous high-end seaside resorts that enjoy international recognition.

The population living in the administrative perimeter shrunk down from around 863,000 in 2010–843,545 in 2021, which sum up to a population density of 341 inhabitants/Km^2 (ISTAT, 2021). The demographic structure has seen an increase in the median age in the last decade, increasing from 44.5 in 2008 and reaching 47.3 in 2021; following a similar trend to the regional and national dynamics, but with a higher value if compared to the regional and national median age of 46.1 and 45.9 years (ISTAT, 2021). Similar negative trend has been followed both by the aging index, which rose from 165 to above 200, and by the dependency ratio from 51.9 % to 59 % (ISTAT, 2021).

The metropolitan city of Venice in term of aging index has been performing similarly to the national trend but its starting point was higher, while the dependency ratio had similar starting point in 2008 but saw a more marked negative trajectory if compared to the national level, which increased from 52.1 % to 57.3 %.

According to the 2010 agricultural census, the agricultural sector in the metropolitan city of Venice is characterized by a number (almost 75 %) of small farms with a utilized agricultural area (UAA) in average lower than 5 ha, which, however, account for less than 20 % of the total UAA (ISTAT, 2011). Furthermore, other types of agriculture such as family gardens are numerically important, more than 6000 in the metropolitan area of the city, however and as expected, with a very low percentage of UAA occupied by them (ISTAT, 2011). In terms of land use, 90 % of the UAA is arable land.

In the Veneto region, a higher percentage (33 %) of the workforce is still employed in the industrial sector (against the Italian average of 20 %). Furthermore, most of the regional enterprises are small or medium-sized (SMEs), representing 99 % of enterprises in 2019 and, in the same year, these enterprises employ almost 65 % of the regional workforce (ISTAT, 2021). Similar trends emerge in the metropolitan city of Venice where, however, the service sector employs 70 % of the workforce due to existence of a strong touristic sector, while industry workers count for the 28 %. Others important economic catalysts of the metropolitan area are represented by the heavy industry in Porto Marghera and the commercial harbour of Venice which employee more than 20 thousand workers and contribute to generate the 13 % of added value of the metropolitan city (Port of Venice, 2022). Ultimately, small companies in the industrial sector and in the agricultural sector coexist. Moreover, farms are smaller in the area where small industrial enterprises are more widespread.

As remembered, among the service sector, particular relevance is covered by the touristic related activities. The metropolitan city is home of the UNESCO (1987) world heritage site named “Venice and its Lagoon”, which comprise all the islands of Venice and its lagoon, and it is mostly comprised in the territory of the municipality of Venice. This site is significant both from an artistic and architectural perspective, owing to its numerous historical buildings and art pieces, as well as from an environmental standpoint, as it provides a habitat for various species of flora and fauna.

This cultural and historical heritage has transformed the

Table 2
Metropolitan city of Venice (2017).

Area	N. of municipalities	Surface (Km^2)	Population	Population Density	Surface/ population*1000	Tourists (Presences)/1000	Tourist Intensity	Land Consumption*
A-T	1	416	261,138	628	1.59	11,685.82	44.75	17.2
B1-T	8	739	139,523	189	5.30	24,500.66	175.60	13.7
B1-NT	17	892	162,319	182	5.50	317.40	1.96	11.5
B2-NT	18	425	288,373	678	1.48	531.75	1.84	27.3
Total	**44**	**2473**	**851,353**	**419**	**3.47**	**37,035.63**	**56.00**	**17.4**

Source: Authors elaboration on ISTAT, 2018.
* ISPRA, (2018)

metropolitan city in an attraction pole for tourists, and the metropolitan city of Venice has become a destination of an increasing mass tourism reaching, in the pre-pandemic period, almost 40 million presences and 10 million arrivals in 2019 (ISTAT, 2021). The number of tourists visiting the metropolitan city of Venice accounted for half of the tourists of the whole Veneto region and half of them visited the municipality of Venice, (ISTAT, 2021). A further breakdown of the complexity of touristic flows can be caught from Table 2, which data refer to 2017. The municipality of Venice has a high number of presences (11.5 million), with a value of tourist intensity[4] of 44.75, while the other touristic area (B1-T) has 24.5 million presences with a value of tourist intensity of 175.60. The municipalities classified in the B1-T area are seaside municipalities that live off seasonal tourists characterized by a longer period of stay (5 days on average). On the other hand, the presence of the municipality of Venice (A-T) is scattered throughout the year, and tourists visit the city for its priceless cultural heritage, resulting in shorter lengths of stay. However, these data do not account for day tourists, who visit the metropolitan city without staying overnight for at least one night.

