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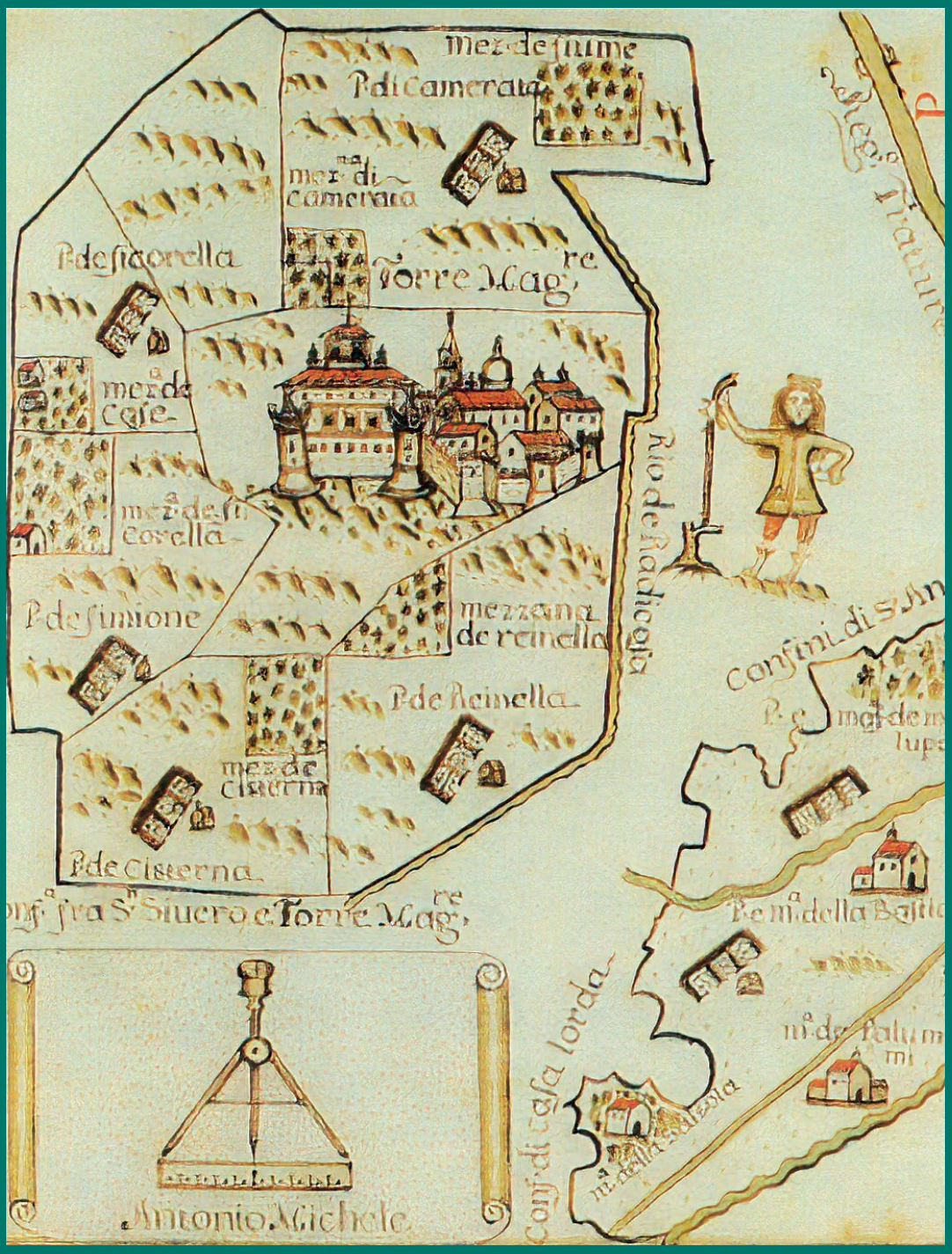

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Evaluating progress in achieving the SDGs at sub-national level in Spain: a multicriteria analysis

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Abstract. The UN 2030 Agenda is the current reference point for achieving sustainable development at the international level. Focusing on the implementation effort and monitoring the progress of SDGs are crucial aspects for achieving the Goals by 2030. The evaluation and achievement of sustainability at the sub-national level is fundamental, as sustainable development is considered achievable if it originates on the local level. Given that, the objective of this research was to assess sustainable development related to the 2030 Agenda considering the 17 regions (autonomous communities) of Spain. The analysis was carried out through the Spatial Sustainability Assessment Model (SSAM), set up as a plug-in of QGIS, which integrates multi-criteria analysis with the geographical tool. The region datasets referred to years 2019 and 2020 to observe a comparison of pre and post-COVID framework and to assess possible changes due to pandemic impacts. Results showed that, both in 2019 and 2020, for the environmental dimension the majority of the regions obtained very low or low results, showing a generally scarce environmental situation. A general decline for the majority of the indices was observed and a decrease in sustainability from north to south was detected, both for the social and the global sustainability dimensions. The social dimension in most cases was the one marking the global ordination of the communities.

Keywords: Sustainable Development Goals, sustainability assessment, multicriteria analysis, MCDA-GIS integration, COVID pandemic, 2030 Agenda.
JEL code: Q01.

1. INTRODUCTION

Since the 1990s, the international community has been committing to several principles and declarations for implementing sustainable development

(Carrillo, 2022). The most recent took effect in September 2015 when the 193 United Nations (UN) Member States adopted the 2030 Agenda for Sustainable Development, an ambitious, transformative action plan aimed at "achieving sustainable development in its three dimensions – economic, social and environmental – in a balanced and integrated manner" (UN General Assembly, 2015).

The UN Agenda 2030 is the current reference point for achieving sustainability in policies and territorial planning at the international level. The Agenda is based on 17 Sustainable Development Goals (SDGs), which follow and expand the prior United Nations Millennium Development Goals (MDGs), including the results of Rio+20 (Ricciolini et al., 2022). The 17 goals, organized into 169 targets, identify global development priorities, effectively defining sustainable development through the three pillars: economic, environmental, and social (Stevens et al., 2016). In particular, they address unfulfilled issues related to extreme poverty, inequality, social injustice, and the protection of the environment by 2030.

Consequently, the Agenda and its goals have given a new impetus to global efforts for achieving sustainable development (Rocchi et al., 2022). Governments and researchers are currently facing the challenge of measuring and monitoring progress towards the SDGs. This crucial task must be rigorously undertaken to evaluate the outcomes of the actions already implemented and address the next decade's unfulfilled goals (Carrillo, 2022). Moreover, in the unprecedented global context caused by the pandemic, an assessment of progress towards the SDGs agenda is even more important, as for many countries the achievement of targets by 2030 has become out of reach (Benedek et al., 2021).

Since 2018, the UN Sustainable Development Solutions Network (SDSN) has produced the Sustainable Development Report (SDR), which includes the SDG Index and Dashboards that ranks countries on goal attainment. This annual report, and regional editions, have become world-leading references for monitoring progress on the SDGs. Every year, the report provides the most comprehensive assessment of the performance of all 193 UN Member States on the 17 SDGs. Governments and civil society alike use the SDR to identify priorities for action, understand key implementation challenges, track progress, ensure accountability, and identify gaps that must be closed to achieve the SDGs by 2030 and beyond (Sachs et al., 2023).

The Europe Sustainable Development Report provides an annual independent quantitative assessment of the progress by the European Union, its member states, and partner countries towards the Sustainable Development Goals (Lafortune et al., 2024). In particular, the report highlights areas of success as well as opportunities for further improvement and uses the data to compare the progress of European sub-regions. The data and findings build on several rounds of consultations with scientists, experts, and practitioners from across Europe, made possible largely through the strong cooperation between the UN Sustainable Development Solutions Network and the European Economic and Social Committee (EESC).

Several studies have been performed at the national level, performing analysis within a specific country, or making comparisons in terms of SDGs among different countries. Great attention in the literature has been given to the European context in particular, thanks to its leading role in the application of the Agenda (D'Adamo et al., 2022). For instance, Ricciolini et al. (2022) used two multicriteria composite indicators to evaluate the sustainability, in terms of SDGs achievement, of the 28 Members of the European Union (pre-Brexit), considering three reference years: 2007, 2012, and 2017. Also Carrillo (2022) developed a composite indicator to evaluate the SDGs' progress using the Eurostat SDG dataset, but considering the 2010–2020 period. Rocchi et al. (2022) measured the Progress of the European Union Countries through the so-called SDGs Achievement Index, a multicriteria-based index, including six different dimensions. Miola and Schiltz (2019) reviewed three common methods to measure the SDGs performance of EU28 countries, illustrating the sensitivity of rankings to the choice of indicators and methodological assumptions. D'Adamo et al. (2022) monitored the progress of Member States (MSs) towards achieving the SDGs, using MCDA but focusing on five economic SDGs only, while Tóthová and Heglasová (2022) concentrated the attention on environmental achievement. In such studies, it is possible to identify some common trends. There are several discrepancies in sustainability level across the member states, with the middle-east and Mediterranean nations usually showing a gap in comparison to Northern Europe (D'Adamo et al., 2022; Kiselakova et al., 2020; Ricciolini et al., 2022; Rocchi et al., 2022). Moreover, for the member states with the highest level of sustainable development is more difficult to improve their performance, while the more backward nations have made considerable progress that, however, has not yet allowed them to close the gaps present (D'Adamo et al., 2022; Rocchi et al., 2022). Finally, studies show that a good level of economic and social development is often associated with a lower level of environmental sustainability, and vice versa (Kiselakova et al., 2020; Ricciolini et al., 2022; Rocchi et al., 2022; Tóthová and Heglasová, 2022).

The practice of ranking countries can be a way to stimulate decision-makers to improve their position (Dahl, 2012) and therefore their national levels of sustainability. However, the evaluation cannot be solely at a national level, although it is perhaps the most significant one (Dahl, 2012) and the most applied in international fora (Canavese et al., 2014). The main aim of the European Union is to set common objectives of sustainable development at the Union level, to be calibrated and adjusted based on the different countries' situation and, within each country, on the basis of the composite territorial areas and local characteristics. It is clear, therefore, that there could exist common measures for the totality of Member Countries, as well as specific territorial measures, tailored based on sustainable development needs, strengths and weaknesses of the different subareas within a country (Paolotti et al., 2019).

Therefore, systems at a local level must be investigated in order to have effective and realistic evaluations of specific territorial contexts, and to determine sound planning actions (Boggia et al., 2018). Sustainable development is considered achievable if it originates on the local level; a bottom-up approach from local to supranational (Ravetz, 2000), complying with the EU subsidiarity principle.

In particular, in the distribution of funds for the growth of territories decision-makers should sustain those areas having difficulties in reaching an equilibrium between economic wealth, social equality, and environmental preservation, and therefore need more immediate incentives towards sustainability (UNCTAD, 2015). To do this, local systems must be analyzed to have actual and accurate evaluations of specific territorial situations and to determine thorough planning strategies to adopt (Ravetz, 2000).

Recently, several studies have been conducted to analyse the achievement of SDGs at the local level. Diaz-Sarachaga et al., 2018 examined the SDG index (Schmidt-Traub et al., 2017), highlighting the need for developing regional SDG Indices to enhance the appraisal of specific regions, and to emphasize the achievement of lower performing goals. Rocchi et al. (2023) proposed an evaluation framework for assessing the progress of the Italian regions in terms of SDGs, within the strategic borders provided by the Italian National Sustainable Development Strategy. The different regions were evaluated concerning a set of indicators associated with SDGs and complying with the strategic objectives of the national strategy, for assessing the relative level of sustainable development reached by each region.

The importance of the diffusion of sustainable development at the local level was recognised by Farnia et al. (2019), who addressed the issue of measuring the Agenda 2030 goals at the urban level in Italy. They used 53 economic, social, and environmental indicators to analyse 98 Italian municipalities and built a composite index by combining the data into two levels. The results showed geographical and demographic heterogeneity within the country when considering each of the Goals, but also underlined how complex phenomena are due to the multidimensional aspects of Agenda 2030.

Xu et al. (2020) conducted a spatio-temporal analysis of progress towards the 17 SDGs in China, at national and sub-national levels (Chinese provinces) using a systematic method. They referred to a series of data from 2000 to 2015, using 119 indicators to calculate the "SDG Index score" (0-100), which represented China's overall performance in achieving all 17 SDGs. This index increased at the national level over the 15 years examined, and each province also increased its SDG Index score over this period; more specifically, scores for 13 of the 17 SDGs improved over time.

The importance of measuring progress at the local level in the context of the SDGs was also investigated by Nagy et al. (2018), who measured the sustainability of the Cluj Metropolitan Area (CMA) located in the northwest region of Romania. Using the simple arithmetic mean of the normalized values, they calculated a score for each of the Sustainable Development Goals (except the 14th goal "life below water"). They then aggregated the results and determined the overall SDG index for each district of the CMA and, finally, for the entire metropolitan area. Finally, they generated a single map representing the entire metropolitan area of Cluj for a visualization of the SDG index for each individual district. Also, Saiu et al., 2022 analyzed the potentials and limitations of three different "neighborhood sustainability assessment tools" for contributing useful guidelines toward urban sustainability assessment.

In order to assess the performance of the cities in Brazil towards the SDGs, the Sustainable Cities Development Index of Brazil (IDSC-BR) was developed as part of the Sustainable Cities Programme (PCS), promoted by the Sustainable Cities Institute (ICS) (ICS and SDSN, 2021). The IDSC-BR provides a comprehensive assessment of the distance between each of the 5,570 Brazilian municipalities and the achievement of SDGs. Using updated data from public and official sources in Brazil, the index is composed of a total of 100 indicators, covering various areas of public administration activities. The methodology for constructing this index was developed by the SDSN. The IDSC score, varying between 0 and 100, represents the percentage of optimal performance; in particular, the difference between the score obtained

and 100 indicates the distance in percentage points a city must overcome to achieve optimal performance. In addition to the score and ranking of each city, the index presents SDG Panels, offering a visual representation of the performance of municipalities in the 17 SDGs; these panels use a colour classification system (green, yellow, orange, and red) to indicate how far a municipality is from achieving each target.

To contribute to the sustainable development of Spanish cities, the report 'Sustainable Development Objectives in 100 Spanish Cities' was presented in 2018 by the Spanish Network for Sustainable Development (REDS) (Sánchez de Madariaga et al., 2018). The municipalities analyzed in the report include 21.5 million inhabitants, constituting almost 50 per cent of the Spanish population. The objective was to help local governments to keep a picture of the achievement of the SDGs, but also to facilitate the exchange of good practices between different Spanish cities. The report measured the level of the 17 SDGs (considering 85 indicators) to highlight the challenges that cities have to face in relation to transport, health, inequality or climate change. Unlike other reports, this one did not rank or compare results, but rather offered a general overview of the state of the goals at the local level in Spain and provided a scorecard for each city. It was not intended to report better or worse performance with the targets, but to offer instruments for local policymakers to define actions to be taken.

Finally, Mascarenhas et al. (2010) emphasized how it is widely recognized that action towards sustainable development is most effective at the local scale, but that there are common resources for which efficient management occurs at a supra-municipal scale, i.e. at the regional level. Indeed, they argued that the regional scale is a good level of governance for planning, coordination, and evaluation of action towards sustainable development.

Following these principles, the objective of this work is to carry out a sub-national assessment of the Agenda 2030, by means of an already tested model, found very suitable for territorial sustainability assessment, i.e. the model SSAM (Spatial Sustainability Assessment Model – Rocchi et al., 2022), for evaluating the progress in terms of SDGs achievement of the 17 autonomous communities belonging to Spain. According to previous studies (Ricciolini et al., 2022; Rocchi et al., 2022), at the national level, Spain has a sufficient level of sustainability with specific shortcomings in some areas. Therefore, it is needed to better understand the situation at the regional level. It was the first evaluation in terms of SDGs, at this territorial level.

The model SSAM is based on spatial MCDA, i.e. Multi-Criteria Spatial Decision Support Systems (for general information about spatial MCDA see Malczewski, 2010). It can be used at local, regional, and national levels, for comparing the sustainability of different territorial areas considering multiple dimensions/criteria. Some applications of SSAM (and of its previous version) at the territorial level can be found in Ottomano Palmisano (2016), Boggia et al. (2018), Paolotti et al. (2019), Rocchi et al. (2022), De Toro et al. (2023), where it proved to be a useful tool integrating Multi-Criteria analysis with Geographic Information Systems for sustainability evaluations. In particular, these last two works analysed SDGs in relation to EU countries in one case, and peri-urban areas in the other.

Therefore, this multi-criteria model seems to be a suitable tool for this type of territorial analysis – i.e. a multidimensional study, since it deals with the Sustainable Development Goals (SDGs) – analysing in this case the supra-communal level. Furthermore, the model allows for a simple and intuitive visualisation of the results, and this can certainly help decision-makers in the definition of policies.

As the main objective of the work was to perform an assessment of Agenda 2030 at the sub-national level, the research steps that were implemented can be synthetized as follows:

- Criteria selection through the choice of a specific set of indicators for the case study analysed (i.e. 17 autonomous communities belonging to Spain) and building of a specific framework for sub-national level assessment of SDGs.
- Application of SSAM – Spatial Sustainability Assessment Model, using the set of indicators previously identified, and of Multi Criteria Decision Analysis, to the 17 autonomous communities.
- Computation of the three basic Sustainability Indices – EnvIdeal, EcoIdeal, SocIdeal – plus the aggregated SustIdeal index.
- Ranking of 17 Spanish autonomous communities before the irruption of the global COVID pandemic (2019 – Pre-COVID) and just after that (2020 – COVID Pandemic).

This study, through its results, could act as an impulse for local sustainability initiatives and, above all, could outline guidelines to be followed at the institutional level; there is also a need for better coordination between authorities to pursue the targets to be achieved, and this is possible with a vision of the situation as clear as possible.

Even if the assessment was applied as a case study to the autonomous communities of Spain, it is designed to be applied in any other territorial context (sub-national or national), as the reference units object of the analysis

(through GIS) are homogeneous territorial areas, that can be for example countries, regions, or sub-regions.

2. MATERIALS AND METHODS

This section provides details about the case study selection and the framework construction, including both the indicators selection and the description of the method applied within SSAM plugin. In particular, the framework construction is a key step to understand the results and their possible shortcomings.

2.1 Case study

The sub-national SDGs assessment was applied to the 17 autonomous communities belonging to Spain (Figure 1). These regions have notable differences in extension and number of inhabitants (Table 1). The largest region is Castilla y León, the most populated is Andalucía, and the most densely populated is Comunidad de Madrid (INE, 2023). A general pattern of low population density in inland regions is observed, except for Comunidad de Madrid, where the capital Madrid is located.

2.2 Criteria selection and reference framework

The selection of indicators for performing the analysis is a crucial step in the study as they are a key tool for monitoring and evaluating different sectors and levels of governance. In particular, the indicators of the Sustainable Development Goals can be seen as a potential beacon to guide humanity on the right path towards sustainability (Lyytimäki et al., 2020).

It is also important to understand the context in which the study is being carried out, to be able to find the indicators that best fit the object of the research, which is in this case the sustainability of Spanish regions concerning the Agenda 2030 Sustainable Development Goals. The choice of indicators should therefore

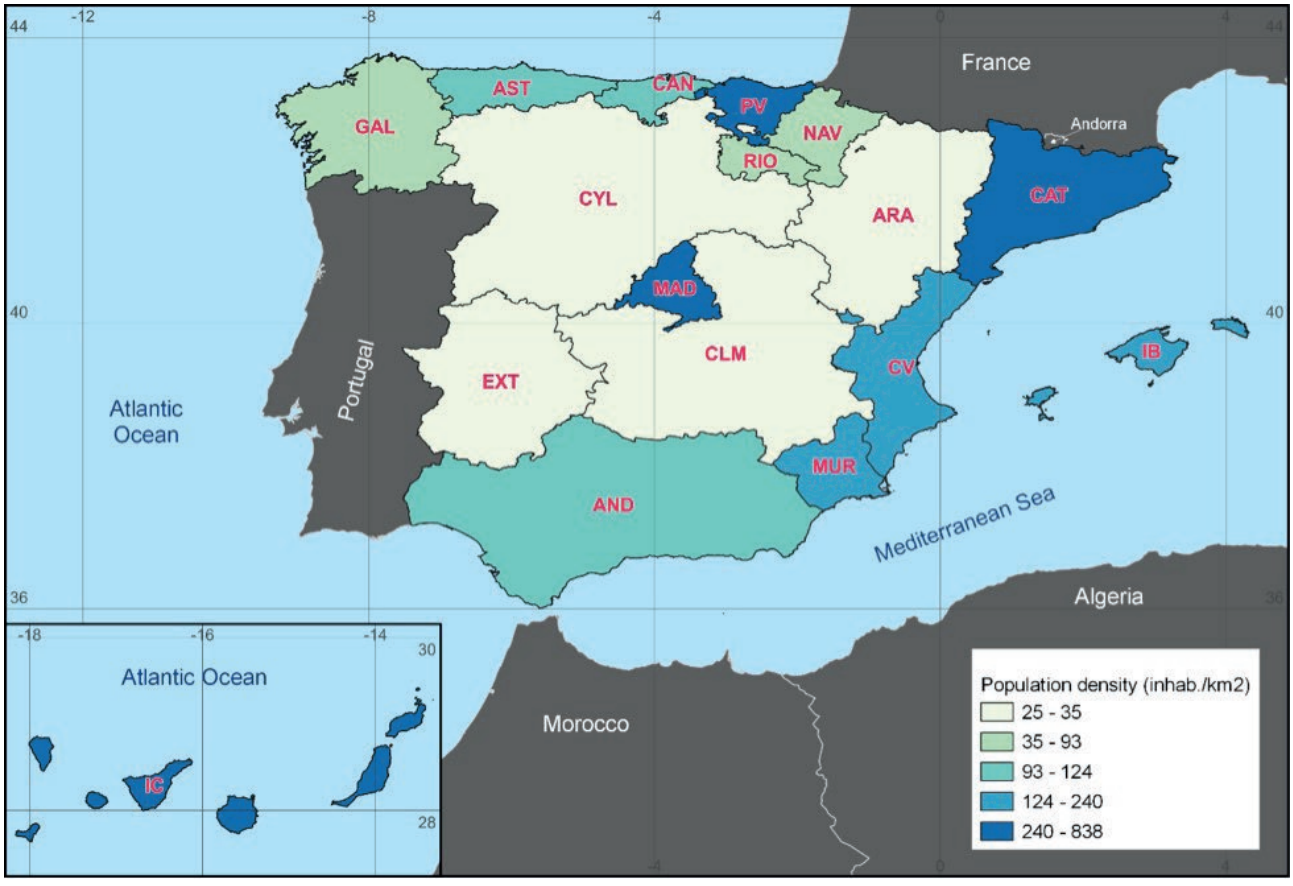

Figure 1. Map of the Spanish autonomous communities analysed in this study and listed in Table 1. Colour scales represent population density (inhabitants per square kilometre). The list of the autonomous communities can be found within Table 1 at the "Abbreviation" column.

Table 1. Area, population and population density of the Spanish autonomous communities included in the study.

Region	Abbreviation	Area (km²)	Population (inhab.)	Density (inhab/km²)
Andalucía	AND	87,599	8,484,804	96.9
Aragón	ARA	47,720	1,331,938	27.9
Asturias	AST	10,604	1,012,117	95.4
Islas Baleares	IB	4,992	1,183,415	237.1
Islas Canarias	IC	7,447	2,178,924	292.6
Cantabria	CAN	5,321	584,708	109.9
Castilla y León	CYL	94,224	2,385,223	25.3
Castilla – La Mancha	CLM	79,461	2,052,505	25.8
Cataluña	CAT	32,113	7,749,896	241.3
Comunidad Valenciana	CV	23,255	5,067,911	217.9
Extremadura	EXT	41,634	1,061,636	25.5
Galicia	GAL	29,575	2,698,177	91.2
Comunidad de Madrid	MAD	8,028	6,726,640	837.9
Región de Murcia	MUR	11,314	1,518,279	134.2
Comunidad Foral de Navarra	NAV	10,391	662,032	63.7
País Vasco	PV	7,234	2,212,628	305.9
La Rioja	RIO	5,045	319,444	63.3

be based on their reliability, relevance and ability to fit the concept being studied, but of course data availability should always be checked. The aim was to outline a possible pathway to support the processes of evaluating the performance of Spanish regions in achieving the Sustainable Development Goals, through the creation of a proper assessment framework.

At the methodological level, assessing Spain's confluence with Europe seems a good quantitative technique to investigate the achievement of the SDGs at the national level (Boto-Álvarez and García-Fernández, 2020). Following this idea, we applied the same methodology for investigating the SDGs achievement at the local level. In particular, we started from the structure of Agenda 2030 in a more comprehensive form, analyzing the policies at the European Union level and the indicators provided by Eurostat and then examining the specific Spanish indicators, with a focus on the various regions, finding a correspondence with the Eurostat data. Therefore, a basic principle for choosing the indicators has been to define a set of specific indicators for Spanish regions in line with those proposed by Eurostat, the Statistical Office of the European Union, in its specific section on Agenda 2030 and the SDGs.

Through these selection parameters, it was therefore possible to study the progress of Spain at a supra-communal level but at the same time to be completely in line with the European Union indicators. This correspondence with the EU is very important because it makes the work comparable with possible other studies carried out on a different local scale or for a different territorial area. Indeed, having a common and reusable set of indicators is crucial for the reliability of the work.

For the search of the indicators, initially, the Spanish National Institute of Statistics (INE) was analyzed; in 2018 INE launched the statistical operation "Agenda 2030 for Sustainable Development Indicators", constituting a framework of statistical indicators that would serve for the monitoring of the Goals and Objectives of the 2030 Agenda in Spain. The indicators for monitoring the SDGs are very complex as they cover the economic, social, environmental, and institutional dimensions; for this reason, in addition to the INE, 16 ministerial departments and the Bank of Spain participated in their preparation. The indicators included in the set of SDGs proposed by INE were selected directly from this source (19 out of a total of 25). Given the difficulties in collecting data for the autonomous cities of Melilla and Ceuta, it was decided to exclude them from the research. Then, other indicators were selected from the databases provided by the official Spanish statistical offices, again following Eurostat's 2030 Agenda indicators guidelines.

Based on these guidelines and analyzing the different databases available, which contain statistical measures useful for monitoring the SDGs of the 2030 Agenda, a careful selection was made to identify the indicators that best represented the 17 Spanish autonomous communities.

The criteria that were considered in the selection process are:

– representativeness of the theme, in relation also to the coverage of the majority of SDGs;

- avoidance of redundant or overlapping indicators.
- availability of data at the regional territorial level; data for monitoring the 2030 Agenda are not always easily accessible, especially when individual regional units are to be evaluated, although within the EU they are more available than in other geographical contexts;
- availability of data for the years under analysis and the possibility of updating the data over the years;

The years covered in the study were 2019 and 2020, to include a comparison of the pre-COVID situation and how it changed in the first year of the pandemic.

For some indicators data were not available for the years under analysis, so the nearest available years were selected. In particular, the indicator "Research and development expenditure as a share of GDP" was not available for 2019 and 2020, so the analysis took into consideration 2018 data; for "Per capita growth rates of household expenditure and income of total population households", "Healthy life years at birth", "Share of forest area", "Recycling rate of municipal waste", "Urban waste generated per capita", "Soil erosion by water" indicators, the analysis took into account 2019 data, because 2020 data were not available.

In order to make a more intuitive assessment of the SDGs, it was decided to divide the total number of selected indicators (25) into the 3 spheres of sustainability, environmental, social, and economic, to obtain a more easily comprehensible set for decision-makers.

These three dimensions were carefully examined while in this case the institutional dimension was not included. Within the 2030 Agenda, the institutional dimension is primarily conceived as a partnership for the goals of various states and actors. Therefore, this aspect was not included in this study, which deals with a more local territorial level.

In the social sphere there were 10 indicators, in the economic one 7 and in the environmental one 8. Tables 2, 3, and 4 show the list of all the indicators divided by dimension, together with the description of the indicators, the unit of measurement in which they are expressed, and the statistical source; moreover, the eventual absence of the data in the INE's 2030 Agenda for Sustainable Development database is indicated with an asterisk. If available, the homologous indicator among the European Statistical Office SDGs Indicators was also specified. This could also be useful for future studies, for comparison with other research pertaining to equivalent geographical areas in other European countries or different geographical levels. Figure 2 identifies the contribution of each indicator to the various SDGs. Environmental indicators cover the largest number of objectives (SDG2, SDG7, SDG6, SDG11, SDG12, SDG13, SDG15), followed by Social (SDG 1, SDG3, SDG4, SDG5, SDG8) and Economic (SDG8, SDG9, SDG10, SDG17). Globally, 14 out of 17 SDGs are measured at least by one indicator.

2.3 Sustainability Indices construction using MCDA

The analysis was made using SSAM – Spatial Sustainability Assessment Model (Rocchi et al., 2022). SSAM is an evaluation tool, aimed at defining a simplified procedure for monitoring the territorial dynamics in progress within a certain area, which allows an integrated reading of social, environmental, and economic issues. Therefore, it is useful for territorial planning activities in compliance with the sustainability principle.

The whole process of SSAM is run in a well-known open-source GIS environment called QGIS (GIS Development Team, 2017). Practically, SSAM is configured as a plugin, written in Python language, which uses the libraries made available by QGIS to perform the processing requested by the user. Being a plugin inside QGIS, in addition to performing the calculations foreseen by the evaluation algorithm – more specifically TOPSIS (Hwang and Yoon, 1981) – the input and output data can be managed like any other geographical data and the user is free to carry out further geostatistical analyses, geoprocessing, or reporting operations. It represents, in fact, a perfect integration of a multi-criteria analysis procedure with the geographical tool.

When we speak of multi-criteria methods, we refer to a family of different methods. As reported, SSAM applies a specific multi-criteria method called TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) developed by Hwang and Yoon in 1981. The concept at the basis of the method is that, in a group of alternatives, the one being at the minimum distance from the ideal solution (best score in each criterion) and the maximum distance from the worst one (worst score in each criterion) is the best alternative. In particular, the method defines a ranking based on several criteria, setting an objective to aim for (ideal point) and one to move away from (worst point), for each evaluation criterion. The ideal solution therefore represents a hypothetical alternative that optimizes the value of each criterion and can be found within the range of the proposed indicators or outside of it.

The distance measured in TOPSIS is used as a proxy for human preference. Alternatives can be ranked on the grounds of the values assumed by the criteria, which are considered as monotonically increasing or decreasing and therefore to be maximized or minimized (Kalbar et al., 2012). The choice of TOPSIS within SSAM deals

Table 2. Social indicators used in the analysis.

Social indicators			
Indicators	Description	Source	Eurostat Indicator
Population aged 25 to 34 years old with a Higher Education level *	Population aged 25-34 with tertiary education is the percentage of the population aged 25-34 who have completed the tertiary and doctoral level of education **Unit of measure: %**	*Explotación de las variables educativas de la Encuesta de Población Activa (INE). Ministerio de Educación y Formación Profesional*	Tertiary educational attainment by sex (sdg_04_20)
Early leavers from education and training *	Percentage of the population aged 18-24 who do not complete upper secondary education and do not attend any type of education-training **Unit of measure: %**	*Explotación de las variables educativas de la Encuesta de Población Activa (INE). Ministerio de Educación y Formación Profesional*	Early leavers from education and training by sex (sdg_04_10)
Percentage of the adult population (15-64 years) studying education or training in the last four weeks	Proportion of 15-64 years old in education or training (formal or non-formal) in the last four weeks as a percentage of all 15-64 years old **Unit of measure: %**	*INE*	Adult participation in learning by sex (sdg_04_60)
People at risk of poverty or social exclusion	The population at risk of poverty or social exclusion is defined as those who are in one of the following situations: – At risk of poverty (60% median income per consumption unit); – In severe material deprivation (with deprivation on at least 4 concepts from a list of 9); – In jobless households or households with low employment intensity (households in which their members in working age worked less than 20% of the total of their working potential during the reference year) **Unit of measure: %**	*INE. Encuesta condiciones de vida*	People at risk of poverty or social exclusion (sdg_01_10)
Severely materially deprived people	People in severe material deprivation (with deprivation in at least 4 items out of a list of 9) **Unit of measure: %**	*INE. Encuesta condiciones de vida*	Severely materially deprived people (sdg_01_30)
Population living in households with certain housing deficiencies	Proportion of people living in dwellings with problems of leaks, dampness in walls, floors, roofs or foundations, or rotting of floors, window frames or doors **Unit of measure: %**	*INE. Encuesta condiciones de vida*	Population living in a dwelling with a leaking roof, damp walls, floors or foundation or rot in window frames of floor by poverty status (sdg_01_60)
Healthy life years at birth	Healthy life years is defined as the average number of years expected to live without activity limitation at current observed mortality and activity limitation rates **Unit of measure: Years**	*INE Encuestas de salud por entrevista*	Healthy life years at birth by sex (sdg_03_11)
Unemployment rate	Proporción de personas paradas respecto a las personas económicamente activas (Total) **Unit of measure: Rate**	*INE. Encuesta de población activa*	Long-term unemployment rate by sex (sdg_08_40)
Participation of women in regional parliaments *	The indicator measures the proportion of women in each of the regional parliaments **Unit of measure: % of women**	*Elaboración del Instituto de la Mujer y para la Igualdad de Oportunidades a partir de las páginas web de los Parlamentos Autonómicos*	Seats held by women in national parliaments (and governments) (sdg_5_5)
Women's normal hourly wage earnings compared to men's earnings *	The indicator measures the percentage of women's wages compared to men's wages **Unit of measure: % of women's wages compared to men's wages**	*INE. Encuestas de Estructura Salarial*	Gender pay gap in unadjusted form (sdg_5_20)

Note (*): indicator not reported in INE (Instituto Nacional de Estadistica) database related to "Indicadores de la Agenda 2030 para el Desarrollo Sostenible".

Table 3. Economic indicators used in the analysis.

Economic indicators			
Indicators	Description	Source	Eurostat Indicator
Annual growth rate of real GDP per capita	Annual growth rate of real GDP per capita (chain-linked volume index) **Unit of measure: %**	*INE Contabilidad nacional anual de España*	Real GDP per capita (sdg_08_10)
Research and development expenditure as a share of GDP	Expenditure on internal R&D as a percentage of GDP at market prices **Unit of measure: %**	*INE*	Gross domestic expenditure on R&D by sector (sdg_09_10)
Number of researchers (in full time equivalent) per million inhabitants	Number of full-time equivalent research personnel per million inhabitants **Unit of measure: Researchers (FTE) per million inhabitants**	*INE*	R&D personnel by sector (sdg_09_30)
Per capita growth rates of household expenditure and income of total population households	Average annualised growth rate over a five-year period of household income per person in the total population **Unit of measure: %**	*INE Encuesta de condiciones de vida*	Adjusted gross disposable income of households per capita sdg_10_20
Proportion of 16-74 years old using Internet in the last three months	Proportion of 16-74 years old who have used Internet in the last three months (preceding the survey) **Unit of measure: %**	*INE Encuesta sobre equipamiento y uso de tecnologías de información y comunicación en los hogares*	High-speed internet coverage, by type of area (sdg_17_60)
Average hourly wage	Gross earnings per normal hour of work of salaried employees **Unit of measure: Euro**	*INE Encuestas de estructura salarial*	
Manufacturing value added as a share of GDP	Ratio of persons employed in the manufacturing sector to the total number of persons employed **Unit of measure: %**	*INE Contabilidad nacional anual de España: principales agregados*	

Note: The indicators "Average hourly wage" and "Manufacturing value added as a share of GDP" are not included in the Eurostat database, but they were included in the analysis because considered relevant for the Spanish economic context.

with the type of criteria used (generally cardinal) and its good performance in case of a large number of alternatives (Kalbar et al., 2012); moreover, it was chosen because its logic is rational and understandable, and also the computation processes are straightforward (García-Cascales and Lamata, 2012).