All these factors have had a great impact and challenged the sustainability of the metropolitan city in all its aspects. From a socio-demographic perspective, out of all the area of the metropolitan city the islands of Venice (where the historic buildings are located) are the one that suffered the most. The increase in tourists have reduced the availability of affordable flats, and brought less services for residents; as consequence the population has been steadily declining reaching, in the historical centre, less than 50,000 residents in 2022 (ISTAT, 2022). Sustainability as a whole has been challenged by the varying patterns of tourist flows, which increased the complexity and viability for decision makers to implement the right policy instruments. Furthermore, the touristic pressure pushed the economy to specialize in tourist related activities, which were those most hit by the international travel restrictions put in place to face the COVID-19 pandemic.

The whole metropolitan city of Venice is a delicate and fragile ecosystem which in the past has already been endangered and polluted by the development of a heavy industry pole (Porto Marghera), and among others especially the petrol industry played a crucial role. In addition to the industrial pollution, the touristic pressure has increased the fragility of the ecosystem. This affects negatively also the level of waste separation, and thus the potential of using recycled material and increasing environmental pollution, which is clearly seen in data as all the municipalities with higher number of tourists have a lower percentage of waste separation (ARPAV, 2018). These environmental pressures add to the pressure already exerted by the resident population.

Focusing on the subdivision of the metropolitan city of Venice, namely the areas A-T, B1-T, B1-NT, and B2-NT, it can be seen how some important differences arise. It is useful to remember that the areas A-T and B2-NT are classified as urbanized while the areas B1-T and B1-NT are more rural. As reported in Table 2, the majority of the metropolitan city surface falls in the rural category. In A-T and B2-NT areas the density of population has a value above 600 while in B1 areas (touristic e non-touristic) the value is below 200. The space available in rural setting (B1) is much bigger with a value of more than 5 Km^2 for a thousand residents; while in the remaining areas the space available is on average 1.5 Km^2 for thousand people. The huge share of population in residing in urbanised area is also reflected in the average land consumption, which reaches 27 % of the total area in B2-NT, followed by the 17 % of the municipality of Venice while other areas have lower values.

4. Results

According to Section 2, this section presents the obtained results from the Rough Set Theory (steps 1–6 of the procedure presented in

[4] Tourist Intensity = Presences / Population

Table 3
Number of conditional attributes per pillar and area present in decision rules.

Area	S							ECO					ENV						N. of rules
	1	2	3	4	5	6	7	1	2	3	4	5	1	2	3	4	5	6	
A-T	2				4								2						4
B1-T	4					2			2				2	2					6
B1-NT	7	1	1		1	2		1	1	1	1		3			1	2		12
B2-NT	4				2								2						4

subsection 2.2), the computation of the Food Attribute (step 7) and the decision rules obtained through the Dominance Based Rough Set Approach (steps 8–9).

More precisely, the results from the RST through RStudio and ROSE2 software are in Section 4.1, in Section 4.2 the Food Attribute is presented while in Section 4.3 the main DRSA decision rules obtained through jMAF software are described. Before presenting the results, it is necessary to note that in RST, the decision attribute is the different territorial characterization (urban, tourist, rural), while in the case of DRSA the decision attribute is the food attribute FA.

4.1. Rough set theory (steps 1–6)

In order to use RST, the dataset has to contain only categorized values, meaning that all continuous attributes must be pre-processed. To discretize the data gathered, as reported by Pięta et al., (2019), the package "RoughSets" of RStudio (Riza et al., 2019) seems to be the fittest instrument available. Due to the heterogeneity between and within attributes, it was decided to use the local discretization procedure (Nguyen, 2001) and have as maximum number of three cuts, i.e., four intervals. [5]

As an example, if we consider the population density (S1), the observations in the Low category are 7 (municipalities with a value lower than 140); in the Medium category 11 (population density between 140 and 258 inhabitant/Km^2); in the Medium-High category 7 (values between 258 and 408 inhabitant/Km^2); in the High category 19 (municipalities with more than 408 inhabitant/Km^2). Note that the cuts values for the population density resemble closely the values adopted in the rural development plan (RDP).

After having categorized the dataset, four of the available algorithms in ROSE2 were used to generate rules: LEM2, LEM2 with Interval Extension, ModLEM Entropy and ModLEM Laplace.

The rules generated by the four algorithms are in total 26, out of which 18 rules focused on overall B1 area (12 rules for B1-NT and 6 rules for B1-T), and the remaining 8 rules split equally between A-T and B2-NT, confirming the higher complexity of the rural areas if compared to urban (Zolin et al., 2017).

Taking a deeper look, it can be seen Appendix C how out of 26 rules 22 are characterized by the attributes of the socio-demographic pillar, 14 are characterized by the attributes of the environmental pillar, while attributes of the economic pillar appear only in six rules.

Table 3 shows for each pillar and area the total number of conditional attributes present in the extracted decision rules.

4.2. Food attribute (step 7)

As described in Section 2.2, the food attribute used in this case study is based on five indicators that, are good proxies for local food demand and supply, given the limited availability of data at the meso-micro level of analysis (municipalities).

Two indicators reflect the demand side, namely resident food expenditure and touristic food expenditure, while three indicators pertain to the supply side, namely the number of fishing firms, the number of agritourism establishments, and the annual working days in agriculture, which, in the absence of updated indicators at the municipal level at the time of writing the paper, provide a rough proxy for the productive function carried out by the agricultural sector (agricultural workdays), by the fishing sector (number of fishing enterprises) and the income diversification function (number of agritourism enterprises).

It has been deemed necessary to take into account the number of fishing enterprises because of the availability of data at the municipal level, and also because the metropolitan city of Venice, thanks to its 160 Km of coasts of the Adriatic Sea, along with the province of Rovigo, boasts the highest number of fishing enterprises in Veneto, representing approximately 31 % of the total in the region.

The significance of the fishing sector is further underscored by the presence of wholesale markets, notably including those of Chioggia, Venice Tronchetto, and Caorle. In the fish markets of Chioggia and Venice, one can also find the transit of fishery products from both foreign and domestic origins, alongside the local landing quota.

Linked to the fishing sector is the restaurant industry, with establishments spread along the coastline and in the immediate hinterland (Veneto Agricoltura, 2022). The decision to take into account agritourism activities, in our opinion, stems from the need to combine the primary sector with the particularly high tourism sector in the area under examination. In this case too, data are available at municipality level.

To combine these indicators into a composite decision attribute, all five of them underwent a max-min normalization procedure. The resulting composite attribute assigns equal weight to demand and supply, as both contribute similarly to the characterization of local food system.

Map 2 highlights the different urban and rural areas (left) and the different intensities of the food attribute (right), in the metropolitan city of Venice.

As expected, the municipality of Venice has the highest value of the food attribute (0.8957) followed by other costal touristic municipalities, such as Chioggia (0.4184), Cavallino-Treporti (0.3460) and Jesolo (0.3161).

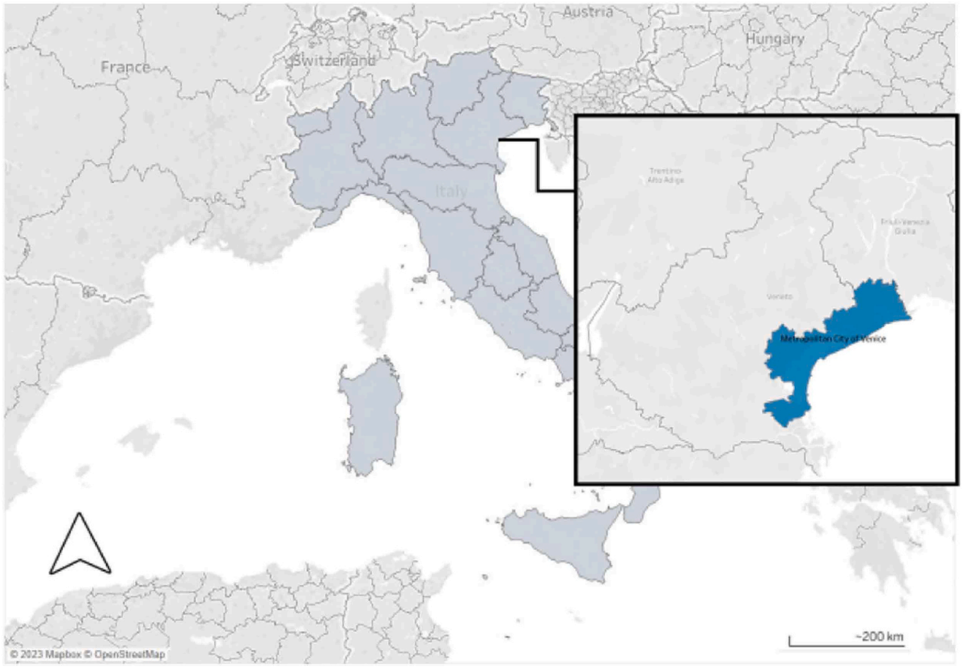
4.3. Dominance based rough set approach (steps 8–9)