The final product of the processing is represented by numerical outputs, but also graphics and maps are produced. By default, SSAM produces three different indices and relative cartographic representations: EcoIdeal (Index of Economic sustainability), EnvIdeal (Index of Environmental sustainability), and SocIdeal (Index of Social sustainability).

The steps of the indices construction are described in the following, using SocIdeal as a reference for all three ones.

STEP 1: Establish a performance matrix

The finite set of criteria for the SocIdeal can be described as: $U = \{u_1, u_2, u_3, \ldots, u_n\}$, (n=10 in this case) while $A = \{A_1, A_2, A_3, \ldots, A_m\}$ is the discrete set of feasible alternatives, representing the seventeen Spanish autonomous communities. Each alternative A is evaluated with respect to the n criteria, whose values constitute a decision matrix denoted by:

$$Z = (z_{ij})_{mxn} \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} u_1 & \ldots & u_n \end{array} \\ \begin{pmatrix} z_{11} & \cdots & z_{1,n} \\ \vdots & \ddots & \vdots \\ z_{m,1} & \cdots & z_{m,n} \end{pmatrix} \end{array} \quad (1)$$

where z_{ij} represents the performance value of the j^{th} Spanish autonomous community concerning the i^{th} criterion described in paragraph 2.2.

STEP 2. Normalize the decision matrix

In the classical TOPSIS approach, the normalized performance matrix can be obtained using the following transformation formula:

$$n_{ij} = \frac{z_{ij}}{\sqrt{\sum_{j=1}^{17} (z_{ij})^2,}} j = 1, \ldots, 17, \quad i = 1, \ldots, 10 \quad (2)$$

Table 4. Environmental indicators used in the analysis.

Environmental indicators			
Indicators	Description	Source	Eurostat Indicator
Area under organic farming	Agricultural area, in which organic farming is practiced, in the first year of practice, in conversion and qualified in organic farming **Unit of measure: %**	*Producción Ecológica 2020. Ministerio de Agricultura, Pesca y Alimentación. Secretaría General Técnica. Centro de Publicaciones*	Area under organic farming (sdg_02_40)
Renewable energies in the Spanish electricity system	Proportion of renewable energy in gross final energy consumption. Renewable generation of each autonomous community over national renewable generation **Unit of measure: %**	*Red Eléctrica de España. Las energías renovables en el sistema eléctrico español*	Share of renewable energy in gross final energy (sdg_07_40)
Share of forest area	Forest area as a percentage of the total area. **Unit of measure: %**	*Ministerio de Agricultura, Pesca y Alimentación*	Share of forest area (sdg_15_10)
Surface of terrestrial sites designated under Natura 2000*	Area of protected terrestrial areas included in the Natura 2000 Network ((the data on the surface area of the Natura 2000 network does not correspond to the sum of the surface areas of SCIs and SPAs, as there are overlaps between the two types of sites that should not be counted twice) **Unit of measure: %**	*Ministerio para la Transición Ecológica y el Reto Demográfico. Red Natura 2000*	Surface of terrestrial sites designated under Natura 2000 (sdg 15_20)
Urban waste generated per capita	Proportion of municipal solid waste collected and managed in controlled facilities with respect to the total municipal waste generated, broken down by autonomous community. **Unit of measure: tonnes per capita**	*INE y Ministerio de Agricultura, Alimentación y Medio Ambiente*	Generation of waste excluding major mineral wastes by hazardousness(sdg_12_50)
Recycling rate of municipal waste	Proportion of recycled municipal waste with respect to the total waste generated **Unit of measure: %**	*INE y Ministerio de Agricultura, Alimentación y Medio Ambiente*	Recycling rate of municipal waste (sdg_11_60)
Total greenhouse gas emissions	Total Greenhouse Gas (GHG) Emissions and other air pollutants from resident units per capita **Unit of measure: tonnes of CO2 equivalent per capita**	*Ministerio para la Transición Ecológica y el Reto Demográfico.*	Net greenhouse gas emissions (sdg 13_10)
Soil erosion by water*	Average soil losses, due to water erosion, according to erosive levels >10 (t.ha-1.year-1) **Unit of measure: %**	*Ministerio para la transición ecologíca y el reto demográfico*	Estimated soil erosion by water – area affected by severe erosion rate (sdg_15_50)

Note (*): indicator not reported in INE (Instituto Nacional de Estadistica) database related to "Indicadores de la Agenda 2030 para el Desarrollo Sostenible".

where n_{ij} is the normalized value of the performance value of the j^{th} autonomous community with respect to the i^{th} criterion. Consequently, after normalization, each attribute has the same unit scale.

STEP 3. Calculate the weighted normalized decision matrix

In MCDA a crucial phase is the definition of the weights, used to quantify the relevance of the selected criteria. The definition of the weights can be grounded on subjective user-defined weighting methods or objective weighting procedures. Although subjective weights are usually preferred, in complex scenarios they can be too difficult to apply and may lead to unsatisfactory results. For this reason, the application of objective methods, based on statistical approaches, random weighting procedures, or information theory, can be a valid alternative.

In the present paper, we calculated weights through a statistical method, the Coefficient of Variation (COV) (El Santawy and Ahmed, 2012). The method calculates the weights considering the COV of performance of all the criteria for each autonomous community. For the COV-based weight calculation the first step is the calculation of another normalized criteria matrix, using the equation:

$$r_{ij} = \frac{z_{ij} - Min(z_{ij})}{Max(z_{ij}) - Min(z_{ij})},\ i = 1, 2, \ldots, 10; j = 1, 2, \ldots 17; \quad (3)$$

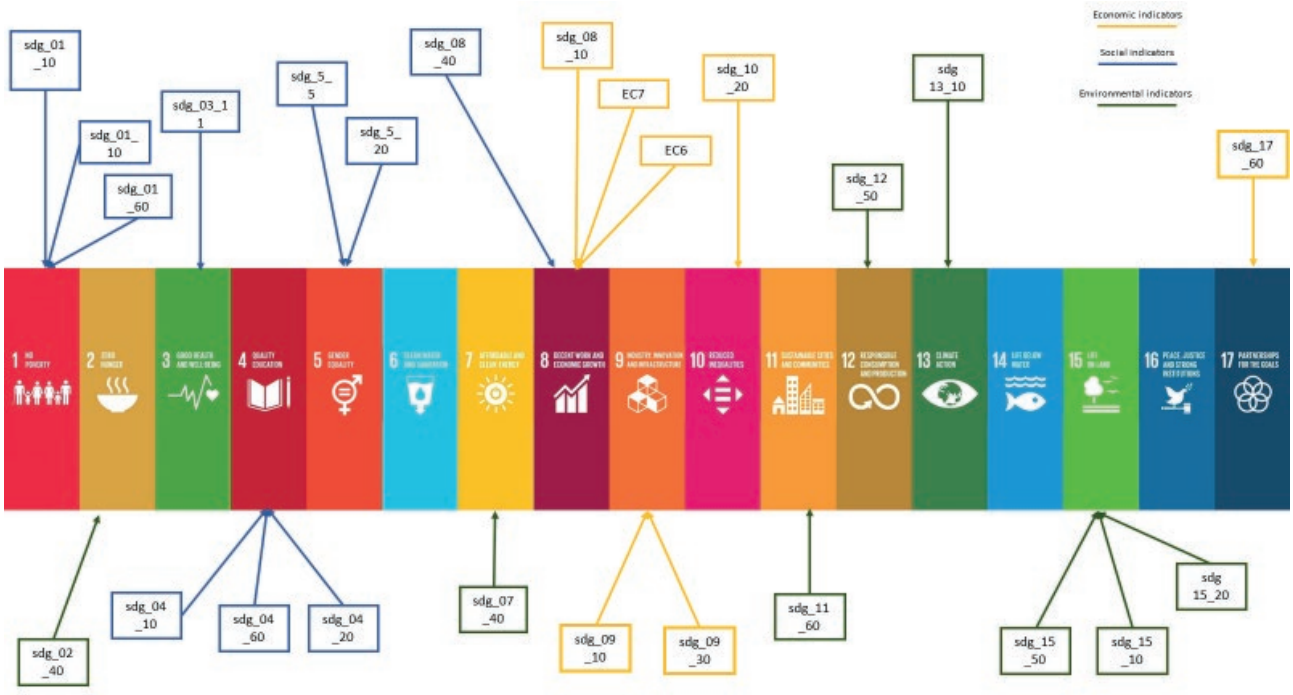

Figure 2. Distribution of indicators among the different SDGs.

$R = (r_{ij})_{mxn}$ is the matrix after range standardisation; $Max(z_{ij})$ and $Min(z_{ij})$ are the maximum and the minimum values of the criterion (i) respectively; all values in R are $0 \leq r_{ij} \leq 1$.

Then, we calculate the Standard Deviation (σ_i) of the normalised matrix $R = (r_{ij})_{mxn}$. The Standard Deviation (σ_i) is calculated for every indicator as shown in equation below:

$$\sigma_i = \sqrt{\frac{1}{17}\sum_{j=1}^{17}(r_{ij} - r_i)^2} \quad (4)$$

where r_i is the mean of the values of the i^{th} indicator after the normalization and $i = 1, 2, \ldots 10$. After calculating the Standard Deviation (σ_i) for all the indicators the COV of indicator i will be calculated as follows

$$CV_i = \frac{\sigma_i}{r_i} \quad (5)$$

The weight w_i for each indicator is then calculated using the equation:

$$w_i = \frac{CV_i}{\sum_i^{10} CV_i} and\ j = 1, 2, \ldots 10 \quad (6)$$

STEP 4. Determine the positive ideal and negative ideal solutions

The positive ideal value set (A^+) and the negative ideal value set (A^-) are determined as follows:

$$A^+ = \{v_1^+, \ldots, v_n^+\}\{(\max v_{ij},\ i \in I)(\min v_{ij},\ i \in I')\} \quad (7)$$

i= 1,2, ..., 10

$$A^- = \{v_1^-, \ldots, v_n^-\}\{(\min v_{ij},\ i \in I)(\max v_{ij},\ i \in I')\} \quad (8)$$

i= 1,2, ..., 32

where I is associated with benefit criteria, and I' is associated with cost criteria.

STEP 5. Calculate the separation measures

The separation of each alternative (i.e.: Spanish autonomous communities) from the positive ideal solution (A^+) is given as follows:

$$d_i^+ = \sqrt{\left\{\sum_{j=1}^{17}\left(v_{ij} - v_j^+\right)^2\right\}},\ 1 = 1,,\ \ldots,\ 17 \quad (9)$$

while the separation of each alternative from the negative ideal solution (A^-) is given as follows:

$$d_i^- = \sqrt{\left\{\sum_{j=1}^{17}\left(v_{ij} - v_j^-\right)^2\right\}},\ 1 = 1,,\ \ldots,\ 17 \tag{10}$$

TOPSIS can be applied using different types of distances: we used the Euclidean distance.

STEP 6. Calculate the relative closeness to the ideal solution

The relative closeness R_j to the ideal solution can be expressed as follows:

$$R_j = \frac{d_i^-}{d_i^+ + d_i^-},\ \text{i=1, ..., 17} \tag{11}$$

$$\text{If } \overline{R_j} = 1 \rightarrow A_i = \overline{A^+}$$

$$\text{If } \overline{R_j} = 0 \rightarrow A_i = \overline{A^-}$$

where the $\overline{R_j}$ value lies between 0 and 1. The closer the $\overline{R_j}$ value is to 1, the higher the priority of the j^{th} alternative.

STEP 7. Rank the preference order

With this passage we rank the best alternatives according to R_j in descending order, which mean to rank the Spanish autonomous communities according to the social dimension. Therefore, the value of R_j is the SocIdeal. The same steps allow the assessment of the other two indices, EnvIdeal and EcoIdeal.

Along with the calculation of the three separated indices, SSAM permits to have an additional global sustainability index, through the weighting summation of the dimensional indices, following the (12):

$$Global\ Index = \sum_{k=1}^{3} w_k R_{jk} \tag{12}$$

where w_k represents the weight of the K^{th} pillar and R_{kj} the index of the K^{th} pillar (Economic, Environmental, Social) for the j^{th} Communities.

All the described steps are handled by SSAM, which needs to work a geographical file as an information base, in particular a GeoPackage format, where the graphic part represents the study area with the single units to be evaluated (in our case study the Spanish autonomous communities), while the alphanumeric part (table of attributes), describes the aspects of the individual territorial units to be analyzed, through the set of selected indicators (in our case study $Z = (z_{ij})_{mxn}$)).

2.4 Statistical methods

SSAM results were statistically analysed with several methods, with the aim of assessing the relationships between the indices and the temporal changes experienced in the autonomous communities. Basic descriptive statistics of the indices (i.e., mean, standard deviation, minimum, maximum, and coefficient of variation) were computed in order to summarize the main features of the SSAM input variables and modelling results. Then, the Shapiro–Wilk (S-W) test of normality was computed to determine the distribution of the variables. The s-W test was used to assess if SSAM input variables and modelling results were well-modelled by a normal distribution or not. The s-W test was computed along with the descriptive statistics. Due to the limited number of variables that fitted a normal distribution, non-parametric tests were preferably adopted for further analyses.

The correlations among the values of each index for the 17 regions were analysed with the Spearman rank correlation test (Spearman, 1904). Spearman test is a non-parametric method used to assess the rank correlation between pairs of variables. It is a non-parametric method that employs a monotonic function (instead of a linear relationship) to describe the relationship among a pair of variables. It was used to compare the modelling results obtained for 2019 (Pre-COVID) against 2020 (COVID pandemic). Spearman rank correlation (rho) values allowed the identification of significant (or not) relationships between the pairs of indices.

For a better visual inspection of these results, boxplots for each index were created. Extreme values in the boxplots were highlighted according to the procedure proposed by McGill et al. (1978). Additionally, Dunn's test (Dunn, 1964) was used for pairwise multiple comparison of Pre-COVID indices (2019) against COVID Pandemic indices (2020). Dunn's test results were used to identify homogeneous subgroups of variables, including these subgroups as letters in the boxplots. Dunn's test was computed using the dates as factor (i.e., 2019 vs. 2020), with a significant level of $p < 0.05$. All statistical analyses and boxplots of the SSAM results were conducted with the R programming language (R Core Team, 2023).

3. RESULTS

The application of SSAM allowed the computation of the three basic indices EnvIdeal, EcoIdeal, SocIdeal, plus the aggregated SustIdeal index for 17 Spanish regions (Figure 3), before the irruption of the global COVID pandemic (2019; Pre-COVID) and after that (2020; COVID Pandemic).

For Pre-COVID indices (Table 5), the regions that reached a maximum value in each of the indices were

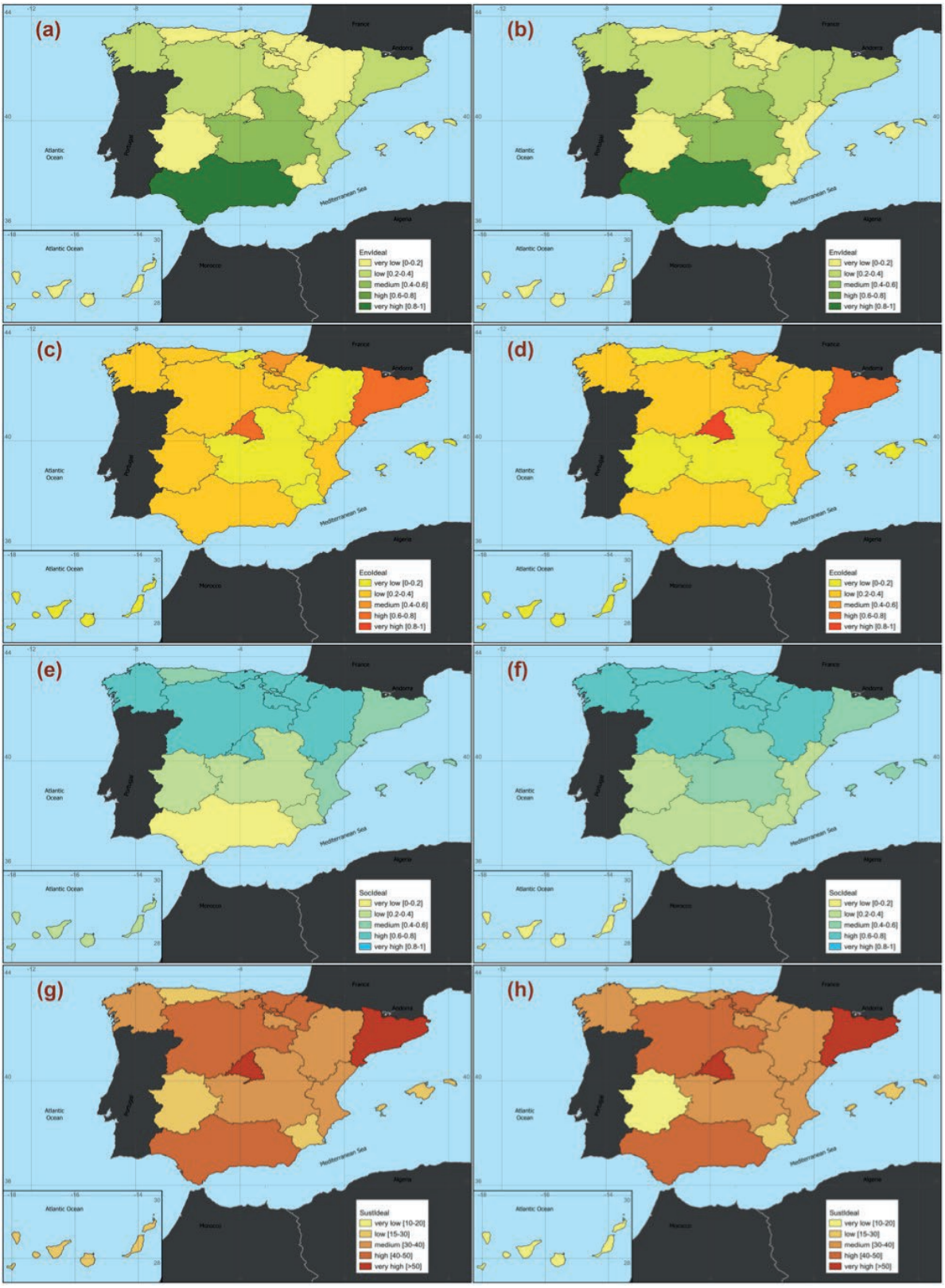

Figure 3. Maps of the indices EnvIdeal, EcoIdeal, SocIdeal and SustIdeal for 2019 (*a*, *c*, *e*, and *g* respectively) and 2020 (*b*, *d*, *f* and *h* respectively).

Andalucía for the environmental dimension (EnvIdeal = 0.857), Comunidad de Madrid for the economic dimension (EcoIdeal = 0.791), Comunidad Foral de Navarra for the Social dimension (SocIdeal = 0.779), and Comunidad de Madrid again for the global sustainability index (SustIdeal = 54.613). Minimum values for the indices were reported for Asturias (EnvIdeal = 0.102), Islas Baleares (EcoIdeal = 0.101), Andalucía (SocIdeal = 0.190) and Islas Canarias (SustIdeal = 20.640). Inter-region variability was notable for all the indices, especially from the point of view of the environmental (CV = 72.893%) and economic (CV = 66.718%) dimensions.

In 2020, during the COVID Pandemic (Table 5), Andalucía also reached the maximum environmental dimension index value (EnvIdeal = 0.823) and Comunidad de Madrid the maximum economic dimension index (EcoIdeal = 0.801). Unlike the previous period, the maximum social dimension index value was for País Vasco (SocIdeal = 0.768) and maximum global sustainability was for Cataluña (SustIdeal = 53.753). For minimum values, some changes were also reported. Cantabria (EnvIdeal = 0.101), Islas Baleares (EcoIdeal = 0.080), and Islas Canarias (SocIdeal = 0.125 and SustIdeal = 12.193) were the regions in which the lowest values were obtained for any of the indices. Additionally, inter-region variability increased for all the indices, especially for SustIdeal which exhibited an increase in the coefficient of variation from 28.378% to 33.672%.

3.1 Temporal changes during the first year of the COVID Pandemic

To analyse the global dynamic of the different dimensions, several graphical and statistical methods were used. Spearman rank correlation test was computed for each index comparing their values before and after COVID irruption (2019 vs. 2020). High Spearman's rho values and significant correlations (p-value ≤ 0.05) were observed for the four indices. Spearman's rho values were 0.94 for the EnvIdeal and EcoIdeal, 0.91 for SocIdeal, and 0.97 for SustIdeal.

Additionally, boxplots allowed a visual comparison of the evolution of the indices during COVID pandemic (Figure 4). Subtle overall change for all the indices was observed by comparing the Pre-COVID situation (2019) against COVID-Pandemic (2020) boxplots. To analyse the magnitude of these changes, the nonparametric pairwise multiple comparisons Dunn's test was computed. It revealed non-significant differences for any of the indi-

Table 5. Results of the indices EnvIdeal, EcoIdeal, SocIdeal and SustIdeal for 2019 and 2020 (better values highlighted in bold).

Region	2019 (Pre-COVID)				2020 (COVID Pandemic)			
	EnvIdeal	EcoIdeal	SocIdeal	SustIdeal	EnvIdeal	EcoIdeal	SocIdeal	SustIdeal
Andalucía	**0.857**	0.390	0.190	47.870	**0.823**	0.395	0.245	48.757
Aragón	0.188	0.188	0.743	37.297	0.205	0.206	0.737	38.260
Asturias	0.102	0.213	0.482	26.543	0.102	0.181	0.605	29.587
Islas Baleares	0.143	0.101	0.579	27.423	0.138	0.080	0.419	21.243
Islas Canarias	0.165	0.114	0.340	20.640	0.143	0.097	0.125	12.193
Cantabria	0.117	0.182	0.728	34.237	0.101	0.180	0.667	31.623
Castilla y León	0.295	0.263	0.719	42.550	0.284	0.272	0.661	40.577
Castilla-La Mancha	0.427	0.142	0.372	31.380	0.401	0.168	0.517	36.220
Cataluña	0.292	0.758	0.504	51.797	0.303	0.791	0.518	**53.753**
Comunidad Valenciana	0.214	0.361	0.489	35.490	0.193	0.367	0.351	30.357
Extremadura	0.191	0.226	0.245	22.063	0.168	0.180	0.222	18.997
Galicia	0.268	0.265	0.637	38.983	0.252	0.253	0.600	36.857
Comunidad de Madrid	0.193	**0.791**	0.654	**54.613**	0.172	**0.801**	0.625	53.250
Región de Murcia	0.166	0.186	0.327	22.657	0.141	0.193	0.371	23.513
Comunidad Foral de Navarra	0.175	0.304	**0.779**	41.913	0.180	0.296	0.679	38.477
País Vasco	0.169	0.452	0.729	45.007	0.181	0.456	**0.768**	46.847
La Rioja	0.160	0.201	0.763	37.463	0.137	0.205	0.738	36.013
Mean	0.242	0.302	0.546	36.349	0.231	0.301	0.521	35.090
Std. deviation	0.177	0.202	0.194	10.315	0.171	0.211	0.198	11.815
Minimum	0.102	0.101	0.190	20.640	0.101	0.080	0.125	12.193
Maximum	0.857	0.791	0.779	54.613	0.823	0.801	0.768	53.753
CV (%)	72.893	66.718	35.616	28.378	74.183	70.031	38.076	33.672

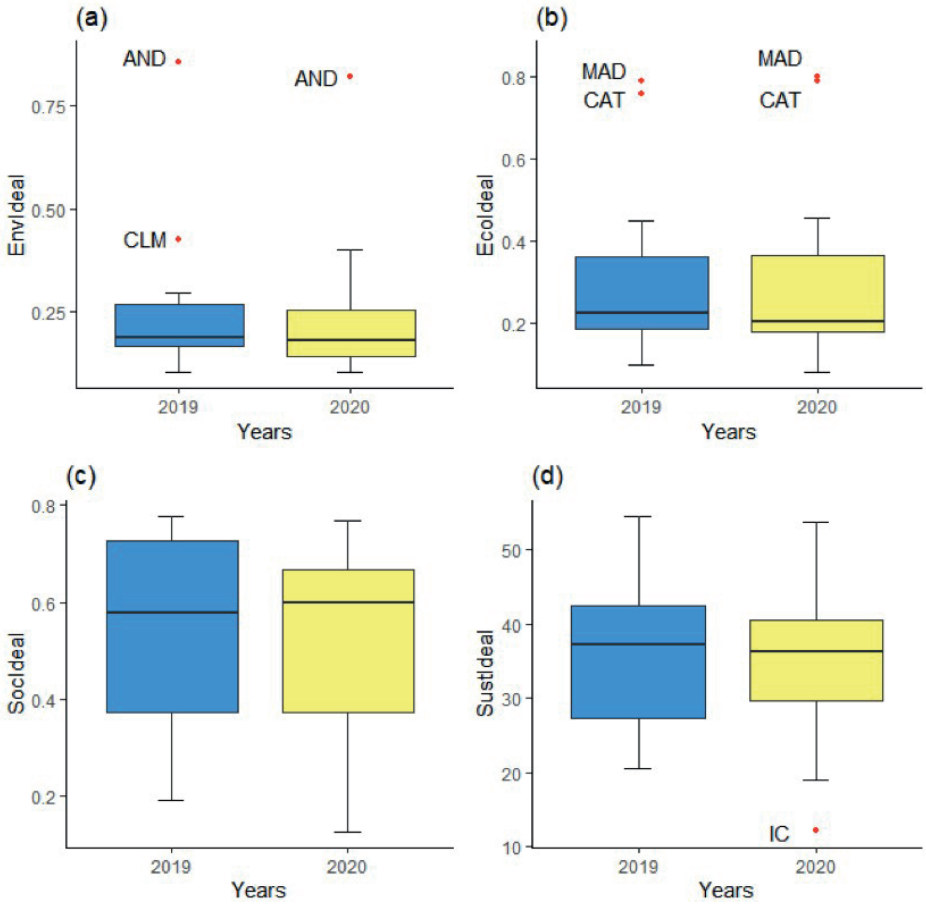

Figure 4. Boxplot for the temporal changes of the indices EnvIdeal (a), EcoIdeal (b), SocIdeal (c), and SustIdeal (d). Extreme values (potential outliers) are shown as red dots and labelled with the abbreviation of their corresponding region.

ces (p-value ≤ 0.05). However, some outstanding values were identified for the environmental dimension (Andalucía for both years and Castilla La Mancha in 2019), and the economic dimension (Comunidad de Madrid and Cataluña for both years). On the contrary, the global sustainability index exhibited an extremely low value for Islas Canarias in 2020. These results suggest that it is necessary to carry out a more detailed analysis (region by region) to understand the particularities of the temporal evolution of the different dimensions.

Thematic maps of the four indices (class thresholds developed for equal intervals) provided a visual analysis of the global results. In general, both in 2019 and 2020, for the environmental dimension (EnvIdeal; Figure 2a and 2b) 11 regions obtained very low results, showing a generally scarce environmental situation; 4 regions obtained low results, just one had intermediate ones, and one region (Andalucía) had the best – very high – results. For the economic dimension (Ecoideal; Figure 2c and 2d), both in 2019 and 2020, a total of 14 regions had low or very low results, also showing a rather negative and uneven economic situation across regions. As mentioned, Comunidad de Madrid and Cataluña were the regions with the highest values (both exhibited high values in 2019, and even Madrid very high values in 2020), while País Vasco had intermediate performances. For the social dimension (SocIdeal; Figure 2e and 2f), in general, the north had better outcomes than the south, having 8 regions with high results. From 2019 to 2020, there was an improvement in Andalucía (very low to low), Asturias (medium to high), and Castilla-La Mancha (low to medium) results and a worsening for Islas Canarias (low to very low), Comunidad Valenciana (medium to low) and Galicia (high to medium). The global sustainability maps (SustIdeal; Figure 2g and 2h) showed a generally good situation, with medium, high, and even very high indexes, especially in the centre-north of Spain. We only observed negative changes in the SustIdel index category for Islas Canarias (low to very low), Extremadura (also low to very low), and Comunidad Foral de Navarra (high to medium).

Table 6. Percentage of change (2019 to 2020) for the indices EnvIdeal, EcoIdeal, SocIdeal, and SustIdeal (best values in green; worst values in red).

Region	EnvIdeal	EcoIdeal	SocIdeal	SustIdeal
Andalucía	-3.9	1.4	28.9	1.9
Aragón	9.1	9.6	-0.8	2.6
Asturias	0.2	-15.2	25.6	11.5
Islas Baleares	-3.4	-20.2	-27.7	-22.5
Islas Canarias	-13.2	-14.9	-63.1	-40.9
Cantabria	-13.7	-0.6	-8.4	-7.6
Castilla y León	-3.7	3.5	-8.0	-4.6
Castilla-La Mancha	-6.1	18.4	39.0	15.4
Cataluña	4.0	4.4	2.7	3.8
Comunidad Valenciana	-10.2	1.5	-28.1	-14.5
Extremadura	-12.2	-20.3	-9.3	-13.9
Galicia	-6.0	-4.3	-5.7	-5.5
Comunidad de Madrid	-11.2	1.3	-4.5	-2.5
Región de Murcia	-15.1	3.6	13.5	3.8
Comunidad Foral de Navarra	3.0	-2.6	-12.9	-8.2
País Vasco	7.0	1.0	5.3	4.1
La Rioja	-14.3	2.1	-3.3	-3.9

For a more quantitative analysis of the temporal changes, the percentage of change for each index and region was computed (Table 6). The most remarkable improvements of the indices were for Aragon with the EnvIdeal index (+9.1%), and Castilla-La Mancha for the other three indices (EcoIdeal: +18.4%; SocIdeal: + 39.0%; SustIdeal: +15.4%). On the contrary, the highest declines of the indices were for Región de Murcia with the EnvIdeal index (-15.1%), Extremadura with the EcoIdeal (-20.3%), and Islas Canarias for the two remaining indices (SocIdeal: -63.1%; SustIdeal: -40.9%). This kind of analysis confirmed the impression given by the maps (in particular the decline of Islas Canarias and the improvement of Castilla-La Mancha detected within the social dimension).

4. DISCUSSION

The implementation of SDGs in Spain is a very complex task that should take into consideration the socioeconomic and environmental context of the population and requires the implication and coordination of national, regional, and local authorities along with social actors. In a country with half of all municipalities at risk of extinction (FEMP, 2017), the differences between the countryside vs large cities and coastal areas are remarkable. This is a consequence of a very acute rural population exodus to cities with the consequent rural economy decline which has triggered the emergence of multiple rural development strategies and projects driven by public institutions that barely consider social engagement and integration of sustainable development goals together (Diaz-Sarachaga, 2020). Unfortunately, institutional decision-making mechanisms are based on consultative approaches that do not favour the effective involvement of social actors in decisions leading to sustainability (López-Rodríguez et al., 2024). This means that the degree of implementation of the SDGs at the national level is deficient at the economic, social, and environmental levels (Boto-Álvarez y García-Fernández, 2020). For this reason, remarkable inter-region differences are expected.

From the point of view of the environmental dimension, Andalucía always reached a very high value in the EnvIdeal index. This outcome may be explained by the high proportion of the agricultural land devoted to ecological agriculture. According to the official values of this indicator, about 45% of Andalucía's agricultural land is cultivated using some kind of ecological agriculture practices. This value is much higher than the average value for Spain (less than 6%), only followed in a long distance by Castilla La Mancha with 17% of ecological agricultural land.

Comunidad de Madrid reached the highest values of the economic dimension for both years. It performed very well for all the economic indicators, but the most remarkable one was the number of researchers per million inhabitants (more than 35,000 for both years), four times higher than the national average. After Comunidad de Madrid, Cataluña also had a powerful economic dimension, with a lower number of researchers but higher values of the manufacturing indicator. On the contrary, Islas Baleares obtained the lowest value of the EcoIdeal. Its economic dimension is very linked with tourism industry while the importance of academic activities (number of researchers) and manufacturing is really poor.

Although boxplots revealed no outliers for the SocIdeal index (see Figure 3), central-north regions consistently exhibited highest values of the social dimension. Their good results are a combination of a reduced unemployment rate and a low proportion of population living in households with certain housing deficiencies.

4.1 Temporal changes

The higher increase in EnvIdeal index was for the Aragón region (+9.1%). This was mainly due to the increase in the renewable energy production indicator. In 2020, 68.3% of all energy generation in this region came from renewable sources, with an increase of 48.6%

over the previous year (REE, 2021). On the opposite, Region de Murcia exhibited a notable reduction of this index (-15.1%), related to lower values of the renewable energy production indicator. The achievement for Aragon is very positive for reducing energy production carbon footprint, but various controversies are arising as a result of how these energy production facilities are planned and implemented in the territory. There is great social concern in rural areas due to the long-term (positive and negative) impacts on the territory (Duarte et al., 2022). In some regions, especially low population density inland autonomous communities, the generation of electricity is significantly higher than consumption (i.e., Galicia, Castilla y León, Castilla-La Mancha, Extremadura, Aragón, and Asturias), promoting spatial inequalities in the distribution of energy production across regions (Perez-Sindin et al., 2022). This problem may negatively affect the consecution of SDGs in rural areas, where small farms, enterprises, and a significant portion of the population don't perceive the environmental benefits of the implementation of new renewable energy infrastructures. In this sense, planning instruments should take into consideration pre-existing activities to ensure compatibility with new renewable energy developments (Prados et al., 2021).

From the point of view of the other dimensions of our sustainability analysis, Castilla La Mancha experienced the most positive increase in the EcoIdeal and SocIdeal. This region experienced the lowest reduction of the GDP during COVID Pandemic, resulting in an improvement of the EcoIdeal index as compared with the other regions. In this sense, autonomous communities whose economies are the most dependent on the tourism-related sector, such as Islas Canarias and Islas Baleares, suffered the biggest impact on their GDP (Pinilla et al., 2021), and consequently, their economic dimension was severely affected. Reinforcing this good resilience to COVID pandemic, Castilla La Mancha obtained a notable reduction of the population with severe material deprivation indicator, which changed from 7.4 to 3.1 (-58%). The improvement of the economic and social dimensions led to a 15.4% increase in the SustIdeal index for Castilla La Mancha.

On the contrary, Islas Canarias experienced the worst change in the global sustainability indicator during COVID Pandemic. Before the pandemic, their values for the three indices were low (SocIdeal = 0.340) or very low (EnvIdeal = 0.165; EcoIdeal = 0.114). During the pandemic, the scenario is worse (all the indices are in the very low range), standing out above all due to the abrupt increase in the population living in homes with certain housing deficiencies (from 15.15% in 2019 to 33.1% in 2020) that promoted a dramatic decrease in the social dimension index (SocIdeal was 0.125 in 2020).

The study of Paolotti et al., 2019 investigated the sustainability of the Spanish autonomous communities, applying the preceding version of SSAM (i.e. GeouUmbriaSUIT). The study had as a reference basis the Europa 2020 context and not the more recent Sustainable Development Goals framework. Therefore, although the aim of the work was to evaluate the sustainability at the territorial level of those areas, the premises for the choice of the indicators to be used were different. Anyway, some interesting correlations between the results of the two studies could be found. In particular, in the previous study a decrease of sustainability from north to south was detected, both for the social and for the global sustainability dimensions. Here we can confirm the same tendency, especially for the social dimension, where the central-north regions exhibited the highest values of the SocIdeal; for global sustainability the trend could be generally confirmed, except for Andalucía, which reached the highest values of global sustainability, showing a sensitive improvement within the ranking in comparison to the previous study. The results reached by Andalucía in terms of global sustainability could be connected to its good outcomes in the environmental dimension.

Another analogy found with the previous study could be that the social dimension is the one that seems to mark the ordination of most of the communities for sustainability. Regarding the economic index results, as in Paolotti et al. (2019), the majority of the regions belong to the low and very low classes, while only a few regions have medium or high class/very high class, and they are located in the most economic developed areas of Spain (Comunidad de Madrid, Cataluña, followed by País Vasco, which are also the most densely populated areas).