In this framework we consider two pillars, i.e. the socio-demographic and environmental pillars as condition attributes, while the proxy of the economic pillar, i.e. the food attribute, plays the role of decision attribute.

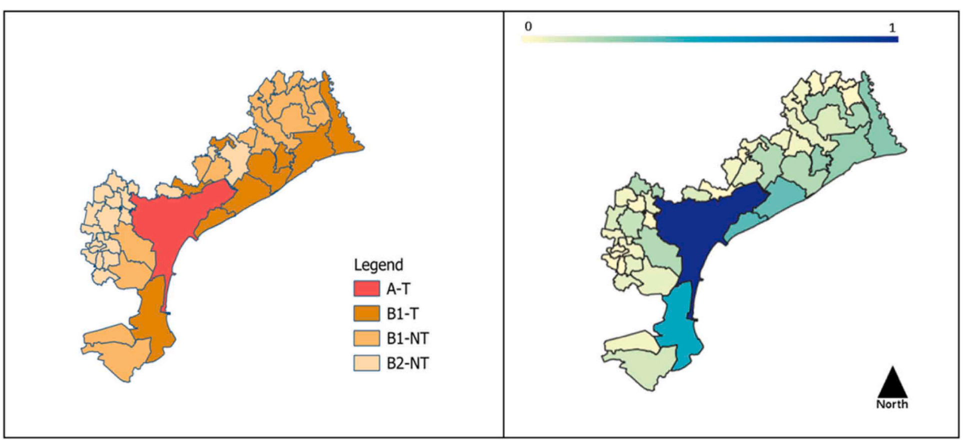
Using jMAF (version 08–03–2019)[6] software (Błaszczyński et al., 2013) and running the dataset with the food attribute a total of 133 certain rules were generated (Appendix D). Among these rules, 61 are of the type "At Least" rules while 72 are rules of the type "At Most". The difference between "At Least" and "At Most" rules is that the former

[5] The procedure made possible to discretize each conditional attribute with respect of the decision attribute without losing any information, as might have been the case for other discretization methods. A higher number of cuts would have had a more pronounced fragmentation effect. To enhance clarity, the four ranges were named low, medium, medium-high, and high (see Appendix B)

[6] Available at: http://www.cs.put.poznan.pl/jblaszczynski/Site/jRS.html [last visited on 26/09/2022]



Map 1. The Metropolitan city of Venice.



Map 2. Urban and rural areas (left); Food Attribute (right) in the metropolitan city of Venice.

rules comprise values of the FA that are greater or equal (symbol: >=) to the value indicated in the rule, while the latter comprise values of the FA that are lower or equal (symbol: <=) to the value indicated in the rule.

Furthermore, in the comparison of the two multicriteria methods, DRSA produces a significantly higher number of decision rules than RST (133 and 26, respectively, with only 6 involving the ECO attributes in RST). This allows for a more comprehensive depiction of complex and varied scenarios. These disparities arise from fundamental differences between the two methods: the variability of the decision attribute (which is continuous in DRSA and limited to "only" 4 values in RST), and the characterization of decision rules (including rules "at least" and "at most" in DRSA, as opposed to rules requiring precise attribute values in RST).

Focusing on the “At Least” rules the number of rules where both the socio-demographic and environmental pillars are present is 27, which represent almost half of the whole rules. 23 rules are based only on the socio-demographic pillar and the remaining 11 rules are based on the environmental pillar. When it comes to conditional attributes, the most common ones are the tourism intensity (S6), land consumption (ENV1) and organic area (ENV6) and each appears at least in 13 different rules.

In addition, all the other conditional attributes are included in fewer rules than education (S4) and dependency ratio (S3), which both appear in 11 rules apiece.