Moreover, in both studies the environmental dimension seems to be quite independent of the economic and social situations, as the richest regions have also good social results but are not at all the most environmentally sustainable. Also, the study of Delli Paoli and Addeo (2019), which aimed to propose a method for comprehensively assessing SDGs, showed that generally the social and economic pillars are quite aligned whereas the environmental pillar is disconnected from them. This may indicate a misalignment between socio-economic and environmental policies that need further investigation.

Spain has a long way to go to fulfil its commitment to the 2030 Agenda and meet EU standards (Boto-Álvarez and García-Fernández, 2020). This process must be developed by understanding the different realities of the population (rural vs urban pollution), the economic disparities between regions, and the problems closest to

people's daily lives (e.g., unemployment, access to housing). This study highlights the different response capacities at a regional level to a negative event such as the COVID-19 pandemic. It is therefore necessary to develop a more comprehensive, integrative, and resilient SDG implementation strategy against possible future events.

5. CONCLUSION

With this work, we tried to evaluate the progress in achieving the Sustainable Development Goals of the autonomous communities belonging to Spain. The UN Agenda 2030 and its SDGs are the current benchmarks for achieving sustainability in policies and territorial planning at the international level. However, the evaluation cannot be solely at a national level, and it is particularly urgent in all cases, as for Spain, where there are gaps in specific dimensions. Systems at a local level must be investigated in order to have effective and realistic evaluations of specific territorial contexts, for evaluating the real level of sustainable development, to calibrate specific policy measures on the basis of the composite territorial areas and local characteristics. For this reason, the regional dimension was chosen for the investigation, and a proper set of indicators was constructed for this level of governance. Starting from the structure of Agenda 2030 and analyzing the indicators provided by Eurostat we examined the specific Spanish indicators available, with a focus on the various regions, finding a correspondence with the Eurostat data. The regions datasets referred to years 2019 and 2020 to observe a comparison of pre and post-COVID framework and to assess possible changes due to the very first pandemic impacts.

The analysis was carried out with SSAM, an integrated multi-criteria analysis tool in a geographic environment. Integrated methodologies that use a number of indicators using a geographic approach improve the results of sustainability studies, since the spatial focus allows for a better representation of actions according to the specific territorial levels considered (local, national, supra-national) and the relative needs individuated. Differences that are found at regional levels identify the need for sustainability strategies that are not homogenous across all national territory.

The application of SSAM allowed for separately considering the three dimensions of sustainability – environmental, economic, and social – and the computation of the three basic indices EnvIdeal, EcoIdeal, SocIdeal, plus the aggregated Sustainability index for 17 Spanish regions, before the irruption of the global COVID pandemic (2019; Pre-COVID) and after that (2020; COVID Pandemic). Results showed that, both in 2019 and 2020, for the environmental dimension the majority of the regions obtained very low or low results, showing a generally scarce environmental situation. Also, the economic dimension results, both in 2019 and 2020, showed a rather negative and uneven situation across regions. For the social dimension, in general, the north had better outcomes than the south, having 8 regions with high results. A general decline for the majority of the indices was observed by comparing Pre-COVID situation (2019) against the first year of COVID-Pandemic (2020). As noticed in a previous study, a decrease in sustainability from north to south was detected, both for the social and the global sustainability dimensions, with the exception of Andalucía, which reached the highest values of the latter. The social dimension in most cases should be the one marking the global ordination of the communities.

Moreover, the environmental dimension seemed to be quite independent from the economic and social situations, as the richest regions had also good social results but were not at all the most environmentally sustainable. This may indicate a misalignment between socioeconomic and environmental policies that need further investigation.

One limitation of the study lies in its being a relative and not an absolute assessment: the best and worst values were chosen within the distribution of available data. Therefore, the outcomes are about the relative performance of the regions and not their absolute progress toward the Agenda achievement. To have an absolute type of study, thus showing absolute progress toward the goals, it is necessary to have absolute worst and best points.

Another limit of the study lies in the fact that obviously only a restricted set of indicators referred to SDGs could be used, given the selection criteria chosen and the availability of data at the regional level. Indeed, it is well known that data for monitoring the 2030 Agenda are not always easily accessible, especially when individual regional units are to be evaluated. Therefore, an improvement of the analysis could concern the consideration of a wider set of indicators, when and if available. In the same way, a complete assessment of all SDGS could lead to a significant enhancement of the assessment framework.

Also, the analysis was now limited to a temporal period of two years, particularly for focusing on the year of Pre-COVID and the year just after that. A further analysis could concern a wider temporal period, even if the indicators about SDGs are available only from a certain time period onwards.

Despite this limitation, these types of analyses are useful for public decision making to understand which regions are lagging behind others. Also, considering the data used this analysis allows the public decision maker to understand in which areas the greatest setbacks occurred due to the pandemic in its first year. Only in this way it will be possible to devise common measures for the totality of member countries, as well as specific territorial measures tailored to the needs of sustainable development, strengths and weaknesses of different subareas within a country.

A further development of the study could concern the inclusion of the institutional dimension within the analysis, in order to have a complete sustainability assessment, also at this territorial level. Another interesting aspect could be making a connection with Spanish policies, concerning the budgets allocated in the different programmes, in order to observe the correlation with the sustainability indexes.

Moreover, this kind of model was designed to be applied in any other international territorial context for which such a kind of analysis could be useful.

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Interpretable Machine Learning for the German residential rental market – shedding light into model mechanics

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Abstract. We compare the drivers in Machine learning models and give insights into their strengths and weaknesses predicting rental prices. The study employs SHAP values to measure feature importance. The study aims to investigate linear regression, decision tree and XGBoost algorithms. The research is unique in its application of IML methods to a large dataset of over 2.4 million observations in the German rental market and its application of comparative statistics using aggregate SHAP values. Main results are the superiority of XGB and LR showing higher SHAP values overall and thus explaining its lower predictive efficacy. DT models capture intricate interactions among variables with fewer features, while XGB accommodates more variables, emphasizing its higher complexity and thus superior performance. The top ten features for DT and XGB models show significant overlap, indicating robust concordance. Specific features are identified that distinguish the models, suggesting that a more complex model, like XGB, handles dummy variables more adeptly.

Keywords: interpretable machine learning, SHAP, real estate.
JEL code: R3.

1. INTRODUCTION

Precisely forecasting and understanding the drivers of real estate rent is vital for various stakeholders like landlords, renters, investors, and real estate brokers. Hedonic pricing models, particularly linear regression (LR) of ordinary least squared regression (OLS), have been traditionally used but face challenges due to the complex nature of renting markets on the one hand (Krämer et al., 2021) and OLS's underlying assumption like linearity on the other (Malpezzi, 2003). Advanced statistical and machine learning (ML) techniques, including Artificial Neural Networks, Random Forest, and extreme gradient boosting (XGB), have gained interest in their ability to address OLS shortcomings. The advent of ML models in the field of real estate appraisal, driven by increased processing power and digitization (Breuer and Steininger, 2020; Piegeler and Bauer, 2021), offers more precise predictions than traditional OLS regressions (Valier, 2020). However, ML models

are often perceived as "black boxes" posing challenges in comprehension compared to LR (Molnar, 2022; Surkov et al., 2022). To address this, interpretable machine learning (IML) methods, also known as explainable artificial intelligence (xAI), provide a solution. These methods offer both global and local level explanations, enabling a better understanding of ML models and specific predictions (Molnar, 2022).

The study aims to shed light on the drivers of German residential rental prices within LR, decision tree (DT) and XGB algorithms using the IML approach of Shapley Additive exPlanations (SHAP) values to measure features' importance on a comprehensive level and apply the results in various comparative approaches in order to get a hand on the mechanics driving each of the models. While literature has already proven the superiority of XGB in the German real estate market (Stang et al., 2023) and Baur et al. (2023) have shown the usefulness of SHAP values in their work using a rather small data set of 30.000 observations, this paper is the first to apply the SHAP method on a truly mass appraisal dataset with over 2.4 million observations for the German rental market. To ensure computational feasibility while preserving the robustness of model interpretability, we apply a systematic data reduction approach. Starting with over 2.4 million observations, we utilize Slovin's Formula to determine an appropriate sample size, resulting in a reduced yet representative dataset of 2,946 observations. Furthermore, Baur et al. (2023) leave it with the depiction of standard summary plots, while our paper applies a new method of aggregating SHAP values to compare groups of variables with each other and between models. Additionally, to the best of our knowledge we are the first to show the working application of necessary data reduction method of Slovin's Formula in real estate context without losing any power of explainability in contrast to previously applies feature reduction methods.

In a first step to show that our models behave in line with literature we first imply LR as baseline. Nonlinearity is introduced leading to the exploration of DT and XGB showing that XGB performs by far the best. In a second step, we apply SHAP values to each model. Their analysis tells that the LR model's main predictor by far surpasses all other influencers while tree-based ML methods don't show such a top "outperformer". The results note further differences in variable impact between LR, DT, and XGB, with LR showing overall higher SHAP values. The analysis suggests that LR's lower predictive efficacy is due to the granularity of individual influencing variables. Dummy variables have weaker predictive power in LR compared to DT and XGB. The significance of dummy variables increases with model complexity. Results show that DT captures intricate interactions among variables with fewer features, as it shows a significant number of features having an average absolute SHAP value of 0. In contrast, XGB, with superior performance, accommodates more variables, emphasizing the model's capability of representing higher complexity. Examining the top ten features for DT and XGB, there is a significant overlap, indicating a robust concordance between the two tree-based models.

The structure of this work is as follows. The second segment applies research on real estate pricing factors, articles on the implementation of machine learning algorithms for predicting rental and housing prices and the evolution of xAI in the field. The third section examines the math behind the statistical prediction methods, the quality measurement, and the interpretation method of SHAP values. Data is described in the fourth part. Results are reported and explained in the fifth part.

2. LITERATURE REVIEW

This section provides a comprehensive review of the existing literature on the history of valuating fair purchasing and rental prices.

2.1 Hedonic pricing model

For a single property, individual evaluation techniques are commonly employed, usually by a real estate expert. However, the process becomes more challenging and time-consuming when assessing multiple properties. Multiple Regression Analysis (MRA), also stated as Hass' Hedonic Price Model (HPM) (Hass, 1922), has been the primary regression technique used in evaluation tasks. They were created to calculate the influence of a good's particular qualities on its value or price, the so-called marginal prices. The total worth of a commodity may then be determined by adding all these marginal prices (Chau and Chin, 2002). The basic hedonic pricing function is as follows (Equation 1):

$$P = P(X_1, X_2, \ldots, X_n), \text{ with } n \in N^+ \tag{1}$$

where X_i stands for the i^{th} attribute's value.

Sirmans et al. (2005) indicate that the hedonic model has multiple founding figures. Court (1939) was the first to apply the hedonic method to calculate car pricing, while Lancaster (1966) and Rosen (1974) extended its application to real estate. Subsequently, a substantial body of literature has emerged, exploring the connec-

tions between property price, or rent and its features. In the context of real estate, property qualities serve as independent variables representing customer preferences, while the sale price or the rent is the dependent variable (Colwell and Dilmore, 1999). The MRA relies on the physical and geographic features of real estate, as supported by the theory of Hamilton and Morgan (2010).

According to Dubin (1988), there are three kinds of building attributes that often affect pricing in a hedonic model: structural, location, and neighborhood factors. Examples of such characteristics are size, the number of rooms, or the property's age (structural), central business districts or train station distance (location) and household income, crime rates, or urban planning elements (neighborhood factors), which reflect the area's broader socioeconomic context (Can, 1992; Stamou et al., 2017). Since the distinction between location and neighborhood factors is not always clear, they are commonly considered jointly (Can, 1992; Des Rosiers et al., 2011; Stamou et al., 2017). The impact of these geographic factors has received a lot of attention in recent years. Interest-worthy factors within this group are mostly found in the environmental, infrastructural, and social domains. Dumm et al. (2016), Rouwendal et al. (2017), and Jauregui et al. (2019) examine the impact of proximity to water on property pricing with regard to factors in the immediate surroundings of a property. The pricing impact of local subsurface conditions like sinkholes or land degradation is demonstrated in studies by Below et al. (2015) and Dumm et al. (2018). There is also attention given to other concerns, such as the impact of distance to urban green areas (Conway et al., 2010) or the presence of air pollution (Fernández-Avilés et al., 2012). Diverse research came to light considering the group of nearby infrastructure facilities and their effect on homes. Hoen and Atkinson-Palombo (2016), and Wyman and Mothorpe (2018) examine how adjacent electric infrastructure, such as wind turbines and power lines, affects real estate values. Chernobai et al. (2011), and Chin et al. (2020) all look at the accessibility of transportation amenities including highway and rail transit. Ahlfeldt et al. (2015) go into the same direction demonstrating the importance of workplace accessibility in a Spatial General Equilibrium Model.

The prospect of simple access to early childhood education and training in the form of local kindergartens or schools, as per Theisen and Emblem (2018), is also a price-determining factor for residential properties, according to these studies. Additionally, Goodwin et al. (2020) show that the existence of property ownership groups has price-determining impacts.

Despite concerns about multicollinearity and outlier samples negatively affecting performance, the MRA remains widely recognized and considered a standard approach in real estate price investigations (Ünel and Yalpir, 2019). However, some authors have highlighted potential issues with the MRA, suggesting that its straightforward nature may lead to biased or underestimated predictions, particularly when dealing with nonlinear data patterns (Connellan and James, 1998; Hui et al., 2007; Suparman et al., 2014; Wang and Li, 2019).

2.2 Evolution of machine learning methods

With the increased processing power, ML techniques have become valuable complements to hedonic models for real estate valuation tasks, leveraging their predictive abilities. While parametric hedonic models represented preliminary by OLS are commonly used for inferential tasks (Pérez-Rave et al., 2019), ML algorithms offer enhanced predictive performance and have gained popularity in real estate literature. These methods excel in recognizing non-linear structures and have become a hot academic topic in HPM research.

Tree-based models, originally introduced by Morgan and Sonquist (1963), have become fundamental in ML. These models have evolved since Quinlan's (1979) DT algorithm. To overcome overfitting issues in single DTs, ensemble learning approaches, like gradient boosting, have been applied (Prajwala, 2015). Gradient boosting, proposed by Breiman (1997) and first applied to regression trees by Friedman (2001), constructs multiple small decision trees from random subsamples of the dataset using residual-like metrics from prior trees. The study by Singh et al. (2020) demonstrates the success of gradient boosting trees in real estate valuation. The XGB method, developed by Chen and Guestrin (2016), is a computationally efficient variation of gradient boosting trees. It outperforms other tree-based ensemble methods, as shown in applications by Kumkar et al. (2018), Sangani et al. (2017), Kok et al. (2017) and Guliker et al. (2022). Stang et al. (2023) apply this approach to a housing data set of 1.2 million observations across Germany and come to the result that XGB is far superior to OLS in this market.

In addition to tree-based models, other non-parametric methods like Support Vector Machines, Artificial Neural Networks, and Gradient Boosting have shown great promise in real estate research. Studies by Chun Lin and Mohan (2011), Kontrimas and Verikas (2011), Yoo et al. (2012), Antipov and Pokryshevskaya (2012), McCluskey et al. (2012), Yilmazer and Kocaman (2020), Awonaike et al. (2022) and many others demonstrate the success of these

techniques over linear regression models in various real estate markets, both economically developed and developing countries. For example, Forys (2022) compares prospect results of OLS vs. ANN in Poznan, Poland, while Deaconu et al. (2022) investigates Generalize Linear Model (GLM) vs. ANN in Cluj-Napoca, Romania.

So far not only the comparison of OLS and ML methods has become a common research field in real estate literature. Moreover, Zurada et al. (2011), Mayer et al. (2019), Cajias et al. (2021) and Tekin and Sari (2022) discuss the performance between different ML methods in real estate research. Al-Qawasmi (2022) gives a good and comprehensive overview of the ML real estate literature between 2017 and 2020 and shows that regression models in form of neural networks, random forests, support vector machines, and pruned model trees are the most frequently employed algorithms. Despite the existing amount of literature, Alsawan and Alshurideh (2022) state in their systematic literature review that the area is still in its infancy and needs further study in order to become dominant in real estate assessment in the future.

2.3 Black Box and Explainable Artificial Intelligence

One building block for ML models on the way to becoming more dominant is the field of so-called xAI. As described in the previous section researchers have examined various ML algorithms, focusing on their predictive capability for market pricing models. According to Athey and Imbens (2019) the emphasis in machine learning literature has primarily been on evaluating out-of-sample performance, neglecting a traditional focus of the statistics and econometrics literature—the capacity for inference. Ensuring model transparency is essential for understanding the contribution of input data characteristics to predictions. In the context of residential rental and property markets worldwide as well as in Germany, where fair pricing and decision-making are crucial, interpretability of ML models has become a rich topic in the field of study.

Feature selection approaches using correlation coefficients (Beimer and Framcke, 2019; Yilmazer and Kocaman, 2020) or multicollinearity analysis (Chen et al., 2017) were employed, but they offer limited insight into feature variables' impact on rent and property price prediction. The same applies to the multivariate exploratory data analysis (Khosravi et al., 2022). Several studies in real estate have combined predictive and inferential goals using ML techniques. For instance, the "incremental sample with resampling" method utilizes random forests to forecast property prices and then employs a parametric hedonic model based on selected variables from the ML algorithm (Pérez-Rave et al., 2019). They use random forests to forecast real estate values on a variety of subsamples. If a feature is included in the final prediction rule of the Random Forests for 95% of the subsamples, the variable is considered important. The final inferential analysis is based on a parametric hedonic model that solely uses the variables that the ML algorithm chose. The informative quality of residuals from LR and ML models is further examined by Pace and Hayunga (2020). They discover that spatial information is still preserved in the residuals of ML models after employing regression trees. Although single trees are simple to comprehend and have a visual representation of their decision rule, they have poor predictive accuracy and are frequently unstable because to their great sensitivity to changes in the data or tuning parameter. Krämer et al. (2023) also make use of sub-sampling on the spatial level by training OLS, Generalized Additive Models, XGB and Deep Neural Network on various levels showing that it has a significant impact on performance. While the above methods provide insight into which variables are important for the trained model, however, the developers do not yet gain insight into the mechanics of the model. Hence, the research field of IML shifted from circumventing the issue of unreadable black box models to improving readability of fully trained models.

Literature suggests model-specific and model-agnostic techniques for interpretability, where model-agnostic techniques have the clear advantage of being applicable to various ML algorithms and hence, provide comparable results (Molnar, 2022). Model-specific ones on the other hand are restricted to one specific ML model form. By demonstrating how input variables contribute to overall model predictions, explainability of the models helps analysts understand what factors the models consider when estimating real estate prices (Konstantinov and Utkin, 2021; Samek, 2020).

Based on their breadth, the XAI techniques may be divided into two main groups: global and local approaches. Global explanations provide a comprehensive description of the model and its key factors, while local explanations analyze individual predictions (Delgado-Panadero et al., 2022).

Permutation Feature Importance (PFI) is employed as a global model-independent tool for feature selection in machine learning, with researchers like Adadi and Berrada (2018) and Fisher et al. (2019) using it to identify significant input variables and train regressors. Lorenz et al. (2023) and Krämer et al. (2023) apply PFI to analyze factors influencing rental prices in German cities, highlighting the impact of variables such as living area, building age, and proximity to city centers. The

text also notes alternative methods like default feature significance and drop-column importance but emphasizes the reliability and practicality of PFI, particularly in scenarios with changing input factors.

The SHAP approach is used to provide a local explanation to the regressors' predictions (Lundberg and Lee, 2017; Sundararajan and Najmi, 2020). Allard and Hagström (2021) use SHAP values to show that location-based features are the most important for various ML models while bathroom and kitchen conditions were less important than they expected. The authors suggested that valuable pricing information must also be found in the house offering text descriptions. Shen and Springer (2022) followed that suggestion and utilized ML to create measures of uniqueness in residential real estate based on written advertisements. The findings suggest that an increase in uniqueness is associated with a rise in sale prices. Alfano and Guarino (2022) also went in this direction and investigated the text structures in internet house sales influencing house prices. They find that the text structure and specific keywords related to investment, panorama, and cultural heritage positively impact house prices, while verbs, punctuation, and keywords associated with transport and tourism do not contribute to price variation. While Alfano and Guarino (2022) use OLS, Baur et al. (2023) combined their approach with modern ML and xAI methods. They trained various statistical models not only on numerical variables but also on textual input from real estate market offers and applied SHAP values to show that offer descriptions play an increasing importance with growing prices.

SHAP values have the big disadvantage that their calculation is computationally very intensive and therefore only feasible with corresponding working memory capacity (Iban, 2022). Therefore, they are only applicable to relatively small data sets. Baur et al. (2023) merely look at 13 features for data set size of about 30,000 observations. Iban (2022) therefore suggests a combining approach of PFI and SHAP. Krämer et al. (2023) circumvent the issue by applying accumulated local effects plots (ALE) to identify the individual influence on pricing. The major drawback is the lack of local interpretability, which SHAP values are feasible of.

To the best of our knowledge this paper is the first that applies the data reduction technique called Slovin's Formula in the real estate ML context. Instead of reducing the number of features of our dataset, which leads to a loss of explainability, we reduce the number of observations before training SHAP values to handle computational power issues. In section 5, we prove that the application is valid in our use case and we do not lose any power of explanation.

3. METHODOLOGY

We provide a brief overview of the most important methods and metrics we use to forecast rental prices and to analyze the forecast. We start with prediction methods and then present the quality criterion and the procedure for interpreting the methods. In order to provide clarity on the overall methodological framework adopted in this study, Figure A1 in the Appendix presents an outline of the steps involved in our analysis.

3.1 Prediction Methods

Ordinary Least Squared

In the realm of machine learning, the go-to baseline model often employed is linear regression. When it comes to forecasting continuous dependent variables like housing prices, the simple OLS model is the method of choice. In Equation 2, we express the outcome as:

$$\hat{y}_i = \widehat{\beta}_0 + \widehat{\beta}_1 x_{1,i} + \ldots + \widehat{\beta}_n x_{n,i} \tag{2}$$

Here, $\hat{y}_i$ signifies the estimated dependent variable for observation i, while $x_{(k,i)}$ represents the true k^{th} independent variables for that observation. β_k provides us with estimates for respective coefficients.

This model excels when the relationship between explanatory and independent variables is linear. Beyond its simplicity and strong predictive capabilities, it offers the unique advantage of facilitating an in-depth exploration of data relationships (Isakson, 2002). With OLS, we can scrutinize aspects such as heteroskedasticity, error term autocorrelation, interactions between independent variables, collinearity, the presence of high-leverage outliers, and whether the actual relationship between variables is indeed linear (Mark and Goldberg, 2001). This makes linear OLS a valuable starting point for gaining profound insights into the data.

However, as we delve deeper into complex, high-dimensional real estate datasets, we find that these models come with their limitations. From simple linear regression, we move on to relax the linearity assumption. We introduce quadratic and interaction terms, leading to Equation 3:

$$\begin{aligned}\hat{y}_i = {} & \widehat{\beta}_0 + \widehat{\beta}_1 x_{1,i} + \widehat{\beta}_2 x_{2,i} + \ldots + \widehat{\beta}_n x_{n,i} + \\ & + \widehat{\beta}_{n+1} x_{1,i}^2 + \widehat{\beta}_{n+2} x_{2,i}^2 + \ldots + \widehat{\beta}_{2n} x_{n,i}^2 + \\ & + \widehat{\beta}_{2n+1} x_{1,i} x_{2,i} + \ldots + \widehat{\beta}_{\left(2n+\frac{n^2-n}{2}\right)} x_{n-1,i} x_{n,i}\end{aligned} \tag{3}$$

For each variable $x_{(k,i)}$, we introduce the respective quadratic term $x_{(k,i)}^2$ and an interaction term

$x_{(k,i)}x_{(k+1,i)}$ with respective other variables, creating a non-linear relationship between independent and dependent variables. The formulation herein encapsulates a scenario wherein both quadratic and interaction terms are systematically incorporated for each feature within our dataset. Owing to computational constraints, practical implementation necessitates an evaluation of extensions that yield optimal predictive enhancements, with subsequent inclusion limited to those deemed most influential. With this model we will check for performance improvement in comparison to the linear OLS in section 5 (Results) to find the most accurate baseline model.

Decision Tree

In our quest for comprehensive investigation, we turn to a foundational tree-based method. Specifically, the Decision Tree (DT) emerges as a potent tool for unravelling intricate patterns while remaining remarkably intuitive (Pace and Hayunga, 2020). The strength of DT lies in its ability to capture nonlinear relationships and interactions, making it more than a simple algorithm. We can think of a regression tree as a hierarchical series of if-else conditions at its core. It effectively partitions data into distinct subgroups, providing predictions for each subset, often represented by the average within that group. This division unfolds through a series of split decisions, with feature variables selected and their spaces divided until a specific criterion, like minimizing prediction errors, is most significantly affected (James et. al, 2013). DTs aim to minimize the residual sum of squares (RSS), as given by Equation 4:

$$\sum_{j=1}^{J} \sum_{i \in R_j} \left(y_i - \hat{y}_{R_j}\right)^2 \tag{4}$$

Here, $\hat{y}_{R_j}$ denotes the mean response for training observations within the j^{th} segment R_j. However, due to the computational impracticality of exploring every possible feature space partition into J segments, a practical method is employed, known as recursive binary splitting. Starting from the root node, data is divided at the feature and point that maximally reduces the RSS. This process iteratively continues, branching into subgroups with each split. Without external constraints, the process persists until the tree precisely describes the training data, creating a leaf node for each observation resulting in zero bias. This pursuit of low bias, however, leads to high variance when applied to new data, rendering Tree methods ineffective for prediction unless complexity is mitigated and generalization introduced (James et al., 2013). To introduce such a predetermined threshold, Equation 4 is extended as follows:

$$\sum_{m=1}^{|T|} \sum_{X_i \in R_m} \left(y_i - \hat{y}_{R_m}\right)^2 + \alpha \left|T\right| \tag{5}$$

In Equation 5, we observe the continued minimization of RSS, as in Equation 4, with the addition of the pruning parameter α and the absolute value of T, representing the number of terminal nodes or in other words a subtree, as $T \subseteq J$. The parameter α balances the trade-off between subtree's complexity and its fit to training data. For $\alpha = 0$ and $T = J$ the subtree equals the original tree generated by Equation 4. Increasing α leads to a smaller subtree, because the tree size increases our function to be minimized. Hence, pruning aims to strike a balance between reducing bias and keeping the number of nodes to a minimum. Achieving the optimal α value necessitates the application of cross-validation techniques.

Extreme Gradient Boosting

Extreme Gradient Boosting (XGB) is a tree-based ensemble learning technique. The goal of ensemble learning algorithms is to combine multiple "weak learners", often represented as individual decision trees, to create a single, robust learner. This approach can be expressed mathematically as follows (Equation 6):

$$\sum_{m=1}^{|T|} \sum_{X_i \in R_m} \left(y_i - \hat{y}_{R_m}\right)^2 + \alpha \left|T\right| \tag{6}$$

In this equation, y represents the response variable, x is the feature space and M signifies the total number of individual trees. The weak learners denoted as h_m are trained sequentially in the boosting ensemble learning technique. u_m is used as a discount factor to account for the weaker learners. As the process unfolds, each subsequent model learns from the mistakes of its predecessors. To minimize the model's loss, gradient boosting employs a gradient descent process by adding more trees. XGB excels at automatically identifying complex patterns, such as nonlinear relationships or higher-order interactions, within extensive datasets. It requires less manual fine-tuning compared to parametric and semiparametric models like OLS, but it requires extensive computational power (Hastie et al., 2001).

3.2 Quality Criterion

Root Mean Squared Error

Root Mean Squared Error (RMSE) is a widely used statistical measure in various fields. In housing price estimation literature it serves as the most applied measurement. Since the focus of this paper is the inspection of ML models, we focus on this specific measure know-

ing that there are many more usable quality criteria out there. It quantifies the accuracy of a predictive model by measuring the average magnitude of the errors or the differences between the actual observed values and the values predicted by the model. It is expressed in the same units as the data being analyzed. A lower RMSE indicates a more accurate model. Mathematically, the RMSE is calculated as follows (Equation 7):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\hat{y}_i - y_i\right)^2} \tag{7}$$

where y_i is the actual observed value, $\hat{y}_i$ is the predicted value and n is the total number of data points. RMSE is particularly useful when we want to compare the performance of different predictive models or assess the goodness of fit for regression models. It provides a single, easily interpretable value that quantifies the model's overall accuracy and is widely used in machine learning, statistics, and data analysis to evaluate the quality of predictions or forecasts. It tends to magnify significant errors due to the squared term, making it sensitive to outliers.

3.3 Interpretable models and SHAP values

Machine learning often operates without full transparency, leading to a lack of insight into the underlying logic behind predictions. To address this, a growing field of research on interpretable machine learning has emerged in recent years. IML aims to improve trust in algorithmic conclusions by offering understandable and mathematically grounded theories (Adadi and Berra-da, 2018; Carvalho et al., 2019; Linardatos et al., 2021).

One way to understand the inner workings of ML models is to employ interpretable ML models. These models, like parametric models, impose constraints on complexity, facilitating inferential analysis. For example, DTs with a depth limit to three splits can provide a complete understanding of how they arrive at predictions (Molnar, 2020). Limiting model complexity, while maintaining predictive performance, can sometimes deprive ML models of their full potential (Breiman, 2001). As a solution, model-agnostic interpretation techniques have been developed, allowing the separation of predictive capabilities from the interpretative framework. Unlike interpretable models, model-agnostic tools do not constrain themselves to specific ML techniques, making them versatile for various learners.

Interpretation techniques can be categorized into two main types: those emphasizing feature relevance and those focusing on feature impacts. Feature relevance techniques identify which feature contributes the most to a prediction, while feature impact techniques explain how a single characteristic influences the forecast. These techniques serve as essential tools for understanding the components of ML models and their global behavior (Hastie et al., 2009).

SHAP Values

One way to measure a feature's impact is the use of SHAP values. Developed by Lundberg and Lee (2017) they are a concept from cooperative game theory that has gained popularity in the field of ML and xAI. SHAP values provide a way to distribute the contribution of each feature or input variable to a model's prediction. They offer a powerful and intuitive framework for understanding how the presence and value of each feature affects a model's output (Lundberg and Lee, 2019; Molnar, 2022).

Considering a model that takes a set of input features we want to determine the contribution of each feature to the model's prediction. For simplicity, we assume we have a binary classification model, and the output is represented by a function (Equation 8):

$$f : 2^N \rightarrow R \tag{8}$$

where N is the number of input features, and 2^N represents all possible subsets of features. In binary classification, R can be {0, 1}. The SHAP value is calculated as the average contribution of a feature across all possible feature combinations. It can be expressed as (Equation 9):

$$\Phi_i(f) = \sum_{S \subseteq \frac{N}{\{i\}}} \frac{|S|!(|N|-|S|-1)!}{|N|!}\left(f(S \cup \{i\}) - f(S)\right) \tag{9}$$

where: $\Phi_i(f)$ is the SHAP value for feature i, $f(S)$ is the model's prediction when using the feature subset S. S is a subset of features excluding feature i. $f(S \cup \{i\})$ is the prediction when including feature i as well. $\frac{|S|!(|N|-|S|-1)!}{|N|!}$ represents the number of ways to choose $|S|$ elements from the set of N elements (Grybauskas et al., 2021). This all-encompassing approach allows SHAP values to provide a more realistic picture of model behavior than other xAI methods, considering combinations, interactions and dependencies for every single observation (Duell et al., 2021; Kumar et al., 2020). SHAP values have gained popularity in various applications, including feature importance analysis, model interpretability, and explainability. They can be used to answer questions like, "How much does each feature contribute to the predicted outcome" and "What is the impact of changing a feature's value on the model's prediction?". This interpretability and transparency make SHAP values a valuable tool for understanding machine learning models and their decision-making processes.

Slovin's Formula

In practice, calculating SHAP values for complex machine learning models can be computationally so expensive that practical implementation is not possible. To address this issue, we apply Slovin's Formula. This method is used in statistics to determine the appropriate sample size for a population, often used in market research and social science studies (Ryan, 2013). It is particularly employed when the population size is large, and the researcher wants to take a representative sample without studying the entire population. Due to computational constraints, we reduce the dataset size using Slovin's Formula in line with existing literature and supposing to not confusing results (Merrick and Taly, 2020). The formula goes as follows (Equation 10):

$$SF = \frac{N}{denom} \text{ where } denom = 1 + N * error^2 \tag{10}$$

where SF is the required sample size, N is the total population size and error is the desired level of precision. It's important to note that Slovin's Formula assumes a random sampling method and a simple random sample. If the sampling method is not random or if the population has specific characteristics, other sampling methods or adjustments might be needed.

4. DATA ANALYSIS

4.1 Introduction of datasets

We acknowledge the potential disparities between cities and submarkets within a country when it comes to real estate pricing. In this context, Blackley et al. (1986) provide compelling empirical evidence of the diversity in pricing across different cities. Dunse and Jones (2002) explain the existence of housing submarkets within the same city, attributing it to factors such as search costs, transaction costs, imperfect information, and a limited supply[1].

Our data deliverer, the Research Data Center (FDZ) Ruhr at RWI offers a unique dataset (RWI-GEO-RED) on German real estate prices, acquired from ImmobilienScout24. This dataset includes information on real estate purchase and rent prices and various characteristics that influence them. It is updated monthly and covers the period from January 2007 to June 2022. The dataset is divided into four separate categories: houses for sale, houses for rent, flats for sale, and flats for rent. ImmobilienScout24 is the largest online platform for real estate in Germany. They claim a self-reported market share of about 50% of all real estate listings in Germany (Schaffner and Thiel, 2022).

The dataset has a significant number of observations, enabling the analysis of small-scale housing markets. Users submit information about their real estate listings. The listed price should be understood as an offering price, not a binding transaction price. While listing prices may differ from actual transaction prices, they are widely accepted as a valid proxy in real estate research when selling prices are not available. Several studies demonstrate that listing prices provide a reliable indication of market trends and property valuation, particularly in markets with low negotiation flexibility or in cases where listing prices closely reflect seller expectations (Knight et al., 1998; Yavas and Yang, 1995). In the German residential rental market, the self-reported nature of listing prices combined with the competitive dynamics of urban housing markets minimizes the gap between listing and realized prices (Schaffner and Thiel, 2022). Moreover, prior research using similar datasets has shown that listing prices effectively capture key market dynamics and enable robust analysis (Lorenz et al., 2023; Krämer et al., 2023).

Advertisers can also include additional property-specific details to enhance their listings and potentially secure a favorable sale or rental price. The structural characteristics of properties encompass details such as property type, year of construction, year of modernization, living area, lot size, quality grade, condition, and the presence of features like a kitchen, parking spot, balcony, terrace, bathroom, or elevator. ImmobilienScout24 does not verify this information but cleans the data from implausible values (Schaffner and Boelmann, 2018).

To address potential price variations within local housing markets, we use the 1x1km grid information, which the RWI generates and applies to the whole German landscape. These grid cells maintain consistency over time and are evenly distributed across all of Germany. The grid level adheres to the EU directive's standardized European projection system, INSPIRE, ensuring that data on the same projection can be merged.

We combine the real estate data set with the RWI-GEO-GRID, also provided by the FDZ Ruhr at RWI. This dataset is based on the same 1×1 km raster. As far as our knowledge goes, the RWI-GEO-GRID is unique due to its combination of socio-economic data and spatial resolution for Germany (Breidenbach and Eilers, 2018).

The dataset provides a wide range of information for each grid cell, including details about households

[1] As we show in our literature review (section 2) the segmentation of real estate markets into submarkets is predominantly driven by the influence of location. Location-specific attributes, such as proximity to central business districts, transportation hubs or other neighborhood characteristics play a crucial role in shaping real estate values.

(e.g. household structure, children, unemployment rates, purchasing power etc.), demographics, mobility (car capability, car brands, and car segments), and building development (e.g. information on different house types). Additionally, the dataset comprises composition data like the number of households, the number of commercial enterprises, the number of houses (including pure commercial buildings), and the number of residential buildings (excluding pure commercial buildings).