It is also noteworthy to note how the CO2 emissions (ENV5) do not exist in any rule.

The “At Most” certain rules are numerically more than the “At Least” rules. Nonetheless, the interaction between pillars looks to be comparable; additionally, there is a predominance of attributes belonging to the socio-demographic pillar, which occurs in 57 rules while the environmental pillar appears in 47 rules. In a similar pattern, 32 rules have attributes from both pillars (almost 50 %), 25 rules have only socio-demographic attributes, and 15 rules have only environmental pillar features. The most common conditional attributes in the rules are tourism intensity (S6), which appears in 40 rules, and land consumption (ENV1), which appears in 23 instances. Additional indicators that appear less frequently but are nonetheless present in approximately 15 rules each include population density (S1), education (S4), and organic area (ENV6). All of the other attributes appear in fewer rules. Attributes S7 (active population rate) and ENV5 (CO2 emissions) are absent.

5. Discussion

The theme addressed in this paper is part of a literature focused on the application of multicriteria methods to different territorial areas and to specific objectives. In this regard, Boggia and Cortina (2010) aimed to rank areas of Italian regions to understand the technical and/or financial support needed for sustainable growth. Carli et al. (2014) focused on analysing the sustainable development of energy, water, and environmental systems in four metropolitan areas in southern Italy. Demartini et al. (2015) analysed agricultural sustainability at the territorial level in northern Italy, suggesting support for projects integrating agriculture with tourism. Ferretti et al. (2020) examined socio-demographic, environmental, economic, and accessibility dimensions in predominantly rural areas of two northern Italian provinces in the Alpine Chain. Hajduk (2021) considered methods for ranking Polish smart cities with county status based on urban smartness indicators. Paolotti et al. (2019) evaluated sustainability at the territorial level of regions in Italy and Spain. Rocha Paz et al. (2021) verified the performance of Brazilian municipalities using indicators segmented into the three dimensions of sustainability. Although sharing the theme of sustainability, their results are hardly comparable due to differences in research questions, methodology, indicators, and territorial level.

In our paper, the exploration of potential relationships and the identification of indicator behaviours to describe territorial sustainability across its components at the municipal level influenced the choice of analytical methods. Using RST yielded 26 decision rules, whereas DRSA produced 133 decision rules.

Following the previous structure, in this section, we summarize and discuss the main results.

5.1. Rough set theory (steps 1–6)

Upon examining the territorial areas, municipalities located in more urbanized regions (A-T and B2-NT) exhibit distinctive features in the extracted decision rules. These areas are characterized by the presence of socio-demographic attributes S1 and S5, as well as the presence of environmental attribute ENV1 (land consumption) in the environmental pillar.

The areas classified as B1-T and B1-NT are characterized by the presence of attributes belonging to all the three pillars. Furthermore, it's worth noting that in areas classified as B1, the decision rules are more numerous, and all pillars are involved in these rules. This trend is particularly pronounced in B1-NT, which demonstrates a rurality with intensive agriculture likely serving the tourist municipalities.

Observing Table 3 it is clear how even within pillars the appearance of attributes is not equally distributed. The population density (S1) is the most common attribute, it appears in all the areas, and it is present in 17 rules. Another important attribute in the socio-demographic pillar is the cultural institution dimension (S5), present in seven rules. For the environmental pillar, the land consumption (ENV1) is present in nine rules, distributed equally among all the classes of the decision attribute. On the other hand, some attributes such as S4 (education), S7 (active population rate), ECO5 (agri-working days), ENV3 (waste separation) and ENV6 (organic area) are never present in the rules.

There are several possible explanations for the lack of presence of certain attributes in the decision rules in the analysed territorial areas. Firstly, it may indicate that their overall importance is relatively low, and that other attributes are more prominently characterized within these areas. Alternatively, the high variability of these attributes within the areas may result in them not appearing in any specific rules.

5.2. Food attribute (step 7)

The food attribute does not represent the sustainability of the agri-food sector, as other and diverse information would be necessary to describe it comprehensively. Its value ranges from 0 to 1, with each of the two components, demand and supply, reaching a maximum of 0.5. Thus, values exceeding 0.5 delineate the concurrent action of both components.

This is the case of Venice municipality (FA=0.8957). With reference to the five indicators of the food attribute, this municipality has the highest value for the resident and touristic food expenditure,

Table 4
*DRSA attributes interconnections in rules.

	S1	S2	S3	S4	S5	S6	S7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6
At Least													
S1	7					3		3					1
S2		4							1	1			1
S3			11	2				1	2				1
S4				11	1			2					3
S5					4								1
S6						14		4	1	1			3
S7							5	3					
ENV1								17			2		1
ENV2									6				1
ENV3										3			1
ENV4											5		1
ENV5													
ENV6													13
At Most													
S1	14		1	1		5		5			2		3
S2		5		2		3		2					2
S3			4			2		4	1				1
S4				19		15		3			1		3
S5					3	2							
S6						40		5	3	4	3		9
S7													
ENV1								23	4	1	1		6
ENV2									9		1		1
ENV3										5			2
ENV4											9		1
ENV5													
ENV6													17

* The table is symmetric, only the upper right corner is reported.

Table 5
Food Attribute: DRSA rules with highest coverage*.

Rule n.	S							ENV						Food Attribute	Support
	1	2	3	4	5	6	7	1	2	3	4	5	6		
At Least															
60											43			0.0065	41
57													0.02	0.0169	33
56								28					0.02	0.0169	31
61	244.1													0.0065	28
59			55.5											0.0113	24
At Most															
133				22.7										0.4184	43
132					3									0.3460	42
127						27.3								0.2034	37
117				15.9		27.3								0.1713	24
123					0	4.6								0.1762	23

* Orange := "<=" of that value; Green := ">=" of that value

respectively around 950 and 350.5 million of euros, and for the supply aspect, the number of agritourism (21). The municipality of Chioggia (FA=0.4184) has the highest value in the number of fishing firms (473), while the municipality of Cavallino-Treporti (FA=0.3460) has the highest value in the agricultural working days (113,013).

The lower value of the food index is obviously observed in the inner municipalities (such as Stra and Teglio Veneto with FA=0.0065, FA=0.0044, respectively) because in these areas the involved conditional attributes generally show lower values.

The introduction of the food attribute ensures that certain aspects of supply and demand can emerge, requiring the use of a different multi-criteria analysis method in which it serves as the decision attribute.

5.3. Dominance based rough set approach (steps 8–9)

Overall, tourist intensity and land consumption are the more common conditional attributes.

It is also critical to comprehend how conditional attributes interact with one another in the rules. As illustrated in Table 4, the interactions between attributes differ depending on the type of rule. While looking at the "At Least" rules, it is clear that when more than one attribute is present in a rule, they tend to belong to two different pillars. This conclusion holds for every conditional attribute with a similar number of appearances in the rules, with the exception of the organic area attribute (ENV6), which appears to have more interactions with the environmental pillar's attributes.

When the focus shifts to the "At Most" rules, the pattern of interactions appears to shift. This type of rules presents an increase in the interactions among the attributes of the same pillar.

Furthermore, it appears that this pattern has no effect on interactions with other pillar attributes, and a high level of interaction persists. Attributes S6 (tourism intensity) and ENV1 (land consumption) are clear instances of this because they are not only more numerous than others, but they also interact with both the socio-demographic and the environmental pillars in a substantial manner.

The 10 selected rules with the higher support, of which 5 "At least", are based on just one pillar (Table 5) per rule. In the "At Least" rules it can be noticed a prevalence of attributes belonging to the environmental pillar. The rule 60 in Table 5, which means "If Wasted Water (ENV4) <= 43 % then the Food Attribute is at least 0.0065", is confirmed by 41 municipalities out of 44, probably due to the inefficient water infrastructures. The four areas are represented and the rule highlights a common concern related to water.

With 28, mainly touristic and not touristic urban, municipalities, the rule 61 highlights the importance of the population density (S1) for the FA in the metropolitan city of Venice, so that "If S1 >= 244.1 Inhabitants/Km^2 then the Food Attribute is at least 0.0065".

In the selected "At Most" rules the conditional attributes belong to the socio-demographic pillar. These rules are composed by few conditional attributes, either one or two. The rule n. 133, which means "If Education (S4) <= 22.7 % then the Food Attribute is at most 0.4184", is supported by all the 43 municipalities with the exception of Venice. Noteworthy is that, even in the presence of a high value of the decision attribute, the rule does not apply to Venice, as the condition attribute S4 (tertiary education) is higher than 22.7 %.