We combine these two datasets and reduce RED to rental apartment data. Since our research focuses specifically on urban rental markets, predominantly consisting of rental apartments, we excluded single-family homes, semi-detached houses, and terraced houses from our analysis. Our dataset covers the period from 2009 to 2021.

The key variable of interest is the monthly rent per square meter (sqm). Each data point represents a real estate property listed on the respective platform, so that in summary, our analysis covers a wide range of property characteristics and geographic factors, providing a comprehensive view of the German residential rental market.

4.2 Preprocessing

Before working with the data, we must apply several preprocessing steps. Since all ML methods benefit from an abundance of valuable data, we aim to generate a dataset with zero missing values.

First, we remove features that are not relevant to our studies like geographical variables other than municipality information, incidental costs, warm rent, and various variables tracking the offers success on the platform like clicks, hits or maturity days. Second, to focus on the largest high-price markets, we drop all city observations except Berlin, Hamburg, Munich, Cologne, Frankfurt, Stuttgart and Düsseldorf. Afterwards, we drop columns with more than one-third of the missing data.

Subsequently, we address missing values in a contextually appropriate way. Some of the categorical features like elevator, balcony, garden, cellar etc. can either be "yes", "no" or "missing". As we stated above, the landlords provide the information voluntarily. Since they have an interest in not hiding information that qualifies for a higher rent, it is reasonable to assume missing values meaning no information provided to be equivalent to "no". Grounds for this procedure come from psychology literature like Katzenbeisser and Petitcolas (2016) and Huang and Yu (2014). We are aware of other handling techniques for missing values, but each of these leads to a conscious incorporation of information loss.

Additionally, we notice an inconsistency between the variables parking lot price and parking lot. There are cases where the parking lot is a missing value while the parking lot price is larger than zero. We assume that there is a parking lot available if landlords call up a price and drop the parking lot price due to many missing values (>33 %). Finally, we have 164.084 observations where the year of construction is missing while providing a year of modernization. In those cases, we take the year of modernization as the year of construction and drop the year of modernization due to a missing value ration above 33%.

For all variables in the GRID data set that have a percentage share as measuring variable we exclude respectively one feature from a group to exclude multicollinearity.

Finally, we perform some statistical data cleansing. For the continuous variables basic rent and living space we drop the 99.99%- and the 0.01%-percentile to exclude strongest outliers. For the year of construction, we have dropped the implausible and missing values. The preprocessing process leaves us with a dataset of 2.411.094 observations and 151 features including rent per sqm as our dependent variable.

Concerning the calculation of SHAP values and given the computational limitations associated with calculating SHAP values on a large dataset of over 2.4 million observations, we apply Slovin's Formula (see Equation 10) to determine an optimal sample size that balances prevision and representativeness. Using a commonly accepted error margin of 0.02 (Harfitalia and Pujangkoro, 2022), the formula provides a reduced dataset set of 2,946 observations. We verify the representativeness of the reduced dataset by comparing SHAP results between the reduced dataset and a randomly selected large dataset of 100,000 observations for the XGB model. The comparison indicates no significant differences (ch. 5.2), ensuring that the reduced dataset remains robust for our analysis. This reduced sample size enables efficient computation of SHAP values for the remaining models.

4.3 Variable description and descriptive statistics

Due to the large number of variables, we depict a comprehensive view in Table A1 (Appendix). Here we group the variables into the categories price information, object features, energy and structure information, regional information, time, neighborhood information, building development, household and population information. For every group variable we give a summarizing description, the elements of the features as well as statistical category of the element. We notice a strong predominance of dummy variables with both two-values and multi-value characteristics. All categorial variables

we make processable by one-hot encoding. We also factor in the year and month of the valuation to capture temporal trends and seasonality (e.g. year_2010 and month_2)

Table 1 presents the descriptive statistics for the non-percentage continuous features. The average monthly rent is 11.35 euros per sqm, with an average living area of 75.29 sqm and 2.52 rooms. The average apartment is on the second floor or third floor (mean: 2.53) and is approximately 56 years old.

Table 2 displays all existing manifestations of our dummies with the respective number of observations and the average rent per sqm for those expressions. We mark the feature expressions that lead to the highest mean rent. For our binary dummies the data behaves as anticipated: features such as the presence of elevators, basements and balconies are associated with higher rents (green mark), whereas assisted living, listed building and public housing lead to lower rents (red mark). Interestingly, the object equipment labeled as 'simple' shows the highest mean rent (orange mark), which may indicate that the explanatory power of object condition variables is limited or potentially confounded by other factors. For multinary dummies such as floor level or heating type we observe that higher-quality or more desirable categories (e.g. higher floor levels or modern heatings systems) are associated with increased rents, while lower-quality options (e.g. ground floor or outdated heating systems) align with lower average rents. This supports the notion that multinary dummies generally capture intuitive and expected patterns in pricing behavior.

Table 1. Key statistics for non-percentage continuous variables.

	rent per sqm	year of construction	living space	floor	number of rooms
count	2,410,690	2,410,690	2,410,690	2,410,690	2,410,690
mean	854.78	1,966.72	75.24	2.53	2.52
std	617.21	41.18	35.24	2.23	1.02
min	8	1,000	9	-1	0.5
25%	458	1,937	53.11	1	2
50%	680	1,972	69	2	2
75%	1,053	2,000	89.30	3	3
max	14,479	2,025	457	45	10

Table 2. Dummy variables, frequency and relation to rent per sqm.

Variable	Characteristic	No.	Share	Avg. rent per sqm
elevator	Yes	930,637	38.6%	12.97
	No	1,480,053	61.4%	10.33
balcony	Yes	1,724,974	71.6%	11.44
	No	685,716	28.4%	11.12
assisted living	Yes	30,100	1.2%	10.03
	No	2,380,590	98.8%	11.36
listed building	Yes	309	0.0%	11.18
	No	2,410,381	100.0%	11.35
fitted_kitchen	Yes	1,256,478	52.1%	12.77
	No	1,154,212	47.9%	9.80
public housing	Yes	54,115	2.2%	6.87
	No	2,356,575	97.8%	11.45
guest toilet	Yes	453,060	18.8%	12.83
	No	1,957,630	81.2%	11.00
garden	Yes	335,059	13.9%	12.22
	No	2,075,631	86.1%	11.21
cellar	Yes	1,531,950	63.5%	11.67
	No	878,740	36.5%	10.79

(Continued)

Table 2. (Continued).

Variable	Characteristic	No.	Share	Avg. rent per sqm
parking lot	Yes	720,013	29.9%	13.12
	No	1,690,677	70.1%	10.59
wheelchair_accessible	Yes	113,257	4.7%	16.75
	No	2,297,433	95.3%	11.08
equipment	Normal	548,668	22.8%	9.96
	Not specified	976,665	40.5%	10.23
	Simple	20,527	0.9%	8.89
	Sophisticated	737,686	30.6%	13.07
	simple	127,145	5.3%	16.31
energy efficiency class	APLUS	7,186	0.3%	16.54
	A	15,481	0.6%	16.09
	B	28,176	1.2%	15.87
	C	17,873	0.7%	13.6
	D	19,994	0.8%	12.78
	E	15,691	0.7%	12.58
	F	8,891	0.4%	12.68
	G	3,245	0.1%	13.01
	H	1,343	0.1%	14.4
	Not specified	2,292,810	95.1%	11.2
energy certificate type	Energy use	679,335	28.2%	11.16
	Energy demand	408,212	16.9%	13.56
	Not specified	1,323,143	54.9%	10.76
type of heating	Cogeneration/combined heat and power plant	10,238	0.4%	14.89
	District heating	141,310	5.9%	13.16
	Electric heating	3,334	0.1%	13.61
	Floor heating	109,573	4.5%	16.99
	Gas heating	73,138	3.0%	12.87
	Heating by stove	10,243	0.4%	9.53
	Night storage heaters	7,215	0.3%	10.75
	Not specified	363,918	15.1%	11.42
	Oil heating	18,193	0.8%	12.26
	Self-contained central heating	260,355	10.8%	10.26
	Solar heating	673	0.0%	14.83
	Thermal heat pump	6,952	0.3%	16.22
	Wood pellet heating	2,522	0.1%	16.69
	Central heating	1,403,026	58.2%	10.78
property condition	Completely renovated	308,617	12.8%	10.81
	Dilapidated	29	0.0%	11.90
	First occupancy	177,326	7.4%	15.50
	First occupancy after reconstruction	202,966	8.4%	12.16
	Like new	255,311	10.6%	14.28
	Modernised	180,418	7.5%	10.69
	Needs renovation	18,717	0.8%	7.61
	Not specified	504,750	20.9%	10.31
	Reconstructed	156,398	6.5%	11.08
	Well kempt	587,774	24.4%	10.18
	By arrangement	18,384	0.8%	8.78

Note: green marks indicate dummy values of 1 increases rent per square meter; red the opposite behavior; orange shows the highest value of the squared rent among several categorical characteristics.

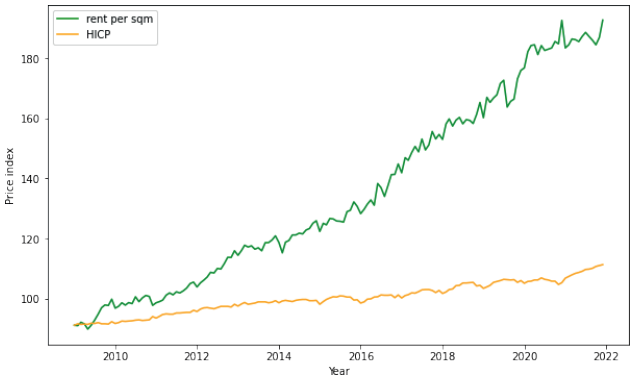

Figure 1. Rent per sqm and Harmonised Index of Consumer Prices (HICP) from 2009–2022.

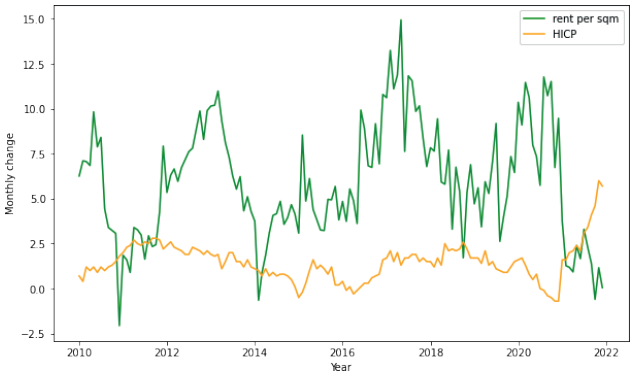

Figure 2. Yearly percentage change of rent per sqm and HICP.

Figure 1 displays the price development presented by the monthly average rent over the observation period as well as the general price level displayed by the Harmonised Index of Consumer Prices (HICP) published by the Deutsche Bundesbank. For both factors we see a constant growth being drastically more rapid for the rent prices. While the HICP moved from 91.1 to 127.2, average rent more than doubled from 91.1 to 192.76. Figure 2 lays focus on the yearly percentage change of both variables again making clear rents strongly outpace common price developments. But there are periods when rent price growth falls behind the HICP change. We see that around 2011 and 2014. Even more evident is the period from 2021 onwards, where the common price level is poised to exceed rents in the midterm. Figure 3 looks at prices over time periods across cities. By far the most expensive city over the whole period is Munich, followed by Frankfurt am Main and Stuttgart, which has seen a tremendous price increase from 2016 onwards. The remaining cities move in the same price range although Berlin is coming from a far lower starting point and has made a strong ascent.

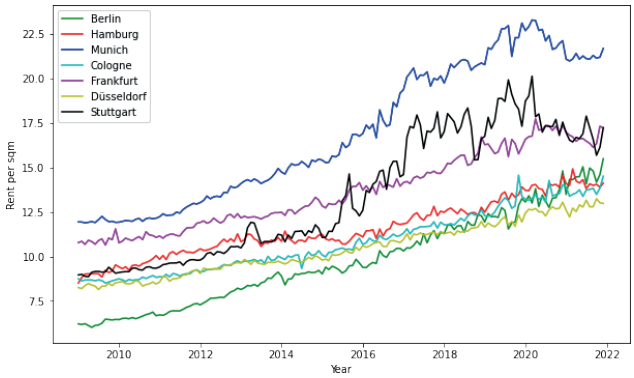

Figure 3. Rent per sqm of cities from 2009-2022.

In summary the data behaves as we would expect from a real estate dataset of the seven biggest cities in Germany and there were no conspicuous inconsistencies. Finally, the dataset was split into an 80% training set and a 20% testing set.

5. RESULTS

5.1 Prediction results

Although not the focus of our predictive study, residuals are an essential aspect, as they guide us in model improvements and ensure robust, reliable predictions. The literature on real estate price forecasts models, which focuses on model performance applies various residual metrics besides RMSE. And although they use metrics like Mean Absolute Error (MAE), Mean Squared Error (MSE), R-squared or Adjusted R-squared, RMSE is widely used for its comparability, error magnification and standard practice. Given its properties, RMSE provides a single, interpretable measure of model error in the same units as the predicted variable, making it particularly useful for communicating results to diverse stakeholders. While other metrics like MAE emphasize absolute deviations and R-squared measures goodness-of-fit, RMSE effectively balances by penalizing larger errors more heavily, offering insight into model performance under typical use scenarios. Consequently, for the purpose of our study, relying solely on RMSE is both practical and justified.

Table 3 summarizes the RMSE for all training and testing results. We initiate our analysis by training a standard OLS model. The RMSE for the training set is 2.96, while it is 2.95 for the test set. Subsequently, we apply statistical filters to address potential overfitting caused by superfluous variables. We apply correlation-

Table 3. Estimation results for train and test datasets over models.

		LR	Dt	XGB
RMSE	train	2.90	2.74	2.08
	test	2.89	2.75	2.12

based feature selection, k-best method, and low variance filters, but none demonstrate an improvement in the OLS model.

To introduce non-linearity, we incorporate squared and interaction terms based on univariate analysis. Squaring minimally improves the model (RMSE: 2.90 (train), 2.89 (test). So does including interaction terms, but to an even lower degree (RMSE: 2.94 (train), 2.94 (test)). Bootstrapping, aiming to make linear regression comparable to modern machine learning algorithms, does not yield improvements (RMSE: 2.95 (train), 2.95 (test)). Due to the at most marginal improvement through non-linearity, we retain simple OLS as our baseline model.

We further explore complexity by training a decision tree model with pruning to avoid overestimation. Hyperparameter tuning identifies optimal parameters as a maximal depth of 9 and minimal splits of 3, resulting in an RMSE of 2.74 for the training set and 2.75 for the test set.

Lastly, we employ an XGB model without hyperparameter tuning, yielding an impressive result of 2.08 for the training set and 2.12 for the test set. These findings align with established literature on ML in real estate market domain, as discussed in literature review in section 2.

5.2 SHAP analysis – preprocessing

As described in the data section (4.2), we reduce the dataset using Slovin's Formula (Equation 10), ensuring computational feasibility without compromising representativeness. This sample size facilitates a detailed SHAP analysis while maintaining the validity of our finding. This leaves us with a sample size of 2,946 observations. SHAP values for XGB, even with reduced data, demonstrated consistent feature importance. Table 4 shows the evaluation of the deviations between the calculated SHAP values of the reduced data set, and a random sample set of 100,000 observations. The average absolute deviation between respective features is just 0.001, the largest difference is 0.02. Overall, we find only 16 out of 150 features that show any deviation at all, and of these, the deviation is only 0.01 for 13 of those features. The results confirm the chosen data reduction methodology to be valid and reliable, so that we use it as the basis for all subsequent applications of SHAP values.

Table 4. Deviation analysis between Slovin's-Formula-reduced and large dataset.

Mean Diff. (abs.)	0.001
Max Diff. (abs.)	0.02
No. non-zeros	16
No. 0.01-Diff.	13

5.3 SHAP analysis – results

This section provides a detailed description of the insights and findings based on SHAP evaluation, culminating in a bullet-point overview at the end of the section. Figure 4 delineates that the LR model predominantly derives its predictive outcomes from the variable denoting the percentage of households with a German head (German (%)). The associated SHAP value of 4.73 markedly surpasses the subsequent significant influence, namely, the count of residential buildings (houses) (1.47). The discernible discrepancy between these two pivotal variables is comparatively diminished within the context of the decision tree. The foremost variable, namely, the share of the Muslim population (non-European Islamic (%)) (1.18), is marginally separated by a mere 0.06 from the second-ranking variable, denoting the city of Munich (1.12). Furthermore, the subsequent features contribute more significantly relative to the primary variable in comparison to the LR model. This observation also holds true for the XGB model, where the differential impact between the leading two features is quantified at 0.23 (1.01 vs. 0.78).

Additionally, the findings indicate a noteworthy disparity in SHAP values, with those associated with LR generally exhibiting substantially greater magnitudes than those observed for DT and XGB models. Table 5 presents the cumulative mean SHAP values (Conceição, 2023), unequivocally illustrating the pronounced preponderance of LR SHAPs (LR: 36.01; DT: 6.94; XGB: 11.06). In conjunction with our understanding that LR demonstrates inferior predictive efficacy, we can deduce that this suboptimal performance stems from the inherent granularity of individual influencing variables or in other words LR tends to overshoot in predicting the target variable.

Furthermore, an insightful revelation from the SHAP analysis is the comparatively diminished signifi-

Table 5. Cumulative mean of absolute SHAP values.

	LR	DT	XGB
SHAP sum	36.01	6.94	11.06

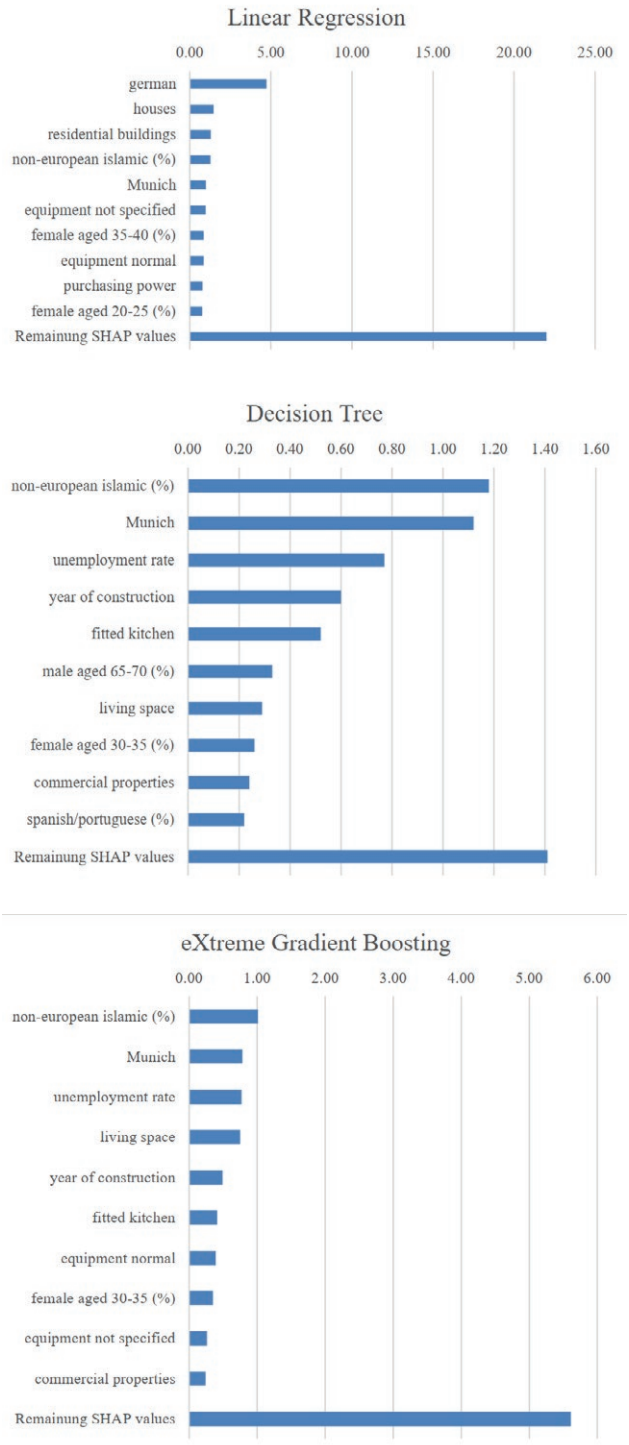

Figure 4. SHAP summary plot for top 10 features.

cance of dummy variables in LR as opposed to the other models. Table 6 provides a summation of the mean absolute SHAP values, accompanied by the percentage allocation of dummy and remaining SHAPs for each respective model (Conceição, 2023). This dual representation ensures comprehensive coverage of 100%. Notably, the proportion of dummy variable SHAPs is least prominent for LR (27%), experiencing a 5-percentage point increment for DT (32%) and further escalating by an equivalent magnitude for XGB (37%). Consequently, we observe an augmentation in the significance of dummy variables with escalating model complexity. This outcome aligns with intuition, given that dummy variables, characterized by binary states, possess inherently weak predictive prowess in comparison to continuous influencing variables, particularly in the absence of permissible interaction terms. It is pertinent to highlight that both DT and XGB, owing to their multilayered structure, facilitate multiple interactions among diverse explanatory variables. This structural attribute allows the relatively coarse predictive influence of a dummy variable to undergo refinement through its interrelation with other variables.

Table 6. Cumulative mean of absolute SHAP values according to variable type.

	LR	DT	XGB
Dummy Variables	9.76 (27%)	2.20 (32%)	4.13 (37%)
Non Dummy Variables	26.25 (73%)	4.74 (68%)	6.93 (63%)

Table 7. Number of features with non-zero SHAP value average.

	LR	DT	XGB
No. Zero-SHAPs	22	104	25

Another salient feature discerned from the SHAP values is the notable disparity in the number of variables that play no role in the model, presenting a distinctive characteristic across models. Table 7 reveals that the count of features with an average absolute SHAP value of 0 is markedly elevated for the DT model at 104, in stark contrast to LR model (22) and the XGB model (25). This observation implies that DT, despite outperforming LR in predictive power with a lower RMSE, relies on fewer variables for its predictions. This would typically suggest a potential compromise in performance; however, the DT compensates by capturing more intricate interactions among relevant variables.

In contrast, a comparable number of variables are deemed relevant for the XGB model. Given its superior performance, one can infer that the allowance for higher complexity in form of more tree layers enables the inclusion of more features, thereby enhancing performance through the utilization of even deeper trees. This is sub-

Table 8. Top 10 features for DT and XGB.

Rank	DT	XGB
1	non-European Islamic (%)	non-European Islamic (%)
2	Munich	Munich
3	unemployment rate	unemployment rate
4	year of construction	living space
5	fitted kitchen	year of construction
6	male aged 65-75 (%)	fitted kitchen
7	living space	equipment normal
8	female aged 30-35 (%)	female aged 30-35 (%)
9	commercial properties	equipment Not specified
10	Spanish Portuguese (%)	commercial properties

Note: colored markers are utilized to represent the overlap between the top 10 features between DT and XGB models. Green indicates features sharing the same rank, orange features within the top ten but with differing ranks, and no color features not appearing in other top 10.

stantiated by Table 5, which illustrates that the sum of the average influence for XGB is nearly double that of DT (11.06 vs. 6.94).

The final insight directs our attention back to Figure 4, portraying the top ten most important features for each model. Examination of these top ten features for DT and XGB reveals a striking overlap. To enhance clarity, Table 8 employs colored markers to denote this overlap. Green signifies features present in the same rank for both models, while orange indicates features within the top ten but not in the same rank. The absence of color denotes variables that do not appear in the other model's top ten. The prevalence of green and orange fields underscores the robust concordance between the two models. Notably, the four features lacking counterparts endorse the notion that a more complex model adeptly accommodates dummy variables. This distinction arises as DT relies on two additional continuous variables (male aged 65-75 (%) and Spanish Portuguese (%)), whereas XGB achieves a similar effect through the inclusion of the two dummy variables, equipment normal and equipment not specified.

To summarize our results on model interpretability, our comparative analysis across LR, DT, and XGB models unveiled five compelling conclusions:

1. Variable Importance:
   - LR heavily relies on a single major variable, while ML models exhibit a broader perspective.
   - Dummy variables gain importance with model complexity.
2. SHAP Magnitudes:
   - LR SHAP values are higher, yet its performance is inferior to ML models.
3. Dummy Variable Significance:
   - Dummy variable importance increases with model complexity, especially evident in DT and XGB.
4. Model Complexity and Relevant Variables
   - A kind of U-shape relationship exists between model complexity and the number of relevant variables.
   - Top features for tree-based ML models (DT and XGB) are strikingly similar.
5. Number of Variables Playing a Role:
   - DT relies on fewer variables with high predictive power, whereas XGB embraces complexity, incorporating more features for enhanced performance.

Our meticulous analysis not only highlights the strengths and weaknesses of each model but also provides valuable insights into the nuanced interplay between model complexity, variable significance, and predictive accuracy. With a focus on practical applications and alignment with existing literature, this study offers a compelling blueprint for leveraging advanced modeling techniques in real estate market analysis. The results are not just numbers; they are a gateway to a deeper understanding of the intricate relationships that govern real estate dynamics, unlocking new possibilities for informed decision-making in the ever-evolving market landscape.

6. CONCLUSIONS

In this comprehensive analysis of predictive modeling for real estate market forecasting, our findings highlight the strengths and limitations of various techniques. Traditional linear approaches, such as OLS, prove to be suboptimal, with non-linearity introduced through squared and interaction terms failing to significantly improve predictive performance. DT models offer a notable improvement, particularly when pruned to avoid overestimation, but it is the XGB that emerges as the most promising, aligning with existing literature in real estate markets. The SHAP analysis provides valuable insights into the interpretability of these models, revealing patterns in variable importance and the impact of model complexity on the significance of dummy variables.

Beyond the technical findings, this study also offers practical insights into the drivers of rental prices in the German residential market. These results can provide a valuable foundation for public policy discussions, particularly in addressing housing affordability and urban planning challenges. For instance, the identified key features

influencing rental prices can guide government initiatives aimed at regulating rents or improving housing market transparency. While the primary aim of this paper was methodological, the results themselves offer actionable insights that warrant further exploration, particularly in collaboration with public institutes and stakeholders.

For future research deeper investigations into the implications of these results, especially regarding policy impacts and regional disparities, can enrich the field. Exploring the interaction between identified predictors and broader socioeconomic trends as well as extending the application of interpretable machine learning models to other real estate contexts, can further enhance the utility of these findings. By sharing this analysis with public governments or non-profit organizations, we align with the broader mission of contributing to societal well-being through impactful research.

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APPENDIX

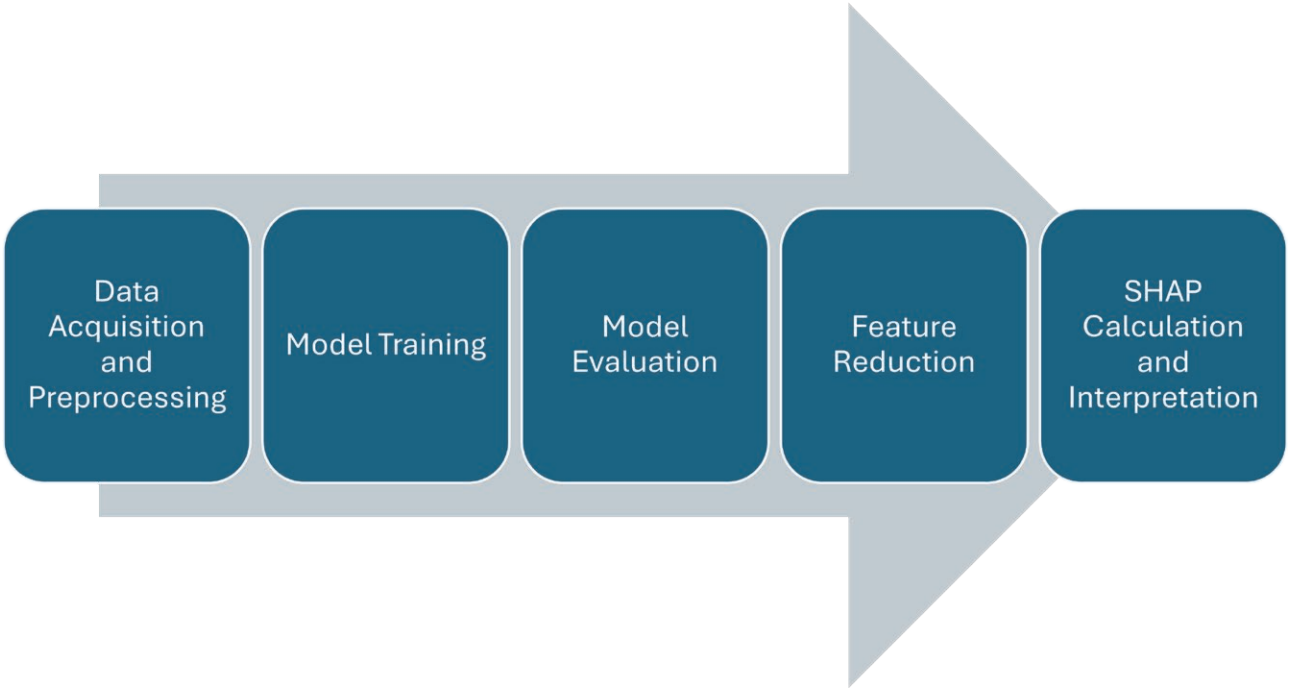

Figure A1. Global Methodological Framework. Note: The methodology begins with data acquisition and preprocessing, where data is collected from two sources and subjected to rigorous cleaning and preparation steps to ensure quality. The prepared dataset is then used to train three models: Ordinary Least Squares (OLS), Decision Tree (DT) and Extreme Gradient Boosting (XGB). Each model is evaluated using Root Mean Squared Error (RMSE). Subsequently, feature reduction is employed applying Slovin's Formula, to manage computational constraints while retaining representativeness. Finally, model interpretability is achieved through the application of Shapley Additive Explanations (SHAP) values, providing insights into feature importance and inner workings of each model.

Table A1. Total feature overview.

Category	Variable	Description	Analyis element within attribute	Variable type
RED				
Price information	rent per sqm	Exclusive rent per squared meter	Euro per sqm	Contiuous
Object features	year of construction	Year that object was built	Integer (Number of year)	continous
	living space	Living area	Number of square meters	continous
	floor	Floor on which object is located	Integer between -1 and 45	continous
	number of rooms	Number of rooms	Integer between 0.5 and 10	continous
	elevator	Elevator in object	Existence: Yes/No	categorical (dummy)
	balcony	Balcony at object	Existence: Yes/No	categorical (dummy)
	assisted living	Assisted living for the elderly	Existence: Yes/No	categorical (dummy)
	listed building	Protected historic building	Existence: Yes/No	categorical (dummy)
	fitted kitchen	Kitchenette in object	Existence: Yes/No	categorical (dummy)
	public housing	Public housing – certificate of eligibility is needed	Existence: Yes/No	categorical (dummy)
	guest toilet	Guest toilet in object	Existence: Yes/No	categorical (dummy)
	garden	(Shared) garden available	Existence: Yes/No	categorical (dummy)
	cellar	Cellar in object	Existence: Yes/No	categorical (dummy)
	parking lot	Garage/ parking space available	Existence: Yes/No	categorical (dummy)
	wheelchair accessible	Accessible, no steps	Existence: Yes/No	categorical (dummy)
	equipment	Facilities of object	Existence: Not specified, Normal, Sophisticated, Deluxe, Simple	categorical
Energy and structure information	energy efficiency class	Energy Efficiency Rating	Existence: Not specified, D, E, B, C, A, G, F, APLUS, H	categorical
	energy certificate type	Type of Energy Performance Certificates (EPCs)	Existence: Not specified, Energy use [Energieverbauchskennwert], Energy demand [Energiebedarf]	categorical
	type of heating	Type of heating	Energy Generation Systems · Gas heating · Oil heating · Thermal heat pump · Electric heating · Cogeneration/combined heat and power plant · Wood pellet heating · Solar heating Energy Delivery Systems · Central heating · Self-contained central heating · Heating by stove · District heating · Night storage heaters · Floor heating	categorical

(Continued)

Table A1. (Continued).

Category	Variable	Description	Analyis element within attribute	Variable type
	property condition	Condition of object	New Buildings · First occupancy · Like new · First occupancy after reconstruction Existing Buildings · Completely renovated · Modernised · Well kept · Not specified · Reconstructed · Needs renovation · By arrangement · Dilapidated	categorical
Regional information	gid2015	Municipality identifier (AGS, 2015)	Existence: Berlin, Hamburg, Munich, Cologne, Frankfurt, Stuttgart, Düsseldorf	categorical
Time period	year	Beginning of ad, year	Integer (Number of year)	continous
	month	Beginning of ad, month	Integer (Number of month)	continous
GRID				
Neighborhood information	Number of households	Absolute number	Integer	continuous
	Number of commercial enterprises	Absolute number	Integer	continuous
	Number of houses (including pure commercial buildings)	Absolute number	Integer	continuous
	Number of residential buildings (excluding pure commercial buildings)	Absolute number	Integer	continuous
Building Development	House type	Percentage per household	%	percentage
Household	Purchasing power	In Euro	Euro	continuous
	Household structure	Percentage per household	%	percentage
	Children	Number per household	%	percentage
	Unemployment	rate Share of the unemployed in the population	%	percentage
	Ethno	Percentage of households	%	percentage
	Foreigners	Percentage of households	%	percentage
	Payment default	Percentage of households	%	percentage
Population	Gender and age structure	Share of inhabitants w.r.t. sex and 17 age groups	%	percentage
	Population structure	Absolute number of inhabitants	%	percentage

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Valuing cultural ecosystem services: an application to forest areas in Marche Region, Italy

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Abstract. This article investigates the perceived relevance of cultural ecosystem services (ES) in two forest areas in the Marche region (Italy) and how users, tourists and locals value them economically. Two surveys were used to collect data from visitors to the two areas. Through Importance Performance Analysis (IPA), we assessed visitors' satisfaction with cultural ES in the two areas under investigation. The economic appraisal of the ecosystem services in the two forest areas was based on a contingent valuation method (CVM) using a double-bounded approach to estimate visitors' willingness to pay (WTP). This type of research, merging qualitative and monetary evaluation of ES can contribute to defining policy management by identifying aspects and activities in natural areas that require specific intervention. Evidence for the economic value delivered by a broader range of ES may support the definition of more effective policy measures for forest areas and create the basis for the definition of payment schemes for ES.

Keywords: cultural ecosystem services, contingent valuation, importance-performance analysis.
JEL codes: Q26, Q50, Q57, Z32.

1. INTRODUCTION

Global interest in the study of ecosystem services (ES) is increasing constantly. ES are defined as benefits people obtain from ecosystems and are generally classified into four main categories: supporting, provision, regulation and cultural, beyond the encompassing supporting category (Millenium Ecosystem Assessment, 2005). The most common examples are protection from hydrogeological instability, pollination, atmospheric regulation, wood supply and all recreational activities. The basic concept behind ES is that human well-being depends on the services provided by nature, and they, in turn, depend on the correct functioning of ecosystems (Haines-Young, 2010). For economists, the term "benefit" refers to an economic advantage provided

by an environmental good or service obtained from the sum of what all members of society would be willing to pay for its use (Barbier et al., 2011). Regardless of the valuation methods, cultural ES often provide the highest monetary value compared to all other services. Cultural services account for about 40% of the total monetary value of ecosystem services at the European level, with a total value of about 50 million euros, of which 62% are from forests (Vallecillo et al., 2019). Forest management, maintenance of accessibility conditions to natural areas, dedicated facilities, etc., are essential for the fruition of ES (Boyd and Banzhaf, 2007) and may represent costs for society and policy. However, economic benefits are difficult to quantify as most ES are public goods without a proper market and explicit monetary value. Consolidated environmental economics approaches for the appraisal of the total economic value of public goods refer to direct and indirect methods. These methods may provide a solution for the monetary value of a natural area but cannot provide a qualitative evaluation of the ecosystem services delivered. In this paper, we follow an integrated approach joining a formal evaluation of qualitative assessments of visitors to two forest areas based on an Importance-Performance Analysis (IPA) (Martilla and James, 1977), together with a contingent valuation method (CVM) using a double bounded model to economically value the willingness to pay (WTP) for cultural services. While CVM is an established approach for evaluating forest ecosystem services (Di Franco et al., 2021), few studies have used a double-bounded model to estimate environmental value in forest areas (Chatterjee, 2019).

The two forest areas, Monte Nerone and the Cesane Regional Forest are in the Marche region (Central Italy). Due to the high recreational attractivity of both sites, we evaluated the cultural ecosystem services identified according to the CICES classification. The two studies were carried out in the year 2022 for MN and in the year 2023 for CRF. The study at MN was part of the BIOSEIFORTE research program (financed by the Rural Development Plan of Marche Region). The study at CRF is part of a Research Agreement between UNIVPM and the local administration (Unione Montana Alta Valle del Metauro).

2. MATERIALS AND METHODS

The first part of the study is concerned with identifying the primary cultural ecosystem services in the two areas studied. In this phase, the CICES V5.1 hierarchical classification was applied to determine which services would be analyzed in the second phase. The next part of the study focused on qualitative and monetary evaluation of these services. Data were collected through a survey distributed to visitors of the two areas, gathering information to i) classify ecosystem services (ES) according to the Importance-Performance Analysis (IPA) methodology and ii) determine visitors' willingness to pay for the conservation of cultural services. This approach allowed us to assess tourists' satisfaction with ES and the economic value they assign to maintaining these services. Figure 1 presents a schematic overview of the ES selection and evaluation procedure implemented in this study.

2.1 Areas of the study: Monte Nerone and Cesane Regional Forest

The study involved two large forest areas in the province of Pesaro and Urbino (Marche Region, Central Italy): the Monte Nerone area (MN) and the Cesane Regional Forest (CRF). The two forests are respectively in the Apennines and pre-Apennines areas (Figure 2). Nevertheless, they have different characteristics due to their natural context, extension, and forest type, and they may be attractive to different cultural and recreational activities. MN is located at a higher altitude, is a broader area, and features a more diversified orographic structure, ecotypes, and landscape. MN is characterized by a forest mosaic and secondary grasslands intended for semi-wild grazing of native cattle and horses of the Catria breed. The MN area covers approximately 1800 hectares with a maximum altitude of 1525 m asl. MN is a typical semi-natural landscape of the central Apennines and represents a destination for hiking and speleological activities. The ownership of most forests and pastures in MN belongs to local rural communities. CRF extends for 1500 hectares at a lower altitude (max 650 m asl). It is mainly a coniferous evergreen forest, and in 2017, it was affected by a severe forest fire. CRF offers an unusual alpine forest landscape in rural farming surroundings. This specific characteristic is due to an extensive conifer plantation (mainly black pine) that was begun by the World War One Austrian prisoners and ended in the 1950s. The CRF was a State property until the 1970s, then attributed to the Marche Region and managed by the Unione Montana Alta Valle del Metauro (a consortium of municipalities in mountain areas) through a 10-year Forest Management Plan. The CRF territory is suitable for mountain biking, trekking and mushroom picking. Wildlife is present and very diverse in both areas, especially in the MN due to its higher naturalness. MN hosts the Natura 2000 Network sites, particularly a Special Area of Conservation (SAC) and

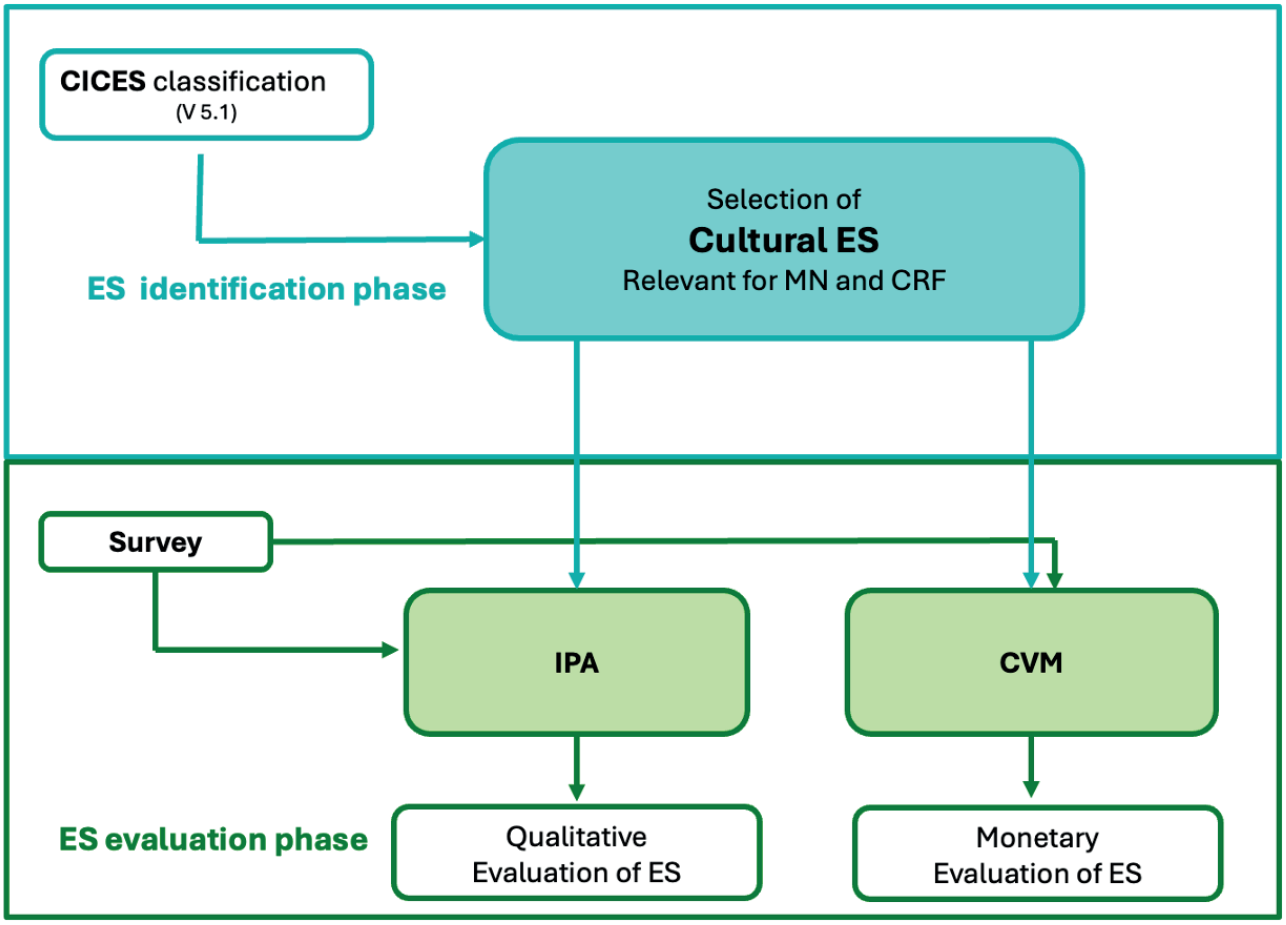

Figure 1. Procedure for selection and evaluation of cultural ES.

a Special Protection Area (SPA)[1]. CFR has lower wildlife potential, being primarily a conifer plantation, but its main high forest structure enhanced the occurrence of important species such as the forest diurnal raptors. In both areas, the presence of the wolf is well documented.

2.2 CICES V 5.1 classification for the identification of ecosystem services

The classification divides ecosystem services into three categories: provisioning, regulating and cultural with a hierarchical structure, which is then divided into divisions, class groups and class types. The hierarchical structure allows users to identify the most appropriate level of detail required for identifying relevant ES. Given our interest in cultural ES, we used the CICES V.5.1 classification because, among other acknowledged schemes (FAO, TEEB and IPBS[2]), it explicitly defines boundaries between ecosystem and society, describing cultural ecosystem services as "all the non-material and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people" (Haines-Young and Potschin, 2018, p. 10) For example, a recreational activity such as an excursion is not considered an ecosystem service but a final service such as a benefit from the landscape amenity or specific geomorphological layout. The V5.1 version is the most recent classification formulated by the European Environment Agency and the "System of Economic and Environmental Accounts (SEEA)" working group of the United Nations Statistics Division.

[1] https://www.regione.marche.it/natura2000/index-home.html (accessed 18 November 2024); https://www.unionemontana.altavalledelmetauro.pu.it/uffici/area-agricola-forestale-ambientale/rete-natura-valutazione-di-incidenza/piani-di-gestione-dei-siti-natura-2000 (accessed 18 November 2024).

[2] https://www.fao.org/fao-italy/it (accessed 18 November 2024); https://teebweb.org (accessed 18 November 2024); https://www.ipbes.net/global-assessment (accessed 18 November 2024).

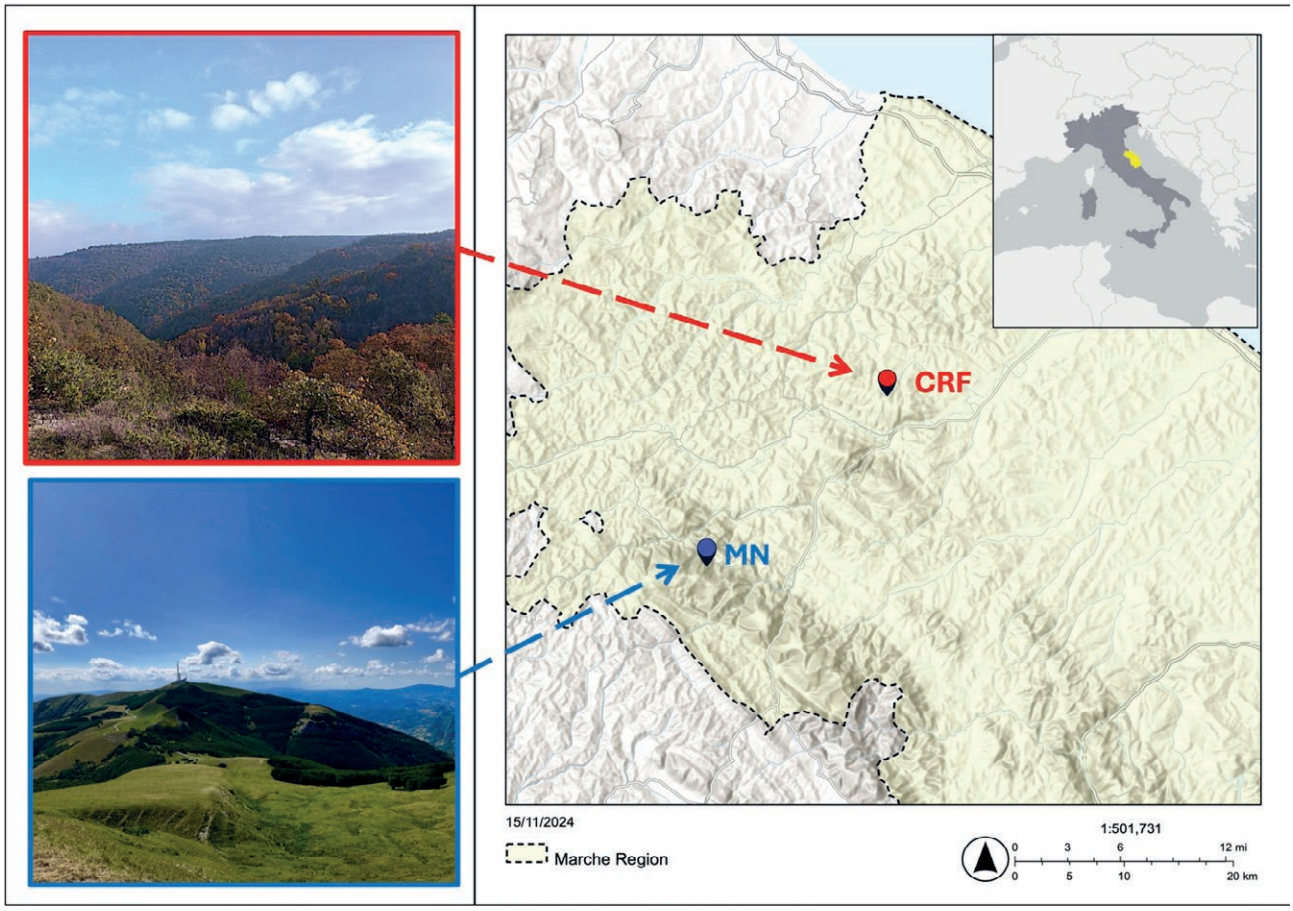

Figure 2. Locational map of the study areas: Monte Nerone (MN) and Cesane Regional Forest (CRF). (Source: Authors processing using administrative borders of the Marche Region).

The hierarchical structure of CICES classification allows the adaptation of ES selection to the specific characteristics, exploiting specific and detailed information available for the two study sites.

2.3 Importance- performance-analysis

IPA (Martilla and James, 1977) is based on the theory of customer satisfaction and compares measures of importance and performance for a set of indicators within a two-dimensional space. Due to its simplicity and practical result interpretation, IPA is widely applied in various sectors such as tourism and leisure, banking, healthcare, etc. (Boley et al., 2017). Fan et al. (2023) assessed cultural ecosystem services in different forest areas in China using IPA to compare ES classification across different natural areas. Other recent IPA applications in the field of environmental studies and the definition of management strategies in recent years refer to Chen et al. (2021), Gambelli et al. (2021), Wu et al. (2022), Suryan and Lee (2024). Deng (2007) discusses how IPA may contribute to supporting tourist attraction managers in making decisions on allocating scarce resources more efficiently and ensuring the highest level of tourist satisfaction. Boley et al. (2017) provide a study to evaluate sustainable tourism initiatives.

In our context, *importance* refers to the relevance that visitors assign to an ES according to their values and preferences, and *performance* refers to the degree of satisfaction for visitors related to the actual ES enjoyment in the MN or CSRF they visit. For instance, a visitor may consider the availability of tourist services as an essential feature but may find the actual availability of these services unsatisfactory when visiting a specific site. Scores for the importance and performance of specific ES are elicited through a 5-degree Likert scale.

IPA compares measures of importance (I) and performance (P) for the set of selected ES in a two-dimensional space. Each ES is uniquely placed in an orthogo-

nal axis diagram by its coordinates, which refer to the average scores for importance and performance. The origin of the orthogonal axis, or crossing point (CP), may refer to the sample mean (or median) of the importance and performance scores of the selected ES or to the Likert scale mean (Sever, 2015). Martilla and James (1977) suggest using the sample mean replaced by the sample median in cases of low variance. Oh (2001) recommends the scale mean, which facilitates result interpretation and comparison, but also considers the sample means as a possible alternative. The sample mean allows for a more effective ES classification. Our study considered the sample mean a crossing point as the output variance was relatively high, and the scale mean did not offer an adequate ES classification.

We have adapted the standard IPA classification to the context of ES valuation and defined the four IPA categories as follows:

"*Satisfactory*": ES with both importance (I) and performance (P) scores higher than their respective crossing points (CP). This category identifies ES that are satisfactory for visitors, as the experienced performance matches the importance they assign to that ES.

"*Unsatisfactory*": ES with I > CP and P < CP. This is the most critical category as it highlights where performance is inadequate compared to the importance attributed to the ES, indicating a need for intervention where possible.

"*Redundancy*": ES with I < CP and P > CP. This category indicates ES where performance exceeds importance, indicating a sort of "oversupply" for an ES with respect to the visitors' preferences.

"*Low relevance*": ES with I < CP and P < CP. This category pertains to ES, where both importance and performance are low; hence, ES may be considered irrelevant for visitors.

2.4 Contingent Valuation Method

The cultural ES considered in this study are non-market goods not subject to tariffs and are, therefore, typically pure public goods. These have no exclusive ownership and no rivalry among consumers (Tuati et al., 2022) and, therefore, escape the supply and demand laws regulating the market and generating a price. The contingent valuation method (CVM) (Alberini and Kahn, 2006; Mitchell and Carson,1989; Carson, 2012) is a widely used direct method for estimating the monetary value of environmental goods without an associate market price. CVM is based on determining people's willingness to pay (WTP) to obtain an environmental good or to accept compensation for not obtaining it (WTA) using a questionnaire compiled by a random sample of respondents (Hanemann, 1991).

The CVM is a direct method for assessing WTP because it involves people stating directly the values they ascribe to environmental goods (Turner et al., 1993). The main advantages of CVM are that it provides estimates independent of the actions taken, captures the value individuals place on environmental assets, and assesses the natural resources that people consider essential even if they have never visited them (Bateman and Turner, 1992). Furthermore, CVM takes into consideration non-use values. The quality of results from a CVM is conditional on how the survey or questionnaire is defined and distributed and on the attitude of respondents (Arrow et al., 1993; Bateman and Willis 2001; Carson et al., 2001, 2003; Mitchell and Carson, 1989; Portney, 1994; Sajise et al., 2021; Whittington, 2002).

Errors and biases related to the survey design can be summarized as follows:

Information bias arises if respondents do not entirely understand the good or service being valued. Inadequate or misleading information can lead to incorrect valuations. The survey must be designed so that responses are informed, not forced, and accurately reflect respondents' interests.

Starting point bias occurs due to an inappropriate (i.e. too low or too high) initial value suggested as a bid in a survey influencing respondents' valuations.

Payment vehicle bias arises when the payment method suggested in the survey (e.g., taxes, donations, payments for a service) can affect respondents' stated WTP. Some payment vehicles might be more acceptable or realistic to respondents than others. It is therefore important to clearly describe the payment arrangements and the hypothetical market, including the responsible parties and the expected benefits: the survey must simulate a satisfactory transition.

General biases related to the survey administration may refer to *design and sampling biases*. The first arises due to poor survey design, such as confusing or leading questions, that can influence respondents' answers. The second one arises when the sample of respondents is not random, is very small, or is affected by low response rates. This could skew CVM results, e.g. if some strongly involved respondents are over-represented in the sample.

Errors and biases that the attitude and stance of respondents may introduce can be summarized as follows.

Hypothetical bias occurs when respondents do not take the valuation scenario seriously because it is hypothetical. As a result, their stated WTP or WTA might differ from what they would pay or accept in a real-world situation.

Strategic bias arises from respondents' "free riding" attitudes, which might intentionally misstate their WTP or WTA to influence the outcome. For example, respondents might understate their WTP to avoid higher costs or overstate their WTA to receive more compensation.

Moral effects may skew CVM results if respondents express a WTP that reflects their general goodwill or moral satisfaction from contributing to a cause rather than the actual value they place on the specific good or service being valued or if they give socially desirable answers if they feel judged by the interviewer.

These errors and biases can be mitigated mainly for those relating to the survey design and distribution. Errors related to respondents' attitudes are more elusive and may be controlled to some extent by trained interviewers. Table 1 summarizes the solution adopted to take the errors and biases of our CVM under control.

There are three primary approaches for eliciting WTP using contingent valuation. The first approach utilizes open-ended questions, where respondents are directly asked how much they are willing to pay for a described good or service within a hypothetical scenario. The second method utilizes payment cards, presenting respondents with a range of possible payment amounts from which they select the one closest to their valuation. The third method employs dichotomous choice questions. Here, respondents are presented with a hypothetical scenario and asked whether they would be willing to pay a specified amount (X), to which they may respond with either "yes" or "no". Our analysis followed a double-bounded dichotomous choice approach. The method was initially proposed by Hanemann et al. (1991). For applications and discussions of this method in environmental studies, see also Hanemann (1994), Batemann and Willis (1994), and Carson Hand Hanemann (2005). The double-bound method asks respondents to accept paying an initial sum of money (bid). If the interviewee accepts the initial bid, a higher bid is proposed, which can be accepted or rejected. If the initial bid is rejected, a lower bid is proposed, which can be accepted or rejected. Initial bids cover increasing monetary values, and respondents for each initial bid are selected randomly. The advantages of the double-bounded approach can be summarized as follows. By asking a follow-up question with a different bid amount (higher or lower, based on the respondent's initial answer), double-bound models gather more information from each respondent while providing a lower and upper boundary to WTP, which cannot be considered in open-ended, payment card or standard dichotomous choice models. As a result, double-bound models reduce the variance of the WTP estimates, improving their statistical efficiency and leading to more precise estimates of willingness to pay (WTP). Also, they can mitigate the hypothetical bias as the second question in double-bounded models can help respondents think more carefully about their WTP, potentially reducing hypothetical bias. Finally, double-bound models mitigate the issue of starting point bias, as the second bid may "adjust" the initial response.

2.5 Structure of the conducted survey at both study sites

The survey for both MN and CRF was based on questionnaires sharing the same structure. These questionnaires were extensively pre-tested before distribution. An introductory section provided details about the general type of research, its authors, and its aims, namely, the evaluation of ES in forest areas. The second section of the questionnaire concerned the personal and

Table 1. Limits of the CVM and solutions to reduce errors.

Limits of CVM	Solutions adopted
Information bias	*Description of the environmental area: its potential and limits (example: fires). Description of possible scenarios with or without economic participation of tourists.*
Starting point bias	*A wide range of random values was chosen from 5 euros to 20 euros for MN and from 10 to 30 euros for CRF.*
Payment vehicle bias	*Pre-testing for different payment vehicles to check for ease of understanding and applicability to the context of the two areas*
Sampling bias	*Selection of a random sample and random initial bids. Compilation of survey with Qualtrics software with mandatory responses.*
Hypothetical bias	*Pilot administration as a pre-test. Detailed description of the current state of environmental assets and the possible future scenario.*
Strategic bias	*It was specified that the sum declared by the interviewee would have created a hypothetical market for research purposes and that they would not have to support any actual payments.*
Moral effects	*Survey administrators were trained in neutrality. Administration of the questionnaire to several interviewees that could make the sample statistically significant.*

demographic data of the interviewee. The third section of the questionnaire concerned questions about the characteristics of the visit (motivation, vehicles used, distance, etc.). The fourth and fifth sections hold questions for eliciting IPA and WTP assessment data, respectively. The questions for the WTP were explicitly adapted to MN and CRF. Questions concerning WTP analysis were asked after the interviewees answered those concerning the importance and performance of the various ES. In this way, we expect their statements about WTP to be expressed after a cognitive evaluation of the areas, hence providing more reliable evaluations.

For MN, we considered the purchase of a car parking ticket for access to different car parking areas as a payment vehicle. The initial bids were 5, 10, 15, or 20 euros per daily ticket that could be used in different sites of the broad mountain area. The unique payment for parking in different areas was used as a payment vehicle due to the simplicity and intuitiveness of payment and the extension of the MN area.

In CRF, we instead asked for the willingness to pay money to contribute to wildfire prevention actions within the sustainable forest management framework. The reason for this payment vehicle was that in the summer of 2017, 150 ha were burned in the CRF. The fire had a considerable emotional impact on visitors and seriously compromised the accessibility to the area for various years. In the CRF questionnaire, we provided information about possible forest disturbances (e.g., fires, frost, wind, insect epidemics) that could have reduced services offered by the forest. For CRF, the initial bids were set as 10, 20, or 30 euros annual payments.

Qualtrics software was used to manage questionnaire distribution and data collection. Questionnaires were distributed face-to-face to visitors for MN and CRF and online. Social media were used for online distribution in collaboration with outdoor and cultural associations. Only respondents who visited the study sites at least once were considered. Consent for data processing according to European data regulation was requested as a necessary condition for compiling the questionnaire. We excluded incomplete questionnaires from the analysis. After removing cases with incomplete responses, we selected and processed 88 questionnaires for MN and 114 for CRF. The samples of visitors for MN and CRF cannot be considered representative of the population, and some differences are presented in Fig 5 and discussed in section 3.2. Also, questionnaires were distributed in the summer months, when the number of visitors was higher. The seasonal bias of data collection should be taken into consideration when interpreting the results of the analysis.

3. RESULTS

3.1 Identification of Cultural Ecosystem Services

The selection of the relevant Cultural ES for MN and CRF was managed mainly through the collaboration with local stakeholders involved in preliminary ES selection in the BIOSEIFORTE research project for MN and in the Research Agreement for the CRF. On-site inspections and participatory meetings with local stakeholders were used as the basis for the final ES selection.

The services identified are listed in Table 2. Exploiting the possibility of including non-listed ES in CICES V5.1 protocol (identified by generic ES service with two last digits "xx" code), we added "refreshment opportunities", "environmental education activities", "guided nature tours", and the "presence of historic sites" to the standard CICES classification (Table 2).

The final selection of ES is common for both MN and CRF. The satisfaction of visitors for these ES were analyzed in the IPA.

3.2 Main visitors' characteristics and features of the visits

The second and third sections of the questionnaire referred to the visitor's demographic data and the features of the visits for the MN and CRF (Figure 3). A chi-squared test was performed to check for statistical differences between the distribution of the various variables in the two samples. The two samples are statistically different for all variables except gender; therefore, we separated MN and CRF for IPA and WTP estimation.

For both areas, the share of male visitors is relatively higher than that of females. The most represented employment category is "employee", followed by a significant amount of "student" for both samples. Age distribution is more uniform for MN due to a large share of students visiting, while older visitors are more common at CRF. These data might explain why high-income visitors are more frequent at CRF. Concerning the general features of the visits, the average distance in CRF is shorter than in MN, with nearly 70% of visitors from less than 30 km. The short distance covered by visitors of CRF may be the reason for the higher number of visits per year in this area, even if for both areas, the interviewee mostly visits the place 2 to 5 times per year. Short distances may also be the reason for "word of mouth" as the primary source of information for the visit. Finally, "leisure" (walking, sport, and relaxation) is the most relevant reason for visiting both MN and CRF, confirming cultural ES's relevance at both sites.

Table 2. Selection of cultural ES in Monte Nerone (MN) and Cesane Regional Forest (CRF).

Section	Division	Group	Class	Class type	Code	MN cultural ES	CRF cultural ES	Reclassification of ES for IPA
Cultural	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	By type of living system or environmental setting	3.1.1.1	MTB trails, 39 CAI trails, horse trails, silvoterapic trail (CNR).	MTB trails, 16 CAI trails, horse trails	Hiking trails variety. Usability for disabled people. Usability for children
		Physical and experiential interactions with natural abiotic components of the environment	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions		6.1.1.1	11 underground cavities for speleological activities	Special surface geological formations	Hiking trails variety. Usability for disabled people. Usability for children
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge		3.1.2.1	3 floristic areas, 3 sites Nature 2000 network: SPA, SAC and SPA/SAC	3floristic areas	Richness of flora and fauna
			Characteristics of living systems that enable education and training		3.1.2.2.	Martelloscopes	Martelloscopes	Richness of flora and fauna
	Other characteristics of nature that have cultural significance	Other	Other	Use nested codes to allocate other cultural services from living systems to appropriate Groups and Classes	6.3.1.1	Presence of historical cultural sites. Tourist accommodation services		

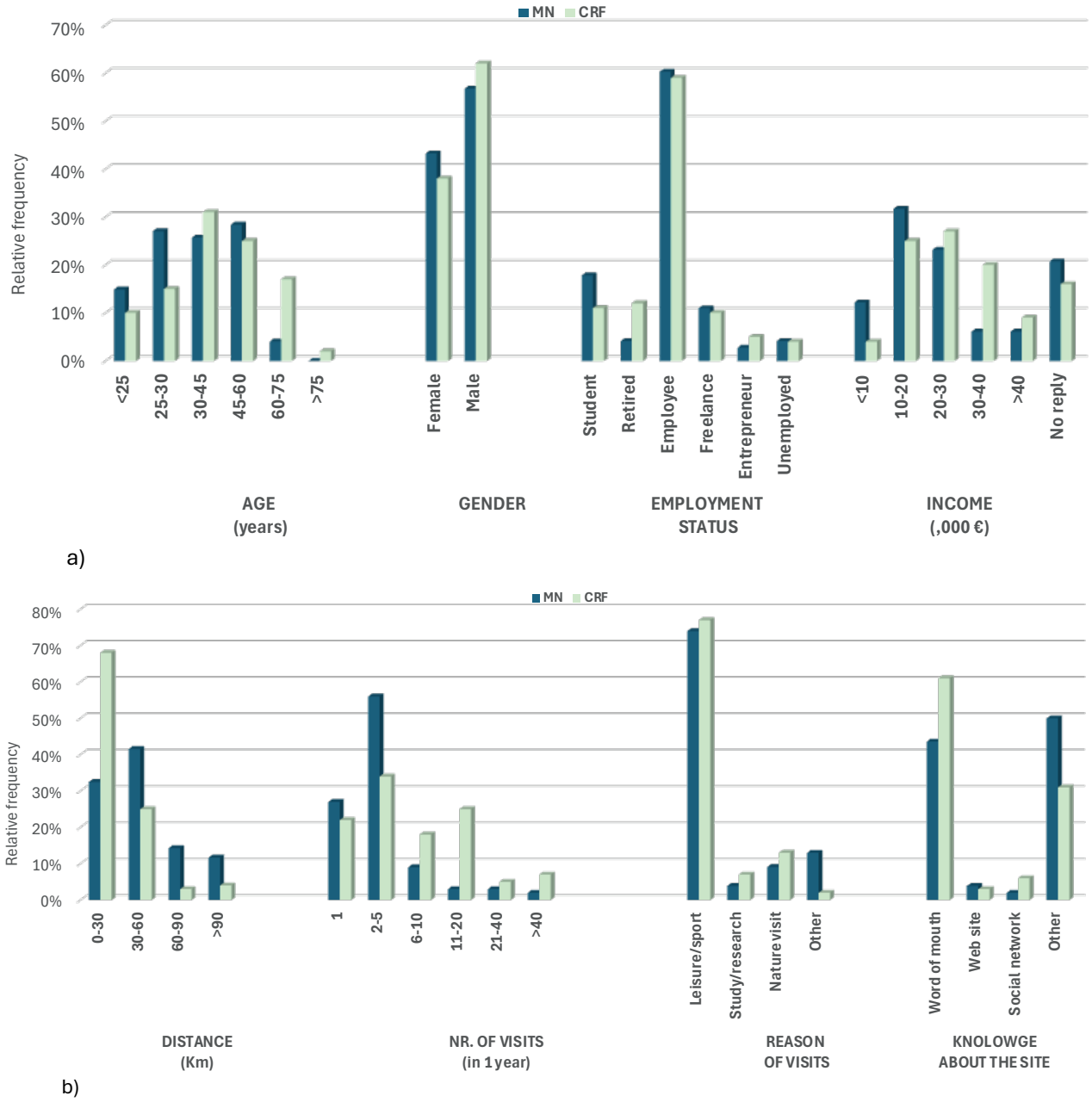

Figure 3. Demographic data (a) and visit features (b) for Monte Nerone (MN) and Cesane Regional Forest (CRF).

3.3 Importance Performance Analysis (IPA)

According to Martilla and James (1997), interviewee satisfaction is a function of two components: the importance of the product or service and the performance of the system that provides it. Importance and performance were rated by interviewees in both MN and CRF using a 5-point Likert scale. The results of the IPA are shown in Figure 4, where the selected cultural ES are placed in the four quadrants according to the average scores for importance and performance. Sample means were used as crossing point coordinates (Silva et al., 2011; Martilla and James, 1977). The overall outcome from IPA is that ES are broadly distributed on the bisector of the *Satisfactory* and *Low Relevance* quadrants. This result indicates that visitors' expectations are met in MN and CRF: the performance of ES (which indicates how much visitors have enjoyed the ES) is proportional to the importance

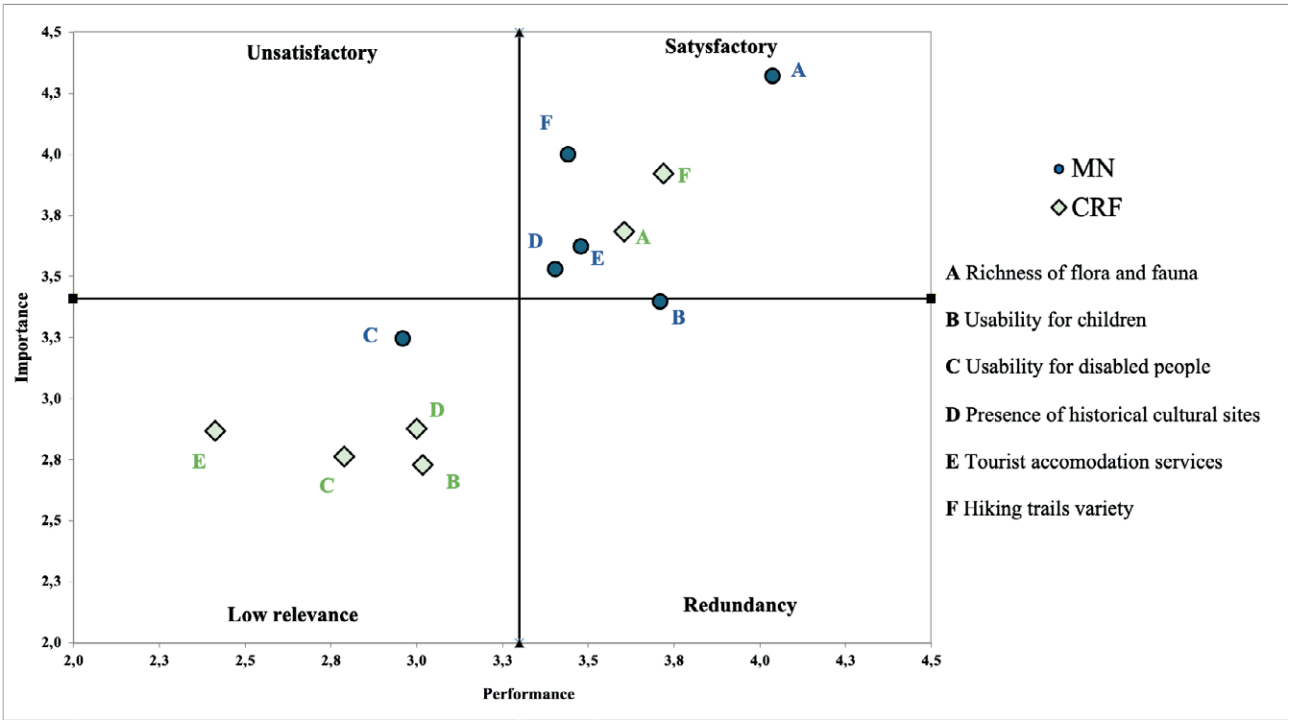

Figure 4. Classification of relevant cultural ES in the Monte Nerone (MN) and Cesane RF (CRF) areas according to visitors' perceived importance and performance (IPA).

they give to the ES. A second general result is that the number of ES classified as *Satisfactory* is higher for MN.

The "richness of flora and fauna" and the "hiking trails variety" are the two ES with the highest *Satisfactory* scores for both MN and CRF. However, some differences may be identified between the two areas. Given its wider environmental and ecosystem diversity (different forest types, grasslands, pastures, mountain peaks, etc.) MN has a higher animal biodiversity that hikers perceive better. CRF not only features a lesser landscape heterogeneity but also hikers perceive biodiversity mainly within the forest. The outcomes of "tourist accommodation services" are controversial. Accommodation services are available in MN and are more relevant here due to the larger size of the area and the longer travel distances for visitors.

On the other hand, the "low priority" classification of this ES for CRF may be due to the large percentage of visitors from neighbouring areas and the scarcity of local overnight accommodation. "Usability for children" was classified as *Satisfactory* for MN and *Low Relevance* for CRF. This result is related to the environmental features of the two areas. In MN, meadows become outdoor destinations for family, even in winter, and allow leisure and sports activities in the snow, which is unusual in the Marche region. Closed forests entirely cover the CRF area with some steep slopes, which may be unsuitable for children. Usability for people with disabilities was classified as *Low Relevance* for CRF and MN. This result might be conditioned by the lack of respondents with disabilities in the sample. Finally, visitors' satisfaction with the "presence of historical sites" in MN reflects the availability of heritage sites due to the broader area that includes villages and other historically relevant sites. The proximity of Urbino, a UNESCO heritage site, is not considered a relevant aspect for visitors to CRF.