The rule 127 highlights the importance of the tourism intensity (S6) index in the metropolitan context. The rule, "If S6 <= 27.3 then the Food Attribute is at most 0.2034", has 37 supporting municipalities. The rule confirms the validity of the methodology, if the territorial dimension is considered: all the municipalities defined as non-tourist support the rule.

In the "At Least" rules the organic farming attribute, even if in small dimension, has an environmental positive effect, even if in presence of a low value of the decision attribute. In addition to these, other important environmental risks such as the land consumption and the water wasted seem to play an important role. Concerning the socio-demographic side important seems to be demographic characteristics such as the structural dependency index and the population density.

Among the "At Most" rules, it stands out the number of appearances of the tourist intensity attribute. It is clear that the decision attribute is strongly defined by the number of tourist and has some influences of a small number of other social attributes (i.e., S1 and S4).

6. Concluding remarks

This study focused on the Metropolitan city of Venice aiming at analysing its (un)sustainability.

Along with more traditional concerns like floods, river protection, and preservation of the priceless natural heritage, this metropolitan city also deals with issues related to demographic and social aspects like population ageing and depopulation as well as the tourist flows compared to the number of residents.

The analysis of the complex sustainability of this area required the use of multicriteria methods to describe the various dimensions and to provide useful indications to decision makers.

At this end, a multi-step approach based on the RST and its evolution DRSA was employed.

The first approach helped to understand within urban and rural areas, touristy or otherwise, the role of the three pillars of sustainability and the interconnections between the selected indicators.

RST highlighted a particular relevance in the rules of socio-demographic attributes, in particular population density and cultural institutions. Among the environmental attributes, land consumption stands out. In rural municipalities (B1 and B2), on the other hand, the presence of indicators belonging to the various pillars of sustainability is more frequent, demonstrating the greater complexity of the aforementioned areas.

The second approach, DRSA, allowed for the analysis and representation of potential connections between the characteristics (attributes) related to certain aspects of the demand and supply in the agri-food sector and the other pillars of sustainability (social and environmental).

The DRSA results highlighted the role of land consumption, tourist pressure and of education in the composition of the rules.

As whole, socio-demographic indicators play a relevant role in both approaches, within the environmental attributes, the presence of land consumption emerges.

For policy-makers, these indications could be particularly relevant in defining strategies(European Commission, 2020). It should be remembered that some changes in desired trends can be incentivized in the short to medium term, such as tourism intensity, education, while others only in the long term, i.e. aging index.

The metropolitan city of Venice participates in numerous community and national programmes and projects, among which are those aimed at protecting the environment (remediation of contaminated soils), natural resources (water, air quality), and obtaining energy from renewable sources. By cross-referencing the analysis results with ongoing projects, it can be observed that the issue of land consumption, particularly important in the multicriteria analysis, is not addressed in any project, whereas CO2 emissions, an attribute of the current condition in RST rules, are partially addressed in a project (AMICA-E) co-financed by the European Commission. Special mention should be made of Mission 2 of the "National Recovery and Resilience Plan" (PNRR), namely the Next-Gen EU (Prime Minister Office of the Italian Government, 2021), aimed at protecting the territory, remediating contaminated soils, green revolution, ecological transition, and water resources, the latter theme being clearly evident in the DRSA analysis results.

In light of the challenges identified by the metropolitan city of Venice and the findings of this analysis, additional measures ought to be implemented or reinforced, especially regarding the alarming rate of land consumption and the escalating tourist influx that dominates and impacts a significant portion of the territory, putting strain on irreplaceable natural resources.

One of the limitations of our study results from the inadequate availability of current public data at the local level at the time of drafting the paper and of physical and economic data on topics pertaining to agricultural and food systems at municipality level. This issue is well known (Blay-Palmer et al., 2018), and institutions that collect and distribute data should improve its update and accessibility.

It is worth noting that this study represents a pivotal research effort. In order to test and compare different results and thereby provide valuable insights for public policymakers, future studies should incorporate various decision attributes. Additionally, the approach suggested here should be expanded to include additional cities or metropolitan areas.

CRediT authorship contribution statement

Mirco Grandi: Data curation, Formal analysis, Resources, Writing – original draft. **Paola Ferretti:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Supervision. **Nicola Camatti:** Funding acquisition, Investigation, Supervision, Writing – review & editing. **M.Bruna Zolin:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2024.103809.

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