3.4 Contingent valuation

For MN and CRF, final samples of 88 and 113 interviewees, respectively, were available for estimating WTP. For MN, 66% of interviewees stated that they would accept in principle to pay a sum for accessing the area (regardless of the payment vehicle); the percentage drops to 61% for CRF. Respondents who stated they would pay to access MN or CRF were asked to participate in the bidding procedure. WTP in the two areas was estimated using two payment vehicles (see section 2 for details). Initial bids were different for MN (5€, 10€, 15€, 20€) and CRF (10€, 20€, 30€) and were proposed randomly to interviewees. The distribution of acceptance and refusal for the different initial bids are shown in Table 3.

Table 3. Bids acceptance rates for Monte Nerone (MN) and Cesane Regional Forest (CRF).

MN Bid_1		MN Bid_2		
5 euro	No (0%)	*3 euro*	-	-
	Yes (100%)	*7 euro*	Yes (43%)	No (57%)
10 euro	No (23%)	*7 euro*	Yes (67%)	No (33%)
	Yes (77%)	*13 euro*	Yes (40%)	No (69%)
15 euro	No (61%)	*10 euro*	Yes (27%)	No (73%)
	Yes (39%)	*20 euro*	Yes (43%)	No (57%)
20 euro	No (54%)	*10 euro*	Yes (43%)	No (57%)
	Yes (46%)	*30 euro*	Yes (17%)	No (83%)
CRF Bid_1		CRF Bid_2		
10 euro	No (46%)	*5 euro*	Yes (100%)	No (0%)
	Yes (54%)	*15 euro*	Yes (58%)	No (42%)
20 euro	No (39%)	*15 euro*	Yes (25%)	No (75%)
	Yes (62%)	*25 euro*	Yes (57%)	No (43%)
30 euro	No (42.5%)	*25 euro*	Yes (11%)	No (89%)
	Yes (57.5%) *	*35 euro*	Yes (53%)	No (47%)

The bidding acceptance frequencies for MN show an overall inverse proportionality to bid level, except for the 20€ bid, showing an acceptance rate slightly higher than the 15€ bid. Bidding acceptance frequencies for CRF show a different pattern, where acceptance frequencies are almost uniform across the three bid levels, with the 20€ bid receiving the highest score. This result is not straightforward, and the reasons could be related to the relatively higher income levels of visitors, the local residence of most visitors, and the high frequency of visits in this area. All these aspects might lead to a firm commitment to protecting the CRF through the proposed payment for forest management and fire prevention purposes.

The estimation of WTP using the double-bound approach was performed with the *doubleb* command for STATA. Based on maximum likelihood estimation and developed by Lopez-Feldman (2012), the command allows for the direct estimation of the WTP value for double-bound models. Table 4 shows the results of the WTP, where Beta is the estimate of WTP and Sigma is the estimate of the model's variance. For both MN and CRF, the model coefficients are statistically significant. We also considered including explanatory control variables, such as demographic variables of visit features. Still, their contribution was not statistically significant and provided no improvement in the explanatory power of the models.

Table 4. Results of double-bounded estimation for WTP in MN and CRF.

	Coef.	Std. Err	z	P> [z]	[95% Conf. Interval]	
MN						
Beta	7.446355	1.408938	5.29	0.000	4.684887	10.20782
Sigma	10.74857	1.549162	6.94	0.000	7.712271	13.78487
				Nr of obs: 88		
				Log-likelihood: -115.23535		
CRF						
Beta	13.69401	2.343849	5.84	0,000	9.100147	18.28787
Sigma	20.08853	2.888438	6.95	0,000	14.4273	25.74977
				Nr of obs: 113		
				Log-likelihood: -144.56443		

4. DISCUSSION AND CONCLUSIONS

This study demonstrates that it is possible to analyze the valorization of services and environmental benefits linked to forests, considering the wide range of ecosystem services beyond the wood product supply. Today's forests, especially in the Apennines, are no longer used solely for timber harvesting, which remains a significant opportunity for local owners if practised through adequate forest management plans. Several forests today have lost their production functions and became suitable sites for enhancing other utilities such as outdoor recreation, environmental education, etc. Therefore, public and private forest management should consider providing products and services as society requests today (Mammuccini, 2004; Suryawan and Lee, 2024).

Based on the CICES classification, this study identified various cultural ecosystem services provided by the MN and CRF areas. Through empirical assessment of user evaluations of the area, most respondents appreciate these services; many are willing to pay sums of money to maintain these services through measures oriented towards sustainable forest management.

IPA results show a generally satisfactory valuation of ES, particularly for MN. Visitors' expectations are generally met in both areas, but the satisfaction is higher for MN. The "richness of flora and fauna" and "hiking trail variety" obtained the highest satisfaction scores in both areas. Only the "accessibility for disabled people" is critical for MN.

The WTP values, namely 7.50 euros for MN and 13.70 euros for CRF, cannot be directly matched as different payment vehicles were considered according to the different characteristics of the two areas. However, studies concerning WTP related to forest areas in Italy, though if using different estimation methods, provide quite similar results. Riccioli et al. (2020) investigated the WTP for the potential income deriving from the

tourist-recreational value of the forest divided into management methods, coppice, tall trees and free evolution. They used the open method and identified an average WTP of 7.70 euros for tall trees. Sgroi et al. (2016) assessed payments for ecosystem services for Mediterranean forests in Sicily, identifying a WTP between 10 and 12 euros. Dimonopolous et al. (2022) estimated WTP based on CVM to protect a national forest area in Greece with a mean willingness to pay per household between 5.5-9.5 euros per semester. Paletto et al. (2015) estimated tourists' WTP for visiting the Austrian Alps to be around 10.7 euros.

Except for the payment of a mushroom picking permit in CRF, there is no remuneration for Services, such as landscape and recreation analyzed in this study, as well as the slope erosion risk reduction or climate mitigation provided by the forests or are particularly relevant for society. There is an apparent contradiction between the presence of significant positive externalities produced by the forest regarding society benefits and the absence of adequate remuneration or public financial coverage capable of 'internalizing' at least partially the generated benefits. The lack of adequate support for ES might jeopardize the stability of ecosystem service provision through adequate forest management measures. Our study may provide a basis for the definition of supporting policies for the two forest areas, which could also consider introducing some form of payment for ecosystem services (PES). Regional forest laws and regulations should be revised and promoted, as suggested by European directives (Forest Strategy 2030) and National laws (TUFF 2018); the valorization of forest utilities such as forest and ecosystem biodiversity, both very sensitive to climate changes. PES (Wunder, 2018; Muradian et al., 2010) are financial incentives for maintaining or enhancing ecosystem services. Payments are based on private agreements or may consider the participation of public local authorities. The general aim would be to align economic benefits to environmental conservation for forest areas, encouraging sustainable practices by compensating landowners or resource managers for their activities' positive impacts on ecosystem functions and services.

This study assessed only a specific type of ES offered by CRF and MN forests. It would be interesting to reiterate the analysis in different seasons to check for possible differences in the evaluation of ES due to different seasonal contexts of the forest areas. Also, extending the analysis to the other ES categories, namely provisioning and regulating, would provide a more comprehensive framework of the overall benefits in the two areas. Finally, surveys for collecting data concerning the number of visitors per year in the two areas would allow a comprehensive estimation of the economic value of MN and CRF.

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Impact of the armed conflict on environmental safety and resilience of the urban environment in Ukraine

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Abstract. The article aims to examine how the armed conflict affects the environmental safety and resilience of the urban environment in Ukraine. The author analyzes the impact of infrastructural, social, economic, and environmental resistance on the city's ability to maintain a socioeconomic and ecological balance and minimize the mass destruction of its infrastructure. The article employs general scientific and special methods, including theoretical generalization, comparison, systematization, abstract-logical, prognostic, logical, and analytical methods. The article relies on an integrated approach when assessing environmental safety and its preservation; it primarily involves implementing preventive measures necessary to ensure the viability and sustainability of urban areas in the conditions of war and after its end. The findings confirm that a close interaction between public authorities, scientific institutions, public organizations, and the population can help to achieve sustainable development and urban environment safety in Ukraine. It is suggested to focus on climate-neutral post-war recovery and strengthen the potential of territorial communities in further scientific research.

Keywords: environmental consequences of war, environmental safety, public administration, public authorities, resilience, urban environment.
JEL code: K32.

1. INTRODUCTION

In the current conditions of the war in Ukraine, issues of environmental safety and resilience of the urban environment are of particular relevance. Military actions lead to infrastructure destruction, environmental pollution, and disruption of living conditions in cities. This creates additional risks to public health and complicates access to basic services and resources. New challenges are also associated with the restoration of the destroyed areas. The most critical problems are the damage or destruction of utility systems

and transportation infrastructure. The population's limited access to vital resources, such as water, threatens sanitary conditions. When Russia blew up the Kakhovka hydroelectric power plant in 2023, the water that spilled from the Kakhovka reservoir flooded many communities and killed dozens of residents and thousands of animals (Ivanova, 2024). In addition, Ukraine has lost its irrigation system and drinking water, which were supplied from the Kakhovka water reservoir. Chemical leaks and damage to industrial or agricultural enterprises increase the environmental burden on already exhausted ecosystems. A dire threat was the loss of control over radiation-hazardous facilities caused by the occupation of the Chornobyl Nuclear Power Plant in 2022. Russian military personnel detonated the ammunition used on the territory of the Zaporizhzhia Nuclear Power Plant (the largest in Europe) (Perha, 2023).

In such circumstances, a comprehensive approach is essential for assessing the state of the environment and developing effective strategies for maintaining environmental safety. This approach should go beyond emergency responses to immediate threats and focus on long-term planning. It should include technical and legal solutions, where the central focus is on urban resilience. It usually becomes an indicator of a city's ability to survive crises.

The principles of resilience developed by the Organization for Economic Cooperation and Development (OECD) deserve special attention within the framework of this analysis. The OECD defines resilience as the ability of subjects at different levels (individual, public, national) to withstand crises, adapt to them, recover, and function under long-term challenges, transformations, and uncertainty. The OECD emphasizes that the principles of resilience should be implemented from the lowest (household) to the highest (international) levels. These principles concern the following:

1) preparedness involves the availability of knowledge and capabilities for effective prediction, response, and recovery from dangerous events.
2) responsiveness concerns the ability to respond quickly and positively during and after a crisis.
3) connectivity is the degree of connection or separation between people, places, and things, the nature and strength of the interaction between the components of the system.
4) learning and innovation embrace the acquisition of knowledge or skills that change collective awareness and the emergence of new norms, ideologies, and institutions.
5) self-organization is the ability to create formal or informal networks, institutions, organizations, or other social groups, regardless of the state or other central authorities.
6) diversity and redundancy mean the presence of different forms, types, or ideas, as well as redundant capabilities and backup systems that allow for maintaining basic functions in case of failures.
7) inclusion is the involvement of various stakeholders in decision-making processes.
8) social cohesion is a sense of belonging and mutual respect between members of the community, as well as the relationship between government and citizens, which allows everyone to feel like an equal participant.
9) thresholds are clearly defined acceptable levels of well-being, access to rights and common resources (MacLeman et al., 2017).

The main goal of the OECD approach is to help systems plan, perceive, recover, and adapt to failures and minimize the negative impact on critical system functions. It complements rather than replaces traditional risk management practices, i.e. places a key emphasis on sustainability, modularity, and a holistic approach to ensuring system resilience. Resilience should be viewed through the prism of social harmony and the readiness of the population to self-organize. Creating a strong link between resilience and security is the key to ensuring sustainable urban development even in times of war. It is also an important component of the post-war reconstruction of the state. To respond to these challenges, this study focuses on the following question: How can sustainability principles be effectively integrated into the urban environment to ensure environmental security in wartime? The answer to this question is crucial for shaping urban development policies and strategies.

2. THEORETICAL FRAMEWORK

Analyzing the evolution of the meaning the concept of resilience conveys, it is safe to say resilience has an interdisciplinary character, combining different areas of cognition. However, there are a few domestic studies in the area of public administration, where resilience is considered at the urban level through the prism of environmental safety. The first definition of resilience, brought into scientific use by such researchers as Smith and Werner, was associated with the physical properties of matter because of its resistance to restoring a deformed form. Later, the term began to be used in psychology and interpreted as psychological flexibility, stress resistance, etc. Some aspects of resilience are studied in the scientific works of Pyrozhkov et al. (2021), which are devoted to

national stability in the modern world. The author considers various aspects and factors affecting the sustainability of the state, suggesting methodological approaches, models, and strategies to ensure it.

Pakhnenko (2022) interprets the concept of local community resilience (sustainability) and analyzes its component elements. The researcher examines how communities can navigate and overcome challenges, ensuring sustainable development and population well-being. Ivaniuk (2022) scrutinizes the main theoretical aspects of resilience in the context of socioeconomic systems. The author determines key concepts, models, and approaches to understand and evaluate the ability of socioeconomic systems to adapt and withstand external influences and stressful situations. In the context of this study, the scientific research of Melnyk (2024), Klymenko and Ukhnal (2023), and Sukhodolia (2023) are of greatest interest. Defining the specifics of implementing critical infrastructure resilience, Melnyk (2024) emphasizes that it (critical infrastructure resilience) "reflects its ability to adapt to changes and recover after the emergence of crises." Implementing a resilience paradigm in Ukraine's critical infrastructure is crucial for national economic security and sustainability in the face of growing threats and risks (Klymenko and Ukhnal, 2023).

Instead, Serzhan (2023) reveals the features of implementing the resilience of the urban environment in Ukraine against the background of global challenges; the researcher generalized the everyday experience of citizens' lives during the war to understand the stability of the urban environment in practice. According to the researcher, sustainable cities can absorb, recover, and prepare for future shocks (economic, environmental, social, or institutional); they contribute to sustainable development, well-being, and inclusive growth. Kachuriner (2022) and Melnik and Sierova (2023) consider critical infrastructure resilience through the promotion of specialization, competition, economies of scale, innovation, and technology transfer at the global level. Bezditnyi (2024) notes that trade can help reduce production costs and achieve better environmental results under such conditions. Thus, the experience of the citizens' lives in Ukraine during the war is an important lesson for the development of sustainable, adaptive, inclusive, and recession-proof urban environments.

3. MATERIALS AND METHODS

The impact of the armed conflict on environmental safety and the resilience of the urban environment in Ukraine was grounded on the study of many legal, scientific, and analytical materials. The materials analyzed in this study consisted primarily of two main sources: 1) normative and legislative acts regulating environmental safety requirements, and 2) scientific works by domestic and foreign authors. These materials served as the foundation for analyzing how the ongoing armed conflict has disrupted urban environments in Ukraine, impacting their capacity to sustain environmental safety and resilience.

Legal frameworks play a critical role in regulating environmental safety in Ukraine. The study examined the normative and legislative acts in place to safeguard the environment under armed conflict. These legislative acts included national laws of Ukraine, in particular the Law of Ukraine "On Environmental Protection" (Verkhovna Rada of Ukraine, 1991) and the Law of Ukraine "On Ensuring the Rights and Freedoms of Citizens and the Legal Regime in the Temporarily Occupied Territory of Ukraine" (Verkhovna Rada of Ukraine, 2014) In addition, resolutions of the Cabinet of Ministers of Ukraine regulating environmental safety and emergency response were analyzed. The article also presents the analysis of international legal acts on the protection of the environment during armed conflicts, such as the Geneva Conventions and Additional Protocols thereto.

The study reviewed scientific works by Ukrainian and foreign researchers who focused on environmental safety and urban resilience. The scientific literature reviewed covered such issues as environmental degradation, urban infrastructure damage, resilience strategies, and post-conflict recovery. The review was conducted using various databases. Scopus, Web of Science, and Google Scholar were used to search for international articles. The National Scientific Repositories of Ukraine were used to extract domestic research. The criteria for selecting sources concerned the peer-reviewed articles published over the last 5 years and relevant to the research topic. A comprehensive analysis of the multifaceted impact of the conflict on Ukraine's urban environments helped to identify key trends and emerging challenges in maintaining urban environmental safety during ongoing hostilities.

Theoretical generalization, comparison, and systematization were used to investigate the theoretical foundations of environmental safety and resilience. By comparing various theoretical frameworks, the research systematically categorized key concepts related to environmental impact, urban resilience, and conflict dynamics. The method of comparison was particularly useful in contrasting domestic and international approaches to environmental safety and resilience in conflict-affected urban areas. The abstract-logical and prognostic meth-

ods helped to formulate the purpose, objectives, and conclusions. The abstract-logical approach facilitated the development of conceptual models that explain the relationship between armed conflict and environmental degradation in urban areas. Prognostic methods were employed to forecast the potential impacts of ongoing conflict on urban resilience. These methods were critical in hypothesizing about long-term environmental challenges and the necessary policy responses. The analytical method allowed for a critical synthesis of the most recent scientific research on the subject. This method provided for generalizing the latest scientific developments by leading Ukrainian and foreign experts on eliminating the effects of the armed conflict on environmental safety and urban resilience. The method also allowed the identification of gaps in existing research. The logical method was employed to clarify and expand the conceptual and categorical apparatus related to the research topic. This approach was instrumental in refining key definitions, such as environmental safety, resilience, and conflict-induced degradation.

Thus, the research combines legal analysis, scientific literature review, and research methods to comprehensively examine the impact of armed conflict on environmental safety and urban resilience in Ukraine. By integrating these materials and methods, the study offers a holistic understanding of the ongoing challenges faced by Ukrainian cities and the strategies required to enhance their resilience in the face of conflict-induced environmental degradation.

4. RESULTS

Resilience of the urban environment is defined as the ability of a city to adapt to external challenges and threats, in particular, social, economic and environmental, as well as to withstand negative influences, adapt to changes and quickly recover from destruction (Lošonczi et al., 2022). In war conditions, resilience is of particular importance, as it ensures the preservation of the vital functions of the city. Cities must not only survive but also maintain functionality and ensure the safety of their inhabitants. It is the resilience of the urban environment that includes the city's ability to respond effectively to crisis situations, adapt to change and recover from shocks. This applies not only to physical infrastructure but also to social and economic systems that ensure the livelihoods of the city, each of which has its own manifestation and features (Clark, 2024).

Infrastructural resilience includes the ability of urban communications, transport, energy systems, water supply, and sanitation to withstand the load during a crisis and quickly recover from damage. Russia caused damage to the infrastructure facilities of Ukraine for almost $155 billion. As a result of hostilities and regular shelling, the number of damaged and destroyed residential buildings is increasing daily: as of January 2024, there are more than 250 thousand buildings. Among them – are 222 thousand private houses, more than 27 thousand – apartments, and 526 dormitories. Direct damage from the destruction of these objects is estimated at $58.9 billion (Figure 1).

Social resilience means the ability of communities to maintain social cohesion and help each other in times of crisis. This includes providing health care, education, and other social services. According to the data presented by the Rating Group in the conditions of hostilities, one-third of the polled Ukrainians suffered material losses as a result of the war. Among them, 62% of citizens living in the territories where there were or are still military actions, 52% of residents of de-occupied territories, and 23% – unoccupied territories (Figure 2).

Economic resilience lies in the ability of the urban economy to withstand economic shocks, keep jobs, and maintain business stability (Abrhám et al., 2018). Military actions affect the economy negatively, leading to the closure of enterprises, and a decrease in employment and incomes. The consequences of the war are its devastating impact and damage to infrastructure, and the lack of raw materials and labor, leading to the temporary or even complete closure of a large number of enterprises (Kyiv School of Economics, 2024). This, in turn, reduces production volumes, leads to mass dismissal of workers and increased unemployment, and worsens consumer demand and export opportunities. At the same time, 64% of Ukrainians have a drop in income. In particular, 18% of respondents have a slightly decreased income,

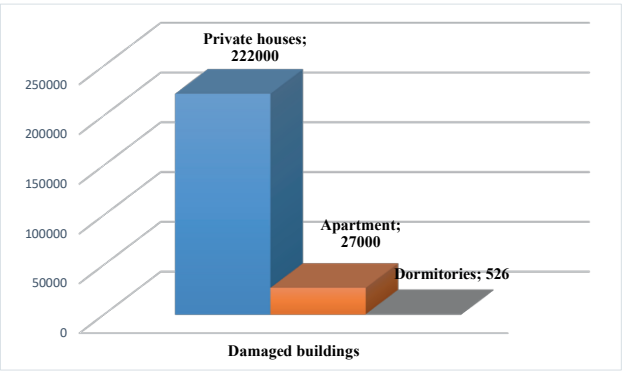

Figure 1. Direct losses from the destruction of infrastructure facilities of Ukrainian cities as a result of hostilities. Source: developed by the authors based on Pakhnenko (2022).

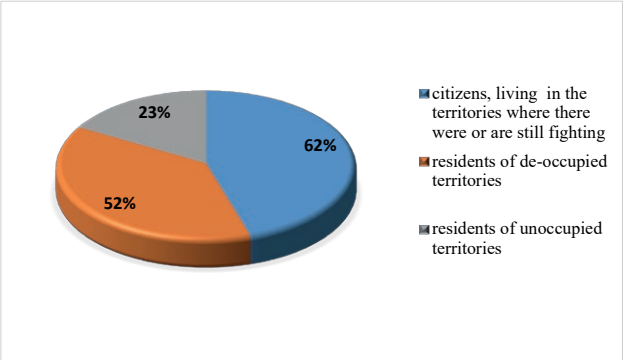

Figure 2. Material losses of Ukrainians as a result of the war. Source: developed by the authors based on the National Institute for Strategic Studies (2022).

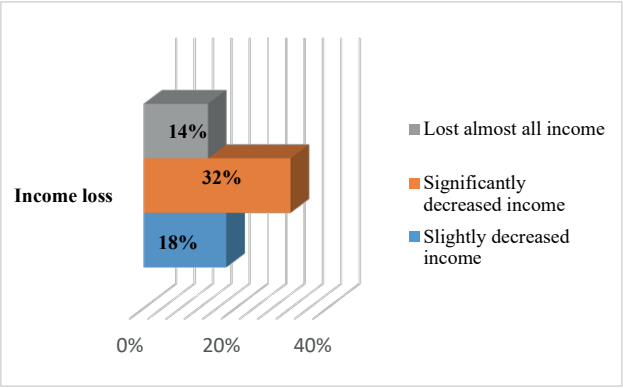

Figure 3. Dynamics of falling incomes of Ukrainians as a result of the war. Source: developed by the authors based on the National Institute for Strategic Studies (2022).

32% – have a significantly decreased, and 14% have lost almost all income (Figure 3).

The consequence of the decline in incomes of the population is the loss of jobs, the delay in salaries or their complete absence, and the depreciation of savings due to inflation. All this leads to a significant drop in the real incomes of citizens. Such processes cause a chain reaction when the mutual strengthening of negative economic factors unfolds in a deep economic crisis (Kimhi et al., 2023a). Overcoming such consequences of war requires considerable efforts and special programs of restoration and stabilization. Environmental resilience determines a city's ability to maintain ecological balance, protect natural resources, and minimize environmental impact (Bautista-Hernáez et al., 2024). The environmental damage caused to Ukraine by Russia's invasion already exceeds 2.2 trillion hryvnias. This amount includes destruction, damage from emissions of harmful substances into the atmosphere, pollution of soils and water resources, as well as the cross-border impact on neighboring countries such as Moldova and Romania. Approximately, every day these losses from a full-scale war increase by about 102 million euros (Kyiv School of Economics, 2024). It is important to pay attention to these consequences and look for ways to reduce the impact of hostilities on the environment.

Constant hostilities such as bombing and shelling of towns and villages have resulted in the release of large amounts of toxic chemicals into the environment. These dangerous chemicals have contaminated soil, water bodies and air, causing several negative health effects on the local population, in particular respiratory diseases, skin irritations and various types of cancer. A serious problem is the impact of military conflict on water resources, especially in conditions of active hostilities, which can lead to pollution of water sources with heavy metals (for example, from mining of water bodies) and nitrogen-containing compounds; destruction of infrastructure, including water and sewer systems, flooding of territories due to the destruction of dams (Kimhi et al., 2023b). Thus, the serious impact of the war on the environment of Ukraine is evidenced by the ecocide associated with the explosion of the Kakhovka Reservoir by the Russians, which led to the loss of 18 billion cubic meters of water and is a huge humanitarian, economic and environmental disaster in the Kherson region of Ukraine.

To this end, given the negative impact of hostilities on water resources, local governments need to: promote long-term planning of water supply through effective use of water, develop an action plan for the restoration of water potential through shoreline protection belts, install real-time water quality monitoring systems to detect pollution; ensure quick restoration of damaged water supply networks and structures. It is important to take into account that the preservation of water resources during military operations is not only an environmental necessity but also a humanitarian responsibility to the population. Another serious environmental problem during the war in Ukraine was the destruction of forests and natural habitats of wild animals. Constant bombing and shelling of forests caused significant damage to ecosystems, forcing many species of plants and animals to leave their homes. This significantly affected the biodiversity of the region, as well as the functioning of local communities that depend on forest resources.

The war also caused significant damage to Ukraine's infrastructure, including factories, power plants and oil refineries. This caused leaks and spills of hazardous substances such as oil, chemicals and radioactive materials, which further polluted the air, water and soil, creating

long-term health and environmental problems for the population of Ukraine. Despite these serious challenges, certain measures are being taken to solve environmental problems in Ukraine. International organizations, in particular the United Nations Environment Programme (UNEP), are supporting the cleanup of contaminated areas and the restoration of damaged ecosystems. The Government of Ukraine is also taking measures aimed at strengthening environmental legislation and increasing funding for environmental initiatives.

After all, to rebuild the country, we will need a significant number of resources. The destruction of entire cities, such as Mariupol, Irpin, Chernihiv, Kherson, the cities of Kharkiv and Donetsk region, led to problems associated with the formation of a huge amount of waste and the attraction of a significant number of natural resources necessary for the restoration of destroyed cities. Although today all the efforts of public authorities are aimed at "green reconstruction," however, such reconstruction requires as many building materials (metal, wood, cement, etc.) as was used in 10 previous years of development of the construction sector in Ukraine. This will be a long-term consequence of large-scale destruction. Accordingly, the resilience of the city's critical infrastructure requires the implementation of measures related to:

- an early warning and risk and threat response system;
- the ability of infrastructure to change flexibly in response to new conditions;
- development of action plans for recovery from accidents and emergencies;
- establishing cooperation with public crisis management bodies and other stakeholders for effective recovery;
- a comprehensive analysis of potential threats and weaknesses of critical infrastructure;
- performing a comprehensive assessment of risks and vulnerabilities of critical infrastructure that require increased attention;
- developing resilience plans and strategies that include anti-crisis measures for prevention, response, and recovery;
- implementation of the necessary investments to improve the technical condition and reliability of critical infrastructure, as well as the introduction of the latest technologies to ensure their rapid recovery from accidents;
- the development of cooperation mechanisms between public authorities, the public, and the private sector to coordinate actions in the event of a crisis, training, and studies of personnel to ensure their readiness to act in emergencies;
- the introduction of modern effective measures and mechanisms for protecting against cyber threats, which requires the allocation of the necessary financial resources (special attention – to the protection of city management systems, communications, and life support services);
- development and implementation of reserve systems and solutions that can ensure the continuous functioning of critical infrastructure in situations of hostilities at the level of territorial communities. This includes the creation of reliable shelters, backup energy sources, water supply systems, and logistics;
- improving the culture of continuous improvement and formation of practical skills and algorithms of actions under martial law among citizens, authorities, and city services. Regular updating of emergency response plans and staff training (Klymenko and Ukhnal, 2023).

All these aspects form a comprehensive approach to ensuring high resilience of critical infrastructure, which allows it to adequately respond to challenges and quickly recover from various crisis events. Such a sufficiently structured and comprehensive approach allows to ensure the stability of infrastructure to various failures and crises systematically. Taking into account all these components, it is important to effectively increase the overall resilience and ability to withstand various crises. As the experience of recent years shows, in conditions of crisis situations, especially those related to military operations, the role and importance of cities increase significantly.

Firstly, cities are economic, social and administrative centers, concentrating key infrastructure, population and administrative functions. Therefore, they become the main targets for influence in armed conflicts. Their damage or capture will have a devastating impact on the livelihoods of the regions and the country as a whole. Secondly, in conditions of war, it is the cities that feel the greatest burden – fluctuations in markets, lack of resources, mass migration of the population, disruption of logistics chains, etc. This poses a threat to the social stability and economic security of cities. Thirdly, cities are becoming the main reception points for internally displaced persons, which requires them to mobilize significant resources and coordinate efforts to provide humanitarian assistance. This significantly complicates the management and functioning of cities. In this regard, forced resettlement of the population creates an additional burden on the infrastructure and social services of those cities that take displaced persons (Grum and Kobal Grum, 2023).

Thus, the level of security, sustainability, and viability of cities in a crisis is considered to be a determining factor for the country's ability to withstand exter-

nal threats and ensure the survival and development of its citizens. Therefore, the ability of Ukrainian cities to withstand the challenges of war and demonstrate resilience is one of the key manifestations of resilience throughout the country. The close interaction of society and urban space plays a decisive role in this situation. Here are some examples:

1) Volunteer movement and self-organization of local communities. In the conditions of Russian aggression, it was city residents who took responsibility for ensuring life activity, safety, and assistance to those who needed it. This has created an additional resource of resilience.
2) Adaptation of urban infrastructure to military threats. Cities took measures to strengthen critical infrastructure, create shelters, organize evacuations, etc. This greatly reduced the devastating effects of shelling and bombing.
3) Creation of effective warning, shelter and evacuation systems.
4) Coordination of efforts of local authorities and the public. The harmonious interaction of governing bodies, utilities, and educational and medical institutions with active residents made it possible to respond to challenges more effectively.
5) The active involvement of internally displaced persons (IDPs) in the urban environment contributes not only to the support and integration of IDPs themselves but also to the strengthening of the overall social fabric of cities, which increases their resilience in war conditions. This is an important contribution to the overall resilience of Ukraine.

According to Britchenko et al. (2022), the key aspects of sustainable cities can also be recognized: adaptability; flexibility of urban systems and infrastructure; recoverability; an advanced emergency response system; readiness; sustainable development; and inclusiveness (Table 1).

These and other measures should ensure the ability of cities to withstand external challenges and threats,

Table 1. Key aspects of environmental safety and their impact on the resilience of the urban environment.

Key aspects of environmental safety	Impact of environmental safety on resilience (stability) of the urban environment:
Energy efficiency and renewable energy sources	efficient use of energy in buildings, transport, heating/cooling systems; development of local renewable energy sources (solar, wind, geothermal)
Water management	efficient use of water, including rainwater collection; treatment and reuse of sewage; sustainable drainage systems for flood prevention
Green infrastructure	increase in urban green spaces, parks, squares; creating "green corridors" for biodiversity migration; the use of plants to absorb pollutants
Resistance to natural disasters	planning and preparing for extreme weather events (floods, droughts, storms); protection of critical infrastructure (energy, water supply, transport)
Circular economy	waste reduction, reuse, and recycling of materials; development of "green" technologies and environmentally friendly industries
Sustainable transport	priority development of public transport, pedestrian and bicycle infrastructure; transition to environmentally friendly modes of transport (electric vehicles, hybrids)
Waste management	improvement of the system of collection, sorting, and processing of household and industrial waste; development of reuse and waste disposal technologies; implementation of "zero waste" principles
Pollution control	soil monitoring and reduction of air, water, and soil pollution levels; introduction of "green" technologies and environmentally friendly industries; regulation of emissions of transport and industrial enterprises
Adaptation to climate change	development of action plans to mitigate the effects of climate change; implementation of measures to improve the sustainability of urban infrastructure; emergency preparedness (floods, droughts, etc.)
Ecosystem services	conservation and restoration of natural ecosystems in urban environments; use of natural solutions for adaptation to climate change; creation of "green zones" around cities
Environmental education and public engagement	educational work among the population regarding a sustainable lifestyle; stimulating citizens' participation in solving environmental problems; collaboration with NGOs, business,es and government for an integrated approach

Source: Compiled by the authors.

while maintaining their livelihoods even in conditions of hostilities. It is this comprehensive work on improving the safety and vitality of cities that becomes a top priority in modern crisis conditions. Such a modern approach to the development of urban areas is becoming increasingly relevant in the conditions of increasing global challenges, one of which is environmental safety and its impact on the resilience of the urban environment.

Having analyzed the results obtained, it is safe to say that all the challenges that Ukraine has faced as a result of Russia's armed aggression require their own phased consideration. There is an urgent need to define the sequence of measures for strengthening urban environment resilience. The priority measures include restoring critical infrastructure (energy supply, logistics, water supply, shelter availability for the population, etc). Rapid evacuation programs should also be developed. In the context of primary measures, it is advisable to create mechanisms for protecting the population from potential human-made accidents. This study identified medium-term measures based on the concept of sustainable development; they include the restoration of Ukraine's ecosystem through the national level and local programs. The second important element of the medium-term perspective is the attraction of international investments to introduce innovative environmental technologies. The state can also refer to and strengthen pre-war programs to support green energy for business. Renewable energy development is a necessary task, which complements the urgent need to solve energy challenges. Such economic activity will help stabilize regions and lay the foundation for further transformations.

As for the long-term perspective, programs for adapting to climate change should be implemented. The implementation should go beyond the participation in such programs and introduce environmental standards into all processes of urban planning. The appropriate legislative framework is to be developed and applied. At the systemic level, it is important to form a sustainability culture and understand the role of each participant in preserving the city as an integral system.

The immediate implementation of any measures requires their assessment since each of them requires different forms of resource provision. Sources of financing can be the budget or any form of external investments. Qualified technical personnel must respond quickly to urgent challenges. Medium-term steps require institutional and regulatory support, as well as the involvement of the expert potential of relevant international organizations. Legislative initiatives and high-quality educational work with the population will be crucial for long-term measures. At the same time, it is necessary to ensure a clear division of responsibility between the main participants in the process. State structures are responsible for coordinating reconstruction and environmental monitoring, as well as for legal regulation and control over the use of funds. International organizations can provide financial and technical assistance, and public associations can involve the population.

5. DISCUSSION

The basic aspects of environmental safety demonstrate its impact on the resilience of the urban environment and imply the mandatory adaptation of cities to emergencies and the development and implementation of some measures to improve this process (Table 2).

To solve environmental problems and increase the resilience of the urban environment in war conditions, public authorities need to implement comprehensive strategies that cover various aspects of urban life. They should promote the development of backup power supply, water supply, and communication systems to ensure uninterrupted operation of critical facilities in case of destruction of the main systems. The further recommendations include the following:

- use mobile health facilities, mobile water treatment stations, and other mobile infrastructure solutions for rapid emergency response;
- promote the development and implementation of support programs for the most vulnerable categories of the population, including displaced persons, children, the elderly, and people with disabilities, as well as develop a system of psychological assistance and support to reduce stress and psychological trauma among the population;
- introduce programs to support small and medium-sized businesses, in particular, the provision of soft loans, subsidies, and consulting assistance;
- stimulate the development of local production and economic activity to reduce dependence on external factors;
- ensure the implementation of measures to protect and restore parks, squares, and other green areas to maintain the ecological balance and create favorable conditions for the recreation of residents, as well as the development of effective waste management systems to minimize the environmental burden in war conditions.

Below are some examples of resilience in Ukrainian cities. During the first months of the large-scale invasion, the city of Kyiv demonstrated a high ability to

Table 2. Measures to improve the environmental safety and resilience of cities in war conditions.

Collaboration and community engagement	Adaptation of urban planning	Resilience of the urban ecosystem	Environmental Risk Management	Protection of critical infrastructure
Involving activists, initiative groups, and volunteers in practical activities to improve the sustainability of the city	Implementation of temporary redevelopment of urban space for new challenges	Conservation and restoration of parks, forests, reservoirs	Minimization of threats from damage to industrial facilities, storage of hazardous substances	Strengthening and duplication of life support systems (water, energy, gas, sewage, etc.).
Informing and educating residents on environmental safety issues	Creation of shelters, storage, and infrastructure to protect the population	Development of "green" infrastructure to maintain the microclimate and absorb pollution	Emergency, leak, or contamination response plans	Improving the sustainability of the transport network and logistics.
Coordination of efforts at the national, and local levels, with international partners	Temporary repurposing of premises for urgent security and logistics needs	Creation of new recreational areas, "breathing lungs" of the city, landscaping of cities	Readiness to eliminate pollution, clean the environment	Creation of spare capacity and alternative routes.
	Revision of evacuation and zoning schemes taking into account environmental risks	Using green technologies in environmental management	Inventory and enhanced control of hazardous facilities	Strengthening of water supply systems, wastewater treatment, energy supply
		Implementation of ecosystem solutions in urban planning	Assessment and monitoring of risks of pollution, accidents, and man-made threats	Increased safety of high-risk facilities

Source: compiled by the authors.

adapt and rebuild. The capital actively worked to ensure the population's safety, developed a shelter system, organized volunteer assistance, and supported the functioning of critical infrastructure. The city of Lviv has become one of the key centers for receiving displaced persons from other regions. The city provided accommodation, medical care, educational services, and employment support for tens of thousands of displaced persons, while actively attracting international assistance to maintain its resilience. As an important port city, Odessa faced numerous challenges but maintained its functionality through effective management and coordination between different services. The city ensured the smooth functioning of the port, which was important for the country's economy.

As you can see, the resilience of the urban environment in war conditions is extremely important for the life of cities and the well-being of their inhabitants. This requires a comprehensive approach that includes infrastructure, social, economic, and environmental measures. The experience of Ukrainian cities that have already passed through severe trials can become the basis for the further development of resilience strategies that will help cities respond effectively to the challenges of war, adapt to new conditions, and recover from shocks. This is an important path to sustainability and development of urban environments, even in the most difficult circumstances. The main components of resilience of the urban environment are: the ability of engineering networks and buildings to withstand the load and quickly recover from damage, the ability of the community to self-organization, support and mutual assistance, the preservation of economic activity, and the creation of conditions for the rapid restoration of business, the preservation of ecosystems and natural resources that ensure the livelihoods of the city.

An integrated approach to preservation and restoration involves preventive measures to reduce environmental risks in wartime, such as: ensuring the environmental safety of military operations, including monitoring the use and storage of hazardous substances; emergency preparedness, including the development of action plans and the creation of resource reserves to respond to environmental disasters; educating and informing the public about actions in case of environmental hazards. In the context of nature conservation and increasing the resilience of the urban environment, special attention should be paid to the implementation of innovative approaches to the restoration of ecosystems of urbanized territories as a network of interacting participants (companies, universities, startups, research centers, etc.) that work together to develop and implement innovative solutions. Innovative approaches to ecosystem restoration include the following components:

- use of drones and satellite technologies that can provide accurate data on the state of ecosystems, identify problem areas and monitor the recovery process, and allow monitoring of large areas with high accuracy;
- the development of bioengineering and genetic technologies, which include the development of genetically modified organisms to deal with invasive species or restore endangered species. Bioengineering can also help create plants that are resistant to climate change or pollution;
- rewilding is an approach aimed at restoring natural processes and ecosystems by reintroducing defunct or extinct species, such as large predators, which can regulate populations of other animals and contribute to biodiversity;
- creation or restoration of natural landscapes in urban and rural areas (Green Infrastructure) and including green roofs, vertical gardens, green corridors that improve the local climate, purify air and water;
- active use of microbiology to clean contaminated soils and waters through natural processes;
- ecological design and landscape planning as an integration of environmental principles into the design and planning of territories, which allows the creation of sustainable and healthy ecosystems, including the creation of artificial wetlands, green parks, and zones for wildlife conservation;
- climate-smart agricultural practices, which include agroforestry, waterless tillage, and mulching, which contribute to increasing soil fertility, preserving water resources and reducing erosion;
- using artificial intelligence and big data (AI and Big Data) to analyze large amounts of environmental data using AI, which allows to identify patterns, predict consequences, and develop effective strategies for restoring ecosystems;
- public engagement and education – innovative approaches that also include the active involvement of local communities in the process of ecosystem restoration through educational programs, volunteer projects, and joint initiatives (Polishchuk et al., 2019).

At the same time, improving the process of managing environmental safety in military conditions involves the following: integration of environmental safety into military planning; development and implementation of standards and procedures that reduce the negative impact on the environment; regular environmental audits and assessments of the impact of hostilities on the environment; implementation of protocols to minimize pollution, waste management, and conservation of natural resources; involvement of environmental specialists in military units to advise and develop measures to reduce environmental risks; training and study of military personnel on environmental safety issues; waste management and disposal.

The other critical measures include the restoration of the affected areas, the development of programs to restore ecosystems affected by hostilities, the use of bioremediation and other methods for cleaning contaminated areas. The authorities should establish the cooperation with international organizations and other countries to exchange best practices and technologies. There should be participation in international conferences and forums devoted to environmental safety in military conditions. It is also required to implement national and international policies that regulate the impact of hostilities on the environment. Involving local communities in the process of monitoring and restoring the environment is also crucial. The information campaigns should be conducted to raise awareness of the importance of environmental safety during hostilities. Furthermore, it is essential to develop climate change adaptation strategies that take into account possible environmental risks in the context of hostilities. Implementation of these recommendations will help to minimize the negative impact of hostilities on the environment of urbanized areas and ensure their environmental safety.

6. CONCLUSIONS

Thus, the impact of environmental safety and resilience of the urban environment on the socio-economic development of cities in military Ukraine is an extremely important task to ensure their sustainability. An integrated approach to conservation and restoration, which includes preventive measures, and environmental assessment is necessary to ensure the viability of urban areas in conditions of war and after its completion. Only with the close cooperation of public authorities, scientific institutions, public organizations and the population, taking into account the climate-neutral post-war restoration and strengthening of the potential of territorial communities, creating jobs and thus ensuring a gradual approximation of the quality of life to European standards, it is possible to achieve sustainable development and environmental safety in the urban environment of Ukraine.

It has been found that to assess environmental risks during the war period, it is necessary to use different methods and approaches: the use of computer models, which allows for predicting the spread of toxic substances in the air, water, and soil; a real-time monitoring system that helps track air, water, and soil pollution levels in conflict zones. This generalization reflects the

complexity of the situation and the need for consolidated efforts both at the national and international levels to address the environmental problems caused by the war. This is critical to ensuring a sustainable future for the country and its people and requires in-depth analysis and well-considered management decisions.

The complexity of data collection in a war zone presents certain limitations. For example, data on the environmental impacts of conflict may be fragmented and limited. Some estimates are predictive in nature, which may impact the accuracy of the results. In addition, the analysis was based on available open sources, which may leave out confidential or unpublished information. The research is also limited by the evolving nature of the conflict and the ongoing collection of reliable data, which may affect the accuracy and comprehensiveness of the analysis. Additionally, the study focuses on Ukraine, limiting its generalizability to other conflict zones. Future research should explore long-term environmental impacts and resilience strategies, especially in the context of post-war recovery and climate change adaptation. Further studies could examine international best practices, the role of technological innovations, and the socio-economic challenges of rebuilding urban environments to enhance environmental safety and resilience in war-affected regions.

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The stigma effect in the Land of Fires: the impact of negative environmental externalities on residential property values

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Abstract. The "Land of Fires" is an area extending between the provinces of Naples and Caserta (Italy). This vast region is notoriously affected by the burial and illegal disposal of toxic and special waste in abandoned quarries or unauthorized landfills, with waste often being burned, triggering numerous toxic fires. These phenomena create a "stigma effect" on the livability of the area under examination, with the local population suffering the most significant consequences. Residents are forced to live in a territory where mortality and cancer incidence rates are significantly higher than the national average. The primary objective of this study is to assess how environmental and social quality in the "Land of Fires" influence prices in the local real estate market. The first part of the study delves into the issues of urban quality in this context and its impact on residential property prices. The second part focuses on a specific portion of the "Land of Fires", known as the "Triangle of Death" which includes the municipalities of Acerra, Marigliano, and Nola, with the aim of evaluating the geospatial variability of real estate values.

Keywords: Land of Fires, stigma effect, environmental externalities, property values.
JEL codes: Q24, Q51, R23, R32.

1. INTRODUCTION

"Contaminate" is a term etymologically derived from the Latin "taminare", which has the precise meaning of "leaving a tactile imprint". In its absolute sense, the term does not inherently carry either a positive or negative connotation. When applied to the history of a country, contamination can be seen as a place's ability to welcome new peoples, thereby expanding its cultural heritage, history, and connection with the world. Through this process, it inherits new customs, traditions, and practices that endure over time, perfectly embodying the concept of "leaving a tactile imprint" inherent in the word's etymology.

The region of Campania (Italy) has long been a land of multiple contaminations in this sense. Greeks, Romans, Spaniards, and Arabs have all been both guests and admirers of the Campanian lands, long regarded as symbols of beauty, wonder, and prosperity. The Romans even bestowed upon it the name *Campania Felix*, highlighting the fertility of its soil. However, today, the territorial area between the metropolitan city of Naples and the southwestern part of Caserta presents a very different image, far from an idyllic, thriving landscape.

Currently, the concept of contamination in this area carries an entirely negative meaning in the collective imagination. Human activity has left a tangible imprint, not through creation, but through the destruction of wealth and beauty. This contamination is defined by the presence of toxic substances throughout the territory, giving rise to the term "Land of Fires" ("Terra dei Fuochi" in Italian).

The expression "Land of Fires" first appeared in 2003 in the *Ecomafia Report* by Legambiente (2003). It was used to describe a vast geographical area encompassing 90 municipalities (56 in the province of Naples and 34 in the province of Caserta), regularly plagued by the illegal disposal and burning of toxic waste, an area covering approximately 1,076 square kilometers and home to around 2.5 million people (see Figure 1).

However, the term "Land of Fires" is often misused, as it originally referred specifically to the phenomenon of toxic fires and not to the burial of waste. Despite this distinction, both issues are frequently conflated under a single label.

The term "Land of Fires" has even been recognized as a neologism in the Treccani Dictionary, which defines it as: *"A vast area, originally rural but now heavily urbanized, located between Naples and Caserta, characterized by frequent fires set by Camorra clans to illegally dumped toxic waste, leading to the release of highly harmful and polluting substances into the air. The situation in the northern area of Naples, which Roberto Saviano has dubbed the 'Land of Fires' due to the recurring waste fires that illuminate a landscape devastated by neglect, is even more dramatic. (Antonio Castaldo, Corriere della Sera, July 25, 2009, p. 11). For years, along with others, I have been recounting the disasters of the Land of Fires, which over time has swallowed up entire municipalities, constantly expanding its boundaries. Ever since Peppe Ruggiero of Legambiente coined this evocative phrase – so far removed from the Land of Fire described by Magellan – it has evoked the same image: just as the Portuguese explorer saw fires along the coast from the sea, those traveling along the Strada Statale 7 bis Terra di Lavoro (Nola-Villa Literno) or the Asse Mediano, if they take their eyes off the road, will see smoke rising from the ground, and if they lower their car windows, they will inhale a pungent, throat-burning odor with an acidic aftertaste. (Roberto Saviano,* Repubblica.it*, November 25, 2013, Cronaca)*" (Vocabolario Treccani, 2013).

Waste management has long been at the center of political, social, economic, and health debates across the Campania region, largely due to a lack of transparency and difficulties in effectively tracing the recycling process, particularly for industrial waste. However, the "Land of Fires" is not just a snapshot of waste mismanagement specific to Campania; it can be considered a broader Italian phenomenon. Across abandoned quarries, illegal landfills, and roadside waste dumps, the same system of circumventing regulations plays out, amounting to a true ecological catastrophe.

This issue has existed for decades. According to Legambiente, between 1991 and 2013, approximately 10 million tons of various types of waste were illegally dumped in Campania (Legambiente, 2013). This included:

- slag from aluminium thermal metallurgy;
- dust from smoke purification systems;
- industrial wastewater sludge;
- liquid effluents contaminated with heavy metals;
- asbestos-containing waste;
- paint residues;
- contaminated soil from remediation activities.

The fires, on the other hand, predominantly involve urban waste, plastics, leather scraps, and textile remnants, producing devastating consequences. These include not only soil and groundwater contamination through leachate but also the release of dioxins into the air and soil. Recent regulations have been introduced to facilitate land mapping in order to assess the presence of contaminants and micro-pollutants such as polycyclic aromatic hydrocarbons (PAHs), pesticides, and heavy metals.

A 2019 study (*Veritas*), conducted by the Sbarro Institute for Cancer Research and Molecular Medicine at Temple University of Philadelphia, along with the National Cancer Institute – Fondazione Giovanni Pascale (Chamber of Deputies of the Italian Republic, 2022), found abnormally high levels of heavy metals in cancer patients from several municipalities in the Naples metropolitan area (Giugliano in Campania, Qualiano, Castel Volturno, and the Pianura district of Naples). Given these alarming conditions, the "medical record" of the land, water, and air in this area paints a bleak picture, where any hope for a greener, healthier future seems to decay alongside the very "monnezza" (a Neapolitan dialect term for "waste") that represents gold for organized crime but a death sentence for the local population.

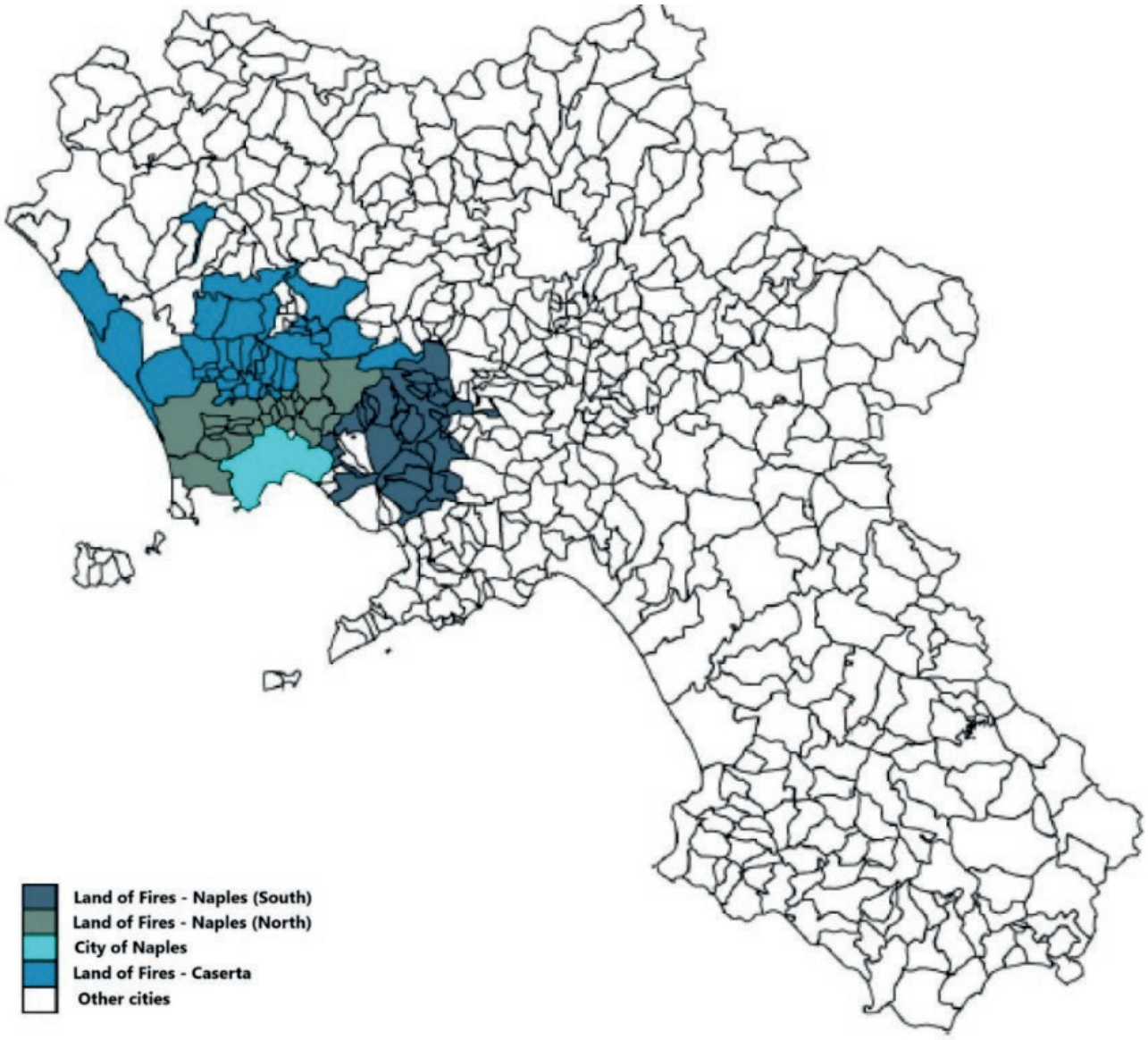

Figure 1. Land of Fires: territorial overview.

In 2025 the European Court of Human Rights has issued a final ruling condemning Italy for failing to adequately protect the inhabitants of the Land of Fires. According to the Court, the health of the population has been put at risk due to the failure to adopt effective measures to counter the phenomenon. Italy is therefore required to introduce, without delay, general measures to adequately address the pollution in the area. This is a historic ruling that acknowledges the serious institutional responsibilities in managing the environmental crisis in the Land of Fires (Corriere della Sera, 2025).

Following an analysis of the relevant literature on the "stigma effect" in the real estate market, this study first provides a territorial overview of the "Land of Fires", highlighting its characteristics and critical issues. It then addresses the challenge of selecting appropriate indicators to measure the phenomenon and evaluate the urban quality of the region in quantitative terms. The first part of the study presents data analysis and a discussion of the results. The second part focuses on a specific area within the "Land of Fires", known as the "Triangle of Death", comprising the municipalities of Acerra, Marigliano, and Nola. The goal is to assess the geospatial variability of real estate values using innovative models such as Evolutionary Polynomial Regression and Geo-Additive Models.

2. LITERATURE REVIEW

Addressing the issue of the impacts of environmental stigma on real estate properties might initially seem to revolve around a single question: What is its economic impact on housing prices? Table 1 provides a general summary of the main references related to this issue. However, reducing the study to the resolution of a single question could lead to the misconception that the only relevant factor is the price of homes affected by contamination, disregarding other related aspects and issues.

The issues addressed by the scientific community are numerous, highlighting how the approach to the problem is not uniform, as it is highly dependent on the context. Soil pollution is one of the key factors contributing to the stigma effect associated with a territory, and its impact on the real estate market is particularly evident. The mere presence of contaminated land increases the perception of risk among residents and potential buyers.

The literature on this topic is extensive; however, it can generally be divided into two main areas:

- soil pollution caused by waste disposal;
- soil pollution caused by water contamination.

When thinking about soil pollution, it is most often associated with the presence of hazardous toxic waste which, through natural degradation or improper disposal processes, leads to the contamination of the surrounding land. This environmental and economic issue has been analyzed by considering the studies summarized in Table 2.

The analysis clearly highlights how the real estate market reflects the distrust people have in living in polluted areas, regardless of the type of contamination affecting habitat quality.

However, an environment with pollution levels exceeding the standard, once remediated and restored to acceptable ecological conditions, tends to shift perceptions regarding its suitability as a residential area, leading to a more or less significant increase in property prices.

3. DESCRIPTIVE VARIABLES OF THE ENVIRONMENTAL, SOCIAL AND URBAN CONTEXT OF THE LAND OF FIRES

3.1 Urban quality: a multidimensional character of a territory

Urban quality depends on numerous factors and is primarily linked to how users perceive the territory in which they live, based on the presence or absence of any

Table 1. Summary of the main references related to the stigma effect on real estate properties.

Year	Author(s)	Site	Issue
1995	Kiel K. A.	Hazardous waste sites	Impact of hazardous waste discovery, effects of disclosure of discovery announcement, influence on property values of future contaminated site cleanup
1999	Dale L., Murdoch J. C., Thayer M. A., Waddell P. A.	Lead smelter	Impacts on property values before, during and after site remediation
2003	McCluskey J. J., Rausser G. C.	Unspecified	Analysis of the short-term and long-term impact of the stigma effect
2005	Decker C. S., Nielsen D. A., Sindt R. P.	Unspecified	Impact of polluting emissions and toxic substances
2006	Simons R. A., Saginor J. D.	Unspecified	Meta-analysis of the effect of environmental contamination
2007	Kiel K. A., Williams M.	Superfund	Impact of superfund sites on local property values
2008	Neupane A., Gustavson K.	Contaminated sites	Impacts of contaminated sites
2016	Phanaeuf D. J., Liu X.	Unspecified	Stigma measurement post site cleanup
2017	Sullivan K. A.	Urban brownfield sites	Effects of remediation on property values and tax revenues
2018	Silaeva P., Akhmedinova K., Redina M., Khaustov A.	Urban areas	Evaluating the correlation between real estate prices and pollution conditions
2019	Noh Y.	Abandoned railways	Real estate market analysis before and after abandoned railways are converted into greenways
2020	Del Giudice V., De Paola P., Bevilacqua P., Pino A., Del Giudice F. P.	Abandoned industrial areas	Impacts of contaminated sites on real estate value
2021	Otsuka N., Abè H., Isehara Y., Miyagawa T.	Contaminated sites	Role of green infrastructure in brownfield regeneration
2022	Tureckovà K., Martinat S., Nevima J., Varadzin F.	Contaminated sites	Impact of distance between properties and contaminated sites
2022	Drenning P., Chowdhury S., Volchko Y., Rosén L., Andersson-Sköld Y., Norrman J.	Urban brownfield sites	Improving ecosystem services in urban brownfield sites

Table 2. Summary of the main references related to the impacts of soil pollution on real estate values.

Year	Author(s)	Causes of contamination	Objective of the study
1992	Ketkar K.	Hazardous waste	Impact on property values due to the presence of a hazardous landfill
2004	Ready R., Abdalla C.	Dump	Effects on property values with respect to the Euclidean distance from the site at risk
2004	Ihlanfeldt K. R., Taylor L. O.	Hazardous waste site	Effects of non-severely polluting hazardous waste sites
2004	Deaton B. J., Hoehn J.J .	Unspecified	Effects on property values with respect to the Euclidean distance from the site at risk
2007	Van Herwijnen R., Laverye T., Poole J., Hodson M. E., Hutchings T. R.	Lead	Remediation using organic materials
2008	Greenstone M., Gallagher J.	Unspecified	Comparison of landfill sites
2010	Affuso E., De Parisot C. V., Ho C. S., Hite D.	Lead	Investigation into the effect of lead pollution
2011	Braden J. B., Feng X., Won D.	Unspecified	Effects of waste polluted sites
2013	Gamper Rabindran S., Timmins C.	Hazardous waste	Localization of the benefits arising from the remediation of contaminated sites
2019	Mei Y., Gao L., Zhang P.	Dump	Relationship between landfills and residential construction prices
2019	Zwickle A. et. al.	Dioxins	Investigation into the effect of dioxin pollution
2020	Baragano D. R., Gallego J. L., Forjan R.	Heavy metals	Use of phytoremediation plants as possible toxicological indicators
2023	Shen X., Ge M., Handel S. N., Jin Z., Kirkwood N. G.	Chemical pollutants	Using spontaneous invasive plants to implement soil phytoremediation

source of pollution, the development of social networks, the natural and cultural habitat, and the potential for economic growth. Considering this general perspective, we can understand that urban quality can be defined as the ability of the urban environment's configuration to meet, both quantitatively and qualitatively, the overall material and immaterial needs of its users by providing the required services.

From this, it follows that urban quality has a multidimensional character: it is not only related to urban development but also to environmental enhancement, health protection, and the ability to satisfy social needs. In this sense, the relationship between a city's urban quality and the needs of its users can be seen as an interaction between the demand for livability, safety, and efficiency – emanating from the local community – and the city's ability to meet these demands. In summary, we can define urban quality based on its components (Saaty and De Paola, 2017; Del Giudice et Al., 2014):

- Environmental Quality: Dependent on the presence of specific environmental resources (climate, landscape, physical-structural characteristics of both settled and natural environments), related to both anthropic and natural systems.
- Social Quality: Dependent on socio-economic and cultural factors, often referred to as "quality of life," including the social and cultural system, identities, and housing characteristics.
- Quality of Life: Linked to individuals' living conditions, as reflected in the health status of the communities themselves.

Based on a meta-analysis of the literature (Sica et Al., 2025), a series of indicators have been defined for the study of urban quality (Table 3). Among these, the indicators selected for the territorial context of interest take into account that data on crime phenomena are not available at the municipal level. Moreover, the data obtained to describe land use characteristics are not correlated with temporal factors, while variables related to land consumption show limited flexibility.

About the social environment, it is important not only to consider the presence of recorded crimes but also to take into account the coexistence of multi-ethnic communities within a given urban context. The Land of Fires, even from this perspective, presents a dramatic reality. On one hand, the high presence of immigrants might suggest a phenomenon of great inclusion and tolerance; on the other hand, it is closely linked to severe instances of labor exploitation and beyond.

In light of this consideration, it was deemed important to study the presence of foreign nationals in the Land of Fires area. For the assessment of environmental quality, however, it was considered useful to analyze the presence of landfills, as they represent a distinctive feature of this region, which suffers from ongoing illegal waste trafficking and disposal. This latter phenomenon

Table 3. Summary of the main indicators to study urban quality.

Environmental Quality	Social Quality	Quality of Life
Presence of dioxin	Presence of multi-ethnic groups	Cancer incidence rate
Presence of heavy metals and/or toxic substances	Crime rate	Respiratory disease rate
Presence of nearby landfills	Population density	Mortality rate
Recycling rate	Residential turnover rate	
Presence of polluted watercourses	Vacancy rate of housing units	
Air quality	Accessibility to essential public services	
Drinking water quality	Obsolescence of housing units	
Remediation rate (completed or planned)		
Environmental certifications		
Presence of abandoned industrial areas		
Presence of contaminated sites		
Presence of contaminated sites		
Amount of waste produced		
Surface area of land suitable for agricultural activities		
Risk of environmental or natural disasters		

gives rise to another critical issue: that of toxic fires. The presence of these fires turns the environment into a true incubator of pollution, affecting both air and soil with dramatic consequences for human health and the surrounding ecosystem.

It is therefore logical to assume that excluding this variable as a descriptive indicator of the reality in Land of Fires would lead to an incomplete analysis of the urban quality of the territory. Consequently, aware that the indicator accounting for the presence of toxic fires is entirely innovative compared to the long list of traditional indicators developed thus far, it was decided to include it in the analysis as it is absolutely necessary for a comprehensive and truthful description of the urban context.

Therefore, the indicators actually employed, expressed in terms of percentage variation – alongside changes in real estate prices – are as follows:

- Mortality rate;
- Presence of multi-ethnic groups;
- Rate of land reclamation;
- Presence of landfills;
- Number of toxic fires;
- Land consumption;

The indicators selected to describe the urban quality of the area under study take into account the following situations:

- available data on crime presence is not recorded at the municipal level in any public archive but only at the provincial level;
- available data related to land use does not account for temporal changes;
- land consumption represents an indicator with limited flexibility.

3.2 Mortality rate

With reference to this indicator, data relating to the mortality rate of 61 municipalities of the Land of Fires were collected, for a time range that starts from 2009 and arrives at 2021 (see Appendix 1). Figure 2 summarizes the mortality quotient of the territory under investigation, obtained through an average operation of the quotients collected for each municipality and repeating the procedure for the period 2009-2021: it is possible to note a significant increase in the mortality rate over time, in reference to the entire area, taking into account the marginal contribution of all the municipalities. The mortality quotients concerning Italy and Campania and those concerning Campania and the two provinces of

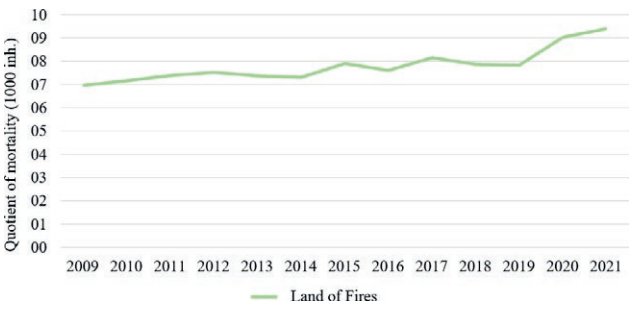

Figure 2. Quotient of mortality in the period 2009-2021.

Naples and Caserta were also compared, where in both cases the trend is substantially similar. In the period considered, it is noted that the mortality rate in Campania is higher than the national average, while the mortality rate in Campania is lower than that of the two provinces investigated (ISTAT, 2024).

3.3 Presence of multi-ethnic groups

A key component to consider in the investigation of a crime-ridden area, useful for assessing the perception of the safety of the place, would be the crime rate, understood as the number of crimes reported in the municipalities of interest. On the one hand, the data available on crime rates are limited only to provincial levels, on the other hand, in the considered area the variable closest to the crime rate is that relating to the presence of multi-ethnic groups in the area, as a symbol not only of inclusion and acceptance but also of significant exploitation, of all kinds.

Settlement development is the driving force behind the settlement of foreign residents in the most disadvantaged places, whose attractiveness derives both from economic reasons and from poor control of the territory; in general, it is precisely the complexity in finding work in disadvantaged areas that facilitates, in addition to social marginalization, also recruitment into criminal organizations, making the perception of the place, by the community, equal to a spoiled, unsafe and unlivable environment. This condition is strongly linked to the crime rate and the number of crimes reported to the judicial authorities.

The intense phenomenon of immigration is such that it has repercussions on economic, social, demographic and cultural aspects of society; it is weighted by evaluating the presence of foreign citizens as a variable of the social and economic intertwining of the territorial context considered, taking into account the possible weight, like the environmental condition, on the investigation conducted (Forte et al., 2018).

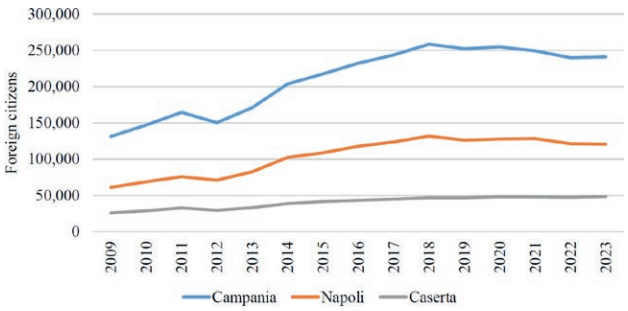

Figure 3. Foreign population in the period 2009-2023.

In the period 2009-2023, the data relating to the foreign population resident in the provinces of Naples and Caserta, show a growing trend, with some municipalities showing increases of over 80-90% in the last decade analyzed (Giugliano in Campania, Castel Volturno, Mondragone), (ISTAT, 2024; Statistiche demografiche e sociali, 2024; see Appendix 2).

3.4 Rate of land reclamation

In order to protect areas subject to pollution, soil remediation works are considered of fundamental importance, implemented with the aim of recovering and restoring a deeply degraded environment; to do this, once the contamination of the site has been established, it is essential to implement interventions aimed at reducing or removing the sources of contamination or, in any case, aimed at decreasing the concentrations of harmful substances to a degree that is equal to or lower than those specified by the legislation, depending on the intended use of the land.

The most widespread contaminants in the territory considered are Hydrocarbons, Heavy Metals and Solvents depending on the areas and types of industrial production (ARPAC, 2024).

In the analysis conducted, a time frame was taken as a reference that starts from 2017 and arrives at 2022, where the data relating to the years 2020 and 2021 are missing. The data are represented in terms of surface area expressed in square meters (see Appendix 3).

3.5 Presence of landfills

Since we are investigating an environmental fabric characterized by strong territorial pollution, it is of fundamental importance to evaluate the presence of negative factors that constitute the pillars of the place, as they designate its peculiar characteristics; among these, the presence of landfills stands out, of a generally abusive nature in the territorial context of interest and at the basis of the contamination of the soil (by percolation into the aquifer), of the air (emissions of vapors and greenhouse gases) and of the general health of the inhabitants. Through the Regional Reclamation Plan of Campania, including a specific census of landfills – including municipal and consortium ones, both public and private – "Vast Areas" have been identified, with the aim of monitoring those surfaces within which the investigations conducted have brought to light a situation that is generally damaged and prejudiced (Regione Campania, 2024).

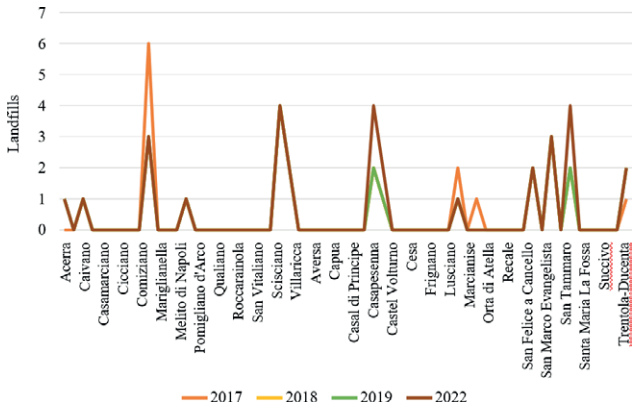

Figure 4. Number of landfills in the period 2009-2023.

Briefly summarizing, using a line graph, the distribution of landfills in the territory enclosed in the Land of Fires, the following municipalities stand out from the others (see Figure 4):

- 2017: Giugliano in Campania, Marcianise, Orta di Atella and Villa Literno;
- 2019: Caserta and Santa Maria La Fossa;
- 2022: Giugliano in Campania, Tufino, Caserta, San Tammaro, Santa Maria La Fossa and Villa Literno.

3.6 Number of toxic fires

The phenomenon of toxic fires derives from illegal activities of systematic burning of waste present in illegal landfills in order to reduce the occupied volume to a minimum (see Appendix 4).

Most of the fires are fueled by piles of special waste (i.e. deriving from industrial activities, demolition and construction activities, commercial activities, machinery, vehicles, etc.) whose management does not follow the treatment methods prescribed by environmental regulations, but the positions taken by a deep-rooted criminal system that disregards costs and controls. These events of significant problem have led to a considerable accumulation of environmental pollutants, contained in the columns of toxic fumes released, including dioxins – highly toxic and carcinogenic substances – which initially settle on grass, soil and water, and which then end up fixing themselves in the adipose tissue of animals that have ingested contaminated food and cause significant damage, not only to the ecosystem, but also to the human health of residents.

The main sources of soil pollution in Campania are gathered in the Caserta hinterland and in the territorial area located north of the province of Naples; among the contaminants, the following are mostly found: textile waste, lead and metals, acids, plastic materials, construction waste, tires and radioactive waste.

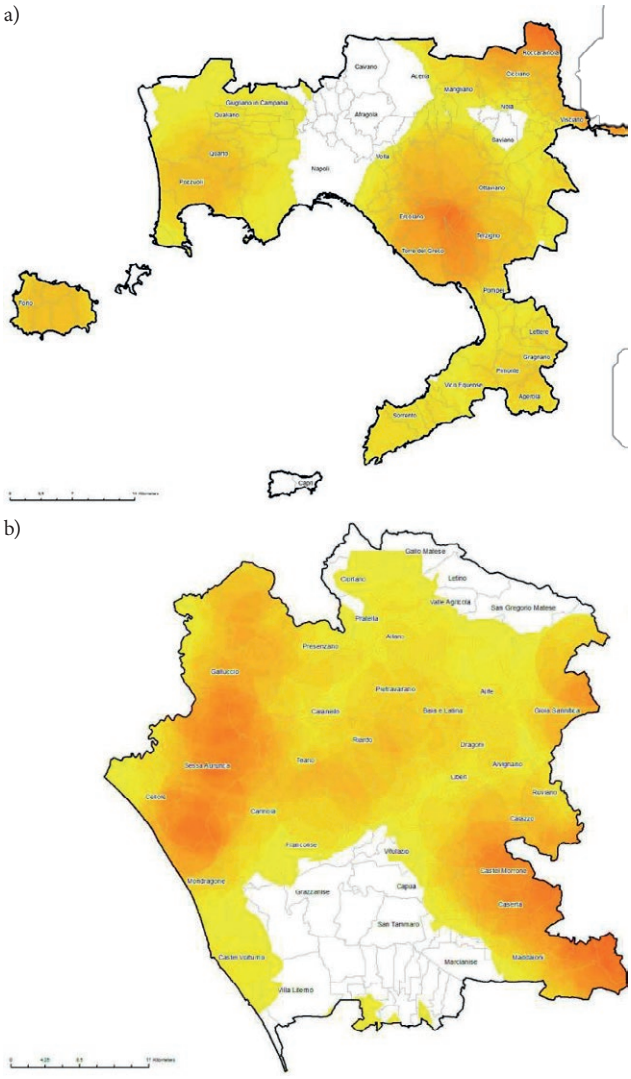

Figure 5. Number of toxic fires in 2021 for the provinces of Napoli (a) and Caserta (b).

As an example, Figure 5 shows the distribution of toxic fires in the provinces of Naples (Fig. 5a) and Caserta (Fig. 5b) for year 2021 (ARPAC, 2024).

3.7 Land consumption

The available data consist of the surface area of consumed land (expressed in hectares), the density of land consumption in relation to the total area of each municipality (expressed in square metres/hectare), and the percentage of consumed land (see Appendices 5 and 6).

Figure 6, derived from the values in Appendix 5, show the trend of land consumption for the entire dis-

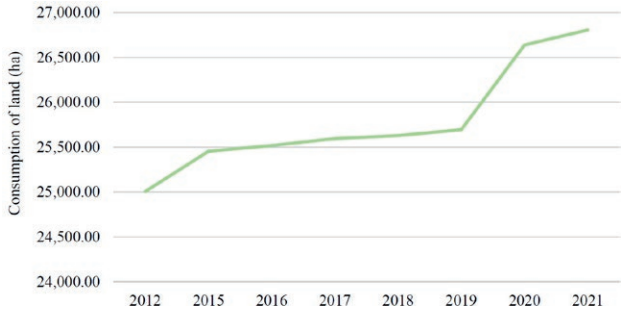

Figure 6. Consumption of land for the Land of Fires.

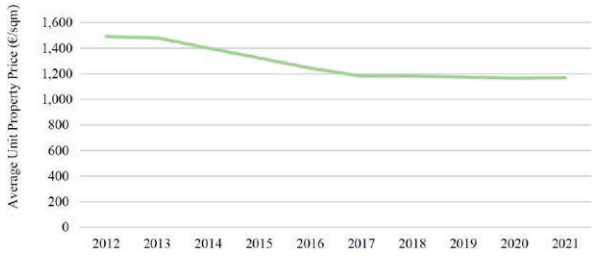

Figure 8. Trend of the average annual prices of residential properties in the territory of the Land of Fires.

trict of the Land of Fires (Sistema Nazionale per la Protezione dell'Ambiente, 2024).

3.8 Real estate market in the Land of Fires

In temporal analogy with the other indicators, the average values of the residential real estate market (€/sqm) of the municipalities constituting the Land of Fires (Immobiliare.it, 2024) were detected, in the period from 2012 to 2021 (see Appendix 7).

Through the Pareto diagram, it is quicker to identify the municipalities that present the highest trends in average annual property prices, in the time range considered. Figure 7 traces the distribution of the data collected in decreasing order and presents a cumulative line on a secondary axis as a percentage of the total.

It is the municipality of Pozzuoli – followed by Quarto, Pomigliano d'Arco and Caserta – that presents the most significant values in the entire territory of the Land of Fires. Santa Maria La Fossa, Castel Volturno and Francolise are, instead, the municipalities that present the lowest trend.

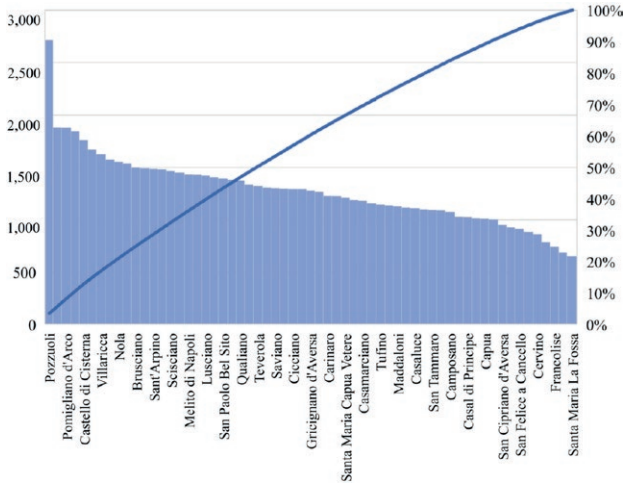

Figure 7. Pareto diagram: the trend of average annual prices of residential properties in the territory of the Land of Fires.

Instead, by using an average operation of the values relating to all 61 municipalities taken into consideration, the average price is obtained, discriminated for each of the years considered, of residential properties located in the Land of Fires (see Figure 8): the trend appears, in general, decreasing, with a dizzying drop after 2013 and which found substantial completion in 2017 (the year in which the recorded value was the lowest).

4. METHODS

4.1 Multiple regression models

Multiple regression models are statistical tools used to analyze the relationship between a dependent variable (or response) and two or more independent variables (or predictors). This methodology is particularly useful for studying complex phenomena where multiple factors influence an observed outcome.

The goal is to estimate the regression coefficients that indicate the contribution of each predictor to explaining the dependent variable, while controlling for the effects of the other predictors.

The general form of the multiple linear regression model is (Simonotti, 1997):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \varepsilon \quad (1)$$

where:

- Y: dependent variable;
- $X_1, X_2, \ldots, X_p$: independent variables (predictors);
- β_0: model intercept (expected value of Y when all X values are 0);
- $\beta_1, \beta_2, \ldots, \beta_p$: regression coefficients (expected change in Y for a one-unit change in X_i, holding other variables constant);

– ε: residual error (the difference between the observed and predicted values).

The coefficients β_i are estimated by minimizing the sum of squared residuals (SSR), which is the difference between the observed (Y_i) and predicted values.

In matrix notation, the model can be expressed as:

$$Y = X\beta + \varepsilon \tag{2}$$

where:
– Y is the vector of observed values;
– X is the matrix of predictors;
– B is the vector of coefficients;
– ε is the vector of errors.

The coefficients are estimated as:

$$\widehat{\beta} = (X^T X)^{-1} X^T Y \tag{3}$$

Main advantages of using a multiple regression model are: allows simultaneous consideration of multiple predictors, identifies relationships between variables, and provides an interpretable model. On the other hand, the main limitations are constituted by multicollinearity (when predictors are highly correlated, the estimated coefficients can become unstable), strong assumptions (requires linearity, homoscedasticity, and normality of residuals), overfitting (adding too many predictors can make the model overly complex and less generalizable).

4.2 Geoadditive models

Geoadditive models are composed by a semi-parametric additive component to express the relationship between model's non-linear response and explanatory variables, and a component with linear mixed effects to expresses the spatial correlation of observed values (De Paola et Al., 2019 and 2021; Del Giudice et Al., 2015 and 2021).

In the case of two additive components, if (s_i, t_i, y_i), $1 \leq i \leq n$, represent the measurements on two predictors s and t for the response variable y, the additive model is:

$$y_i = \beta_0 + f(s_i) + g(t_i) + \varepsilon_i \tag{4}$$

where f and g are unspecified smooth functions of s and t respectively. Therefore, if we define u_+ to equal u for $u > 0$ and 0 otherwise, a penalized spline version of the model (4) involves the following functional form (Del Giudice & De Paola, 2014a and 2014b):

$$y_i = \beta_0 + \beta_s \cdot s_i + \sum_{k=1}^{Ks} u_k{}^s (s_i - \kappa_k{}^s)_+ + \beta_t \cdot t_i + \sum_{k=1}^{Kt} u_k{}^t \left(t_i - \kappa_k{}^t\right)_+ + \varepsilon_i \tag{5}$$

In equation (5) there is the penalization of the knot coefficients $u_k{}^s$ and $u_k{}^t$, where $\kappa_1{}^s$, ..., $\kappa_{ks}{}^s$ and $\kappa_1{}^t$, ..., $\kappa_{kt}{}^t$ are knots in the s and t directions respectively. The penalization of the $u_k{}^s$ and $u_k{}^t$ is equivalent to treating them as random effects in a mixed model.

Setting $\beta = (\beta_0, \beta_s, \beta_t)^T$, $u = (u_1{}^s, ..., u_{ks}{}^s, u_1{}^t, ..., u_{kt}{}^t)^T$, $X = (1\ s_i\ t_i)$ with $1 \leq i \leq n$, $Z = (Z_s|Z_t)$, with:

$$Z_s = [(s_i - \kappa_k{}^s)_+]_{1 \leq i \leq n,\ 1 \leq k \leq Ks},\ Z_t = [(t_i - \kappa_k{}^t)_+]_{1 \leq i \leq n,\ 1 \leq k \leq Kt} \tag{6}$$

penalized least squares is equivalent to best linear unbiased prediction in the mixed model:

$$y = X\beta + Zu + \varepsilon\ ;\ E\begin{pmatrix} u \\ \varepsilon \end{pmatrix} = 0\ ;\quad cov\begin{pmatrix} u \\ \varepsilon \end{pmatrix} = \begin{bmatrix} \sigma^2{}_s \cdot I & 0 & 0 \\ 0 & \sigma^2{}_x \cdot I & 0 \\ 0 & 0 & \sigma^2{}_\varepsilon \cdot I \end{bmatrix} \tag{7}$$

Model (7) is a variance components model since the covariance matrix of $(u^T \varepsilon^T)^T$ is diagonal. The variance ratio $\sigma_\varepsilon{}^2/\sigma_s{}^2$ acts as a smoothing parameter in s direction. Penalized spline additive models are based on low rank smoothers, considering that linear terms are easily incorporated into the model through the $X\beta$ component.

At this point we can incorporate a geographical component by expressing kriging as a linear mixed model and merging it with an additive model such as model (7) to obtain a single mixed model (defined as geoadditive model).

Universal kriging model for (x_i, y_i), $1 \leq i \leq n$ (y_i are scalar and x_i represent geographical location included in R^2 domain) is:

$$y_i = \beta_0 + \beta_1{}^T x_i + S(x_i) + \varepsilon_i \tag{8}$$

where $S(x)$ is a stationary zero-mean stochastic process and ε_i are assumed to be independent zero-mean random variables with common variance $\sigma_\varepsilon{}^2$ and distributed independently of S. Prediction at an arbitrary location x_0 is done through the following expression:

$$y(x_0) = \beta_0 + \beta_1{}^T x_0 + S(x_0) \tag{9}$$

Then for a known covariance structure of S the resulting equation is:

$$y(x_0) = \beta_0 + \beta_1{}^T x_0 + c_0{}^T \left(C + \sigma_\varepsilon{}^2 I\right)^{-1} \left(y - \beta_0 - \beta_1{}^T x\right) \tag{10}$$

where:

$$C = (cov\{S(x_i), S(x_j)\})_{1\leq i,j\leq n} \tag{11}$$

$$c_0{}^T = (cov\{S(x_0), S(x_i)\})_{1\leq i\leq n} \tag{12}$$

For all aspects and matters above reported, a geoadditive model can be described, substantially, as a single linear mixed model as follow:

$$y_i = \beta_0 + f(s_i) + g(t_i) + \beta^T{}_1 \cdot x_i + S(x_i) + \varepsilon_i \tag{13}$$

Or in this further representation:

$$y = X\beta + Zu + \varepsilon \tag{14}$$

where:

$$E\begin{pmatrix} u^s \\ u^t \\ \widetilde{u} \end{pmatrix} = 0 \; ; \; cov\begin{pmatrix} u \\ \varepsilon \end{pmatrix} = \begin{bmatrix} \sigma_s^2 I & 0 & 0 & 0 \\ 0 & \sigma_t^2 I & 0 & 0 \\ 0 & 0 & \sigma_x^2 I & 0 \\ 0 & 0 & 0 & \sigma_\varepsilon^2 I \end{bmatrix} \tag{15}$$

5. CASE STUDY

Once the useful data relating to the variables considered were collected, to provide a synthetic description of the phenomenon for each municipality, an average operation was chosen to take into account what happens in different years. A comparison was carried out between two types of averages by calculating the standard deviation: simple arithmetic mean (AM) and moving arithmetic mean (MAM). The best average was found to be the AM as it generates a lower standard deviation than the MAM. If the individual municipalities are compared based on the standard deviation, the MA is always better than the MS as the relative normal distribution is much more regular than the one considered as the MAM.

For each indicator, and in correspondence with each municipality, the average annual increase for the period 2012-2021 was developed (see Appendix 8).

In the case of interest, we referred to a regression model without an intercept, in order to ignore other possible variables on the average percentage variation of the price.

Any outliers were eliminated from the sample, namely: some small municipalities adjacent to large municipalities, as they may be affected by the influence of the phenomena of the adjacent municipality in addition to those of their own; some municipalities in the coastal area characterized by a strong phenomenon of irregular migration, such that the variable relating to the presence of foreigners would have had a preponderant aspect compared to the other independent variables.

Starting from the exploratory analysis of the regression model, the determination coefficient R^2 is equal to 0.85, denoting an acceptable value in order to hypothesize a good adaptation of the regression plan to the observed points. The value of the corrected R^2 is equal to 0.80, while the multiple R is equal to 0.92, returning an acceptable degree of relationship between observed and predicted values, and the relationship between the set of independent variables defined and the dependent variable is sufficiently adequate. The standard error, on the other hand, corresponds to 0.014: being close to zero, it guarantees that the regression model is accurate.

The confirmatory analysis of the model is the process of testing against a null hypothesis. In regression analysis, the null hypothesis consists in the absence of a linear relationship between the dependent variable and the explanatory variables. Since in our case p-value is associated with the F statistic < 0.05 we can affirm that there is an effective linear relationship between the independent variables and the dependent variable and that the model is not a mere theoretical construction: the relationships in the model actually exist and are not random, therefore there is evidence that at least one variable X_i significantly influences the price variable *Y*.

The equation of the regression model is the following:

$$\Delta_{price} = -\,0{,}392\cdot\Delta_{mortality} - 0{,}217\cdot\Delta_{multi\text{-}ethnic\ groups} - 0{,}090\cdot\Delta_{land\ reclamation} + 0{,}062\cdot\Delta_{landfills} + 0{,}00008\cdot\Delta_{toxic\ fires} - 0{,}791\cdot\Delta_{land\ consumption} \tag{16}$$

Using the regression coefficients and the mean value of the individual independent variables, it is possible to determine the influence of the individual "weighted" variable for the dependent variable; the information obtained from the Weighted Average Coefficient (WAC) is, in fact, more complete as an information set. To define the WAC, both the sign of the mean value inherent to the individual variable and the sign inherent to the "weight" deriving from the results of the regression model must be considered. A summary is provided in Table 4 where the impact of the single variable following a unitary change in price. However, if we consider the average of the price changes in the municipalities of the selected sample, we can see how much the single variable impacts the real average change ($\bar{\Delta}_{\text{price}}$ = -0.031).

We can define the RWAC (Relative Weighted Average Coefficient):

$$CMPR_i = \frac{CMP_i}{\bar{\Delta}_{valore}} = \frac{CP_i * \bar{\Delta}_i}{\bar{\Delta}_{valore}} \tag{17}$$

Through the RWAC it is found that an average

Table 4. Influence of the individual "weighted" variable with respect to the dependent variable.

Variable	Regression coefficients	$\bar{\Delta}$	WAC	WAC %	RWAC	RWAC%
$\Delta_{mortality}$	-0.392	0.037	-0.0145	-1.450%	0.4677	46.77%
$\Delta_{multi\text{-}ethnic\ groups}$	-0.217	0.042	-0.0091	-0.911%	0.2935	29.35%
$\Delta_{land\ reclamation}$	-0.009	-0.002	0.00018	0.018%	-0.0058	-0.581%
$\Delta_{landfills}$	+0.062	-0.0125	-0.00078	-0.078%	0.0252	2.516%
$\Delta_{toxic\ fires}$	+0.00008	2.519	0.00020	0.020%	-0.0065	-0.645%
$\Delta_{land\ consumption}$	-0.791	0.006	-0.00474	-0.475%	0.1529	15.29%

change in real estate prices of -3.1% is correlated with a change of:

- +46,77% in mortality rate;
- +29.35% in the multi-ethnic groups;
- -0.581% in the unreclaimed land;
- +2.516% in the presence of landfills;
- -0.645% in toxic fires;
- +15.29% in land consumption.

It follows that: the mortality rate is the factor that most influences the collapse of real estate prices, followed by the rate of multi-ethnic groups and land consumption. The same qualitative information is obtained from the WAC: observing the absolute value, the ranking of the variables that affect the cost is the same.

Considering the average variation of a phenomenon has allowed us to examine phenomena of temporal evolution in a stationary manner: the results we obtained must therefore always be read in terms of variation in a "horizontal" manner.

There is an inverse relationship between the mortality rate and the variation in prices, the same one present with the rate of multi-ethnic groups, unreclaimed land and land consumption; this implies that as one of the above-mentioned rates increases, there is a decrease in the increase, over time, of real estate prices. The distrust resulting from the poor liveability of a generally unhealthy urban context, such as that of the Land of Fires, is tangible from the high values of all four of the above-mentioned variables; life in a territory that presents: a higher mortality rate than the national average (the causes of which are strongly linked to the low urban quality of the place), a high rate of multi-ethnic groups, tending to increase, generally overshadowed by the possibility of an "easy life" offered by organized crime (just think of the migrant settlements – located in unauthorized or abusive areas – that turn into a real business for eco-mafias), high levels of unreclaimed land and particularly the land consumed by artificial casings, cannot but translate into a disadvantage, which also affects property prices, in which the distrust deriving from the dangerousness of the place is poured, without remedy, onto the real estate market discouraging the value of the assets pertaining to it. However, in the analysis conducted, there are two rates that, by increasing, generate positive variations in prices, they are the presence of landfills and that of toxic fires.

Concerning the first factor, the data show that, from 2017 to 2021, there was a reduction in the quantity of active landfills in the territory, consequently generating an increase in decommissioned plants (a landfill that does not comply with European directives is a danger during the work phase as well as during closure, since the resulting leachate penetrates the subsoil causing irreparable and profound pollution); this increase, while on the one hand it may seem like a potentially positive effect and generate an increase in changes in real estate prices, in reality it hides serious negative implications. The last rate discussed is that relating to fires; the harmful fires for which we have information are those collected by official monitoring that uses actual video surveillance booths. It is a variable with a very low weight – in the order of 10^{-5} – whose positive influence on price changes deserves careful attention; the positive variation in the number of fires recorded is seen to correspond to a positive variation in prices, the impact of which is very small, being a phenomenon characterized by a negative prerogative and extremely monitored and opposed. Despite the actions implemented regarding monitoring, knowledge and prevention, it remains a disadvantageous factor in terms of the liveability of the place.

Synthesizing, in short, what has been exposed, it is clearly noted that the majority of environmental and social phenomena, considered in the analysis, lead to a negative variation in property prices; this is indicative of a real estate market that receives an increasingly smaller number of consents and that appears vigorously stigmatized by the indelible mark that pollution has placed on the territory (the stigma effect, in fact, is not only linked to the dangerousness of the phenomenon but also, and above all, to the perception that one has of it). The situa-

tion worsens if we consider that phenomena such as the setting of fires, dumping activities, and the presence of illegal landfills dedicated to the disposal of illicit waste, appear to be out of control, taking on a greater gravity in the eyes of those who perceive it.

Of the 61 municipalities that are part of the Land of Fires, the municipalities of Acerra, Nola and Marigliano, due to their geographical positioning and the high mortality linked to the onset of tumors, have been defined as "the triangle of death".

The high mortality rate in these municipalities appears to be mainly linked to pollution caused by the illegal dumping of toxic substances in the environment managed by the Camorra, which operates an illegal waste traffic throughout the country, transporting industrial waste produced by industries in northern Italy to the Campania region. The illegal dumping of waste occurs in illegal landfills but often also in legal landfills, all accompanied by the phenomenon of fires that already devastate the entire area of the Land of Fires.

To describe the real estate market of this territory in spatial terms, n. 384 residential properties, chosen in such a way as to homogeneously cover the territory of the 3 municipalities, were detected during the year 2021 (Immobiliare.it, 2024). The real estate market remained stationary until 2024. To take into account the different locations, the data were "homogenized" through specific market ratios drawn up based on data from the Real Estate Market Observatory of the Italian Revenue Agency (Osservatorio del Mercato Immobiliare, Agenzia delle Entrate, 2024).

For each property the real estate market price and the amounts of some real estate characteristics are known, as shown in Tables 5 and 6.

Based on real estate data, the following geoadditive model has been implemented:

$$UPRICE = FLOOR + MAIN + CAR + f(XCOORD, YCOORD) \quad (18)$$

Table 6. Statistical description of the variables used in the geoadditive model.

	UPRICE	FLOOR	MAIN	CAR
Mean	1285.08	1.50	1.31	1.125
Standard Error	26.26	0.087	0.047	0.050
Median	1237.24	1.00	1.00	1.00
Standard Deviation	514.65	1.71	0.91	0.98
Sample variance	264869.60	2.92	0.83	0.96
Interval	2983.33	10.00	3.00	7.00

Table 7. Determination index relating to the subsamples relating to the three distinct municipal territories (Nola, Acerra and Marigliano).

	Acerra (116 properties)	Marigliano (133 properties)	Nola (135 properties)
Multiple R^2	0.944	0.961	0.950
R^2	0.891	0.924	0.903
Adjusted R^2	0.879	0.915	0.894

Results and main indices of model verification are presented in tables and graphics that follow. The determination of knots for the spatial component and its geographical coordinates are identified by the space filling algorithm, implemented in default.knots.2D function library of R Software Wand et Al., 2005). The geoadditive model was therefore estimated by the Re.M.L. method using the spm library of R software.

A preliminary multiple regression analysis conducted on the data relating to the individual municipalities, to verify the reliability of the data used in the geoadditive model, is provided in Table 7.

The estimates of effects in the non-linear model have been significant by values of freedom degrees (df) and smoothing parameters (spar). The values of obtained predictions are consistent with observed data,

Table 5. Description of the variables for the geoadditive model.

Variable	Description
Real estate price (PRICE)	expressed in Euro
Commercial surface (SUR)	expressed in sqm
Real estate unitary price (UPRICE)	expressed in Euro/sqm
Commercial surface (SUR)	expressed in sqm
Level of floor (FLOOR)	cardinal scale
Maintenance status (MAIN)	expressed via a score scale varying from 0 to 3, starting from buildings to be renovated up to new ones;
Number of parking spaces (CAR)	cardinal scale
Geographic coordinates (XCOORD, YCOORD)	expressed with longitude and latitude

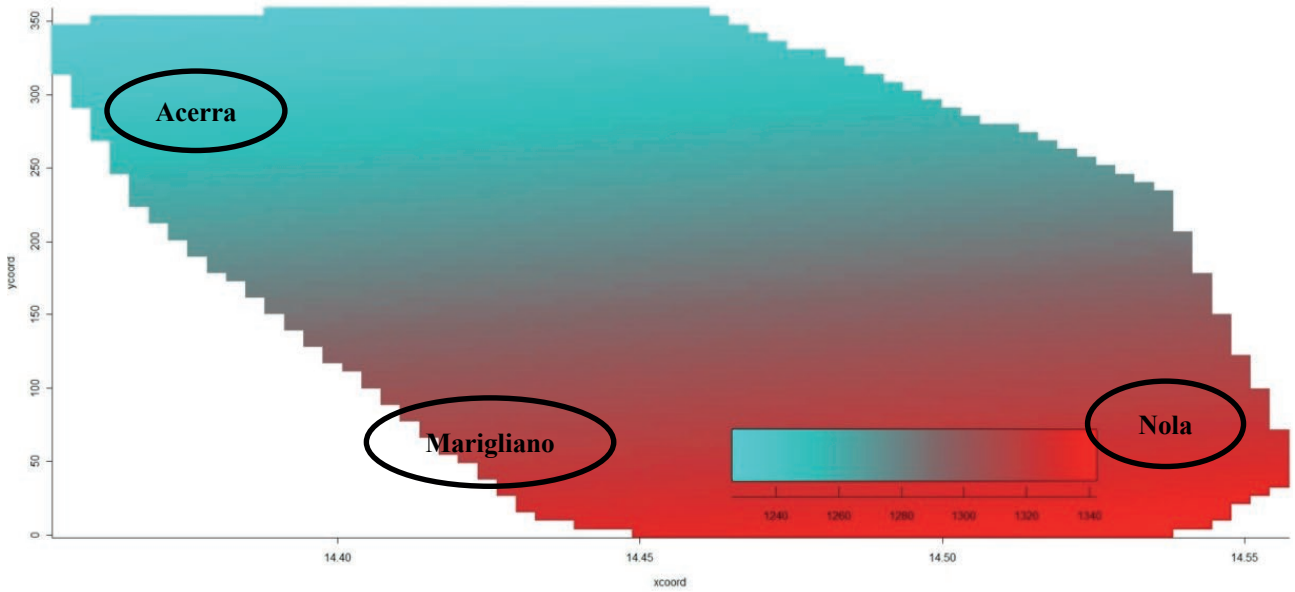

Figure 9. Spatial distribution of real estate unitary prices in the Triangle of Death.

also analysis of residuals has not shown any abnormality in its structure. In examined area, the spatial distribution of real estate unitary prices clearly shows how the geographical component affects the prices of sampled properties.

The main result of the interpolation is a thematic map depicting the real estate unitary values in the urban context considered, in which blue and red colors represent unitary values, respectively, lowest and highest values (see Figure 9).

From Figure 9 it can be observed that unit prices increase from the municipality of Acerra (high vertex of the triangle, with lower prices) to that of Nola (low vertex of the triangle, with higher prices).

Unit sales prices cover a range from € 1220/sqm to € 1340/sqm and fall within the range of values provided by the Real Estate Market Observatory of the Italian Revenue Agency for the areas analysed.

The analysis of the geo-additive model appears to be in line with a series of phenomena related to the urban quality of the municipal contexts considered. To explain the phenomenon of the variability of unit prices between these three municipalities, in the municipality of Acerra there are 137 industries, in that of Marigliano 322 and in that of Nola 484: the number of industries increases from municipality to municipality and with it, the perception of the potential for growth and economic development increases and in accordance with this it is easy to think that a greater prospect of a better environment from a socio-economic point of view is linked to a greater real estate value. If we take into account the fact that in Nola there is the Campania interport, which is an international logistics platform connected to the main world hubs, we realize that the higher sale price, demonstrated by the geo-additive model, of the properties in this area is largely justified. If we consider the percentage of consumed land as an indicator of urbanization (how much artificial has been built on the territory), we see that, for increasing values of the percentage of consumed land, the municipal ranking we obtain is: Acerra, Marigliano, Nola. Therefore, Acerra appears to be the least urbanized municipality while Marigliano is the medium urbanized one while Nola is the most urbanized one. For this reason, it can be assumed that, since the price of a property is directly linked to the urban context and the services that a certain place offers, it increases with the increase in the degree of urbanization since the increase in the latter also increases the services that the city can offer to its residents. The fact that the lowest selling prices refer to the municipality of Acerra, the highest ones to the municipality of Nola and the intermediate ones to the municipality of Marigliano, can also be linked to other factors that are also linked to the perception of healthiness of the area. If we consider that moving from the municipality of Acerra to that of Nola there is a reduction in polluted surfaces of 10%, we can understand how an urban context of better environmental quality is certainly associated with a higher price of properties since environmental quality is an asset that impacts the quality of life of residents who are therefore willing to pay more to

live in an urban context that is considered better as it is home to a lower polluting impact.

When talking about remediation and soil pollution, it is good to remember that the chemical, physical and biological alteration of the soil is linked to anthropic phenomena and human activities that can compromise it, even irreversibly. In this regard, it can be considered that among the most disastrous causes is the incorrect disposal of waste, which often occurs without regulations and in a completely abusive manner. The municipalities considered are part, as we know, of the broader context of the Land of Fires characterized by the presence of abusive fires that are triggered to burn waste that is sometimes even toxic and dangerous. Following this, we realize that going to live in a context where there is a greater ignition of toxic fires is certainly less inviting than going to live in places where phenomena of this type do not occur. If we move from the municipality of Nola to that of Acerra, the data on the ignition of fires (obviously we are talking about those registered but the real number is much higher as the phenomenon appears to be uncontrolled), an increase in fires, on average per year, of 60% is recorded, therefore it is easy to understand that prices in correspondence with this notable increase undergo a notable decrease as the perception, and the actual, dangerousness of the phenomenon discourages buyers from living in these areas.

6. CONCLUSIONS

This work was aimed at verifying how environmental and social externalities influence the market prices of residential buildings in the Land of Fires.

The results obtained make it clear that the problems strongly related to environmental pollution strongly influence the real estate market, even if their consequences appear, only theoretically, less worthy of consideration than those generated by the elements concerning the mortality risk and those relating to social risks, specific to the territory taken into consideration.

The clear sign of a real estate market that admits a number of consents that is gradually declining is visible in the reduction of property values in the selected municipalities, guilty of being located on a land affected by an indelible stigma, related not only to environmental pollution – due to the scattered and massive toxic fires and harmful elements discernible from abandoned industrial and waste disposal sites – but also to an ever-increasing trend in mortality (which sees the development of tumor diseases as the main cause) and multi-ethnic groups subjugated by the presence of criminal organizations, capable of actively establishing themselves in social reasoning.

Through data processing tools, it has been concluded that positional characteristics have effects on the formation of market prices, but how can this information be put to good use? Rather than implementing future estimates regarding the trend of costs, it would be of fundamental and primary importance to make changes to the sick matrix of the "Land of Fires", not only from the point of view of environmental remediation which, only marginally, is already underway – through innovative soil phytoremediation technologies, which allow the restoration of the original conditions, replacing those physical-chemical steps that return totally infertile soils – but also by determining more precise comparison frameworks, in particular for the municipalities not included in the final analysis and through continuous monitoring of those factors that generate the greatest critical issues, drawing inspiration from the operations already implemented regarding the "fire issue". The crisis of the Land of Fires serves as a harsh reminder of the complex interaction between industrialization, lax regulation and environmental degradation and highlights the need for proactive measures to prevent similar crises from emerging elsewhere. It is clear that by learning from the mistakes made on this soil, governments, industries and civil societies can work together to create a more sustainable future, characterised by responsible waste management, strong regulatory frameworks and a commitment to preserving the health of the planet and its inhabitants.

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Appendix 1. The mortality rate for the municipalities of the Land of Fires (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Municipalities	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Acerra	6.5	6.1	6.1	6.5	6.7	6.3	7.1	7	6.7	6.7	7.1	7.9	8.5
Brusciano	6.5	7.1	7.2	6.2	7	6.6	7.5	5.9	7.4	7.5	6.2	8.5	9.2
Caivano	6.5	8.1	7.3	7.1	6.6	7	7.7	7.1	7.6	6.7	7.9	9.8	10.3
Camposano	8.1	7.9	9.2	9.4	9	8.1	10.5	10.3	10.7	9.6	9.9	11.2	10.6
Casamarciano	8.3	7.7	12.1	8.6	9.2	10.9	9.7	11	9.8	11.1	10.2	11.6	15.4
Castello di Cisterna	5.9	5.6	7.1	6.9	6.8	6.8	7	6	6.7	5.4	6.3	6.8	7.8
Cicciano	9.3	7.3	7.5	9.6	7.2	9	8.9	9.1	9	9.7	10.4	8.9	10.6
Cimitile	8.4	9.5	11.4	8.3	7.5	7	9.9	9.8	8.1	11.5	10.4	11.9	9.4
Comiziano	11.6	8.8	8.2	9.3	10.9	10.4	12.1	8.3	13.8	9.6	8	14.2	14.1
Giugliano in Campania	5.3	5.5	5.5	6.5	6	5.6	6.4	5.6	6.3	5.9	5.6	7.2	6.9
Mariglianella	7.2	7.2	6.8	6.3	6.2	5.8	6.7	7.3	6.7	6.2	7.3	8.1	10.28
Marigliano	8.4	8.5	7.8	9	8.6	8.8	9.2	8.7	9.6	9.1	9	10.1	10.2
Melito di Napoli	5.2	5.1	4.9	5.5	4.4	5.8	6.2	6	5.6	5.8	5.8	6.7	7.6
Nola	8.8	9.4	8.7	9.4	8.5	8.5	8.7	9.9	9.2	8.5	8.4	9	10.1
Pomigliano d'Arco	7.8	7.7	9.2	7.7	8.2	8.4	8.6	8.9	9.2	7.9	8.5	9.9	10.1
Pozzuoli	6.7	6.5	6.8	8.1	7.9	7.8	8.1	7.8	8.5	7.9	7.8	9.5	9.9
Qualiano	6.1	5.8	7	6	6.2	7	7.5	7.3	8	7.6	7.2	9.2	9.4
Quarto	6	5	5.3	5.7	5.3	5.4	7	6.2	6.2	5.7	6.5	6.4	6.9
Roccarainola	9.5	9.9	9.6	7	9.8	7.9	6.6	8.5	11.9	10.7	11.5	10.1	12.1
San Paolo Bel Sito	7.4	6.5	5.4	9.2	8.5	8.5	9.4	9.1	11.8	9.3	9.1	7.7	8.9
San Vitaliano	5.7	7.6	7.7	7.3	8.1	7	9.6	7.8	9.9	10.2	7.7	9.9	9.2
Saviano	7.9	7.9	9.6	8.6	9.1	7.9	9.2	7.9	9.8	7.9	9.6	11.2	11
Scisciano	5.6	8.1	7.1	8.6	8.5	8	8.2	8	7.1	6.9	6.5	8.7	8.5
Tufino	8.8	6.4	4.8	9.8	9.6	5.1	8.2	6.7	8.7	8.5	6.9	12.3	13.7
Villaricca	5.3	5.4	6	5.5	6.6	5.7	6.8	6.9	7.1	7	7.5	8.6	8.7
Visciano	9.8	10.7	10.1	9.7	10.9	10.7	11.2	8.3	13.3	11.2	10.8	13.3	10.7
Aversa	7.7	7.3	7.9	8.6	7.6	8.7	8.9	7.9	9	8.6	8.5	10.3	9.4
Capodrise	5.6	6.7	6	6.6	6.2	4.4	5.8	5.9	6.8	6.8	5.7	8.7	7.7
Capua	10.2	9.1	9.8	12.1	8.8	9.7	10.6	10.8	10.9	9.4	10.8	11.4	11.3
Carinaro	5.8	9	5.6	6.9	9.6	6.5	7.5	6.7	7.7	7.6	7.3	5.8	8.8
Casal di Principe	4.2	5.5	5.9	5.8	6.1	6.8	6.6	7	7.4	6.4	7	7.9	9.4
Casaluce	6.2	6.3	8	5.7	5.9	5.6	7.1	6.3	8.5	7.3	7.4	7.7	9.4
Casapesenna	3.6	6.2	6.7	6.3	6.8	7.7	7	5.7	7.9	8.9	7.3	11	11.5
Caserta	8.1	8.5	8.6	9.1	9.3	8.7	10.3	9.3	9.7	9.7	9.5	11.4	10.1
Castel Volturno	10	8.7	7.6	9	7.6	7.6	8.4	7.9	7.8	8	6.9	8.5	8.6
Cervino	8.8	9.7	7.9	11	7.3	8.1	8.3	8.6	5.6	7.8	9.2	9.8	8.3
Cesa	5	6.2	5.8	5	5	6.1	6.1	5.5	5.7	5.8	5.9	7.2	7.4
Francolise	7.2	9.4	9.5	10.2	12.4	11.8	7.7	11	9.2	8.9	9.9	9.1	10.4
Frignano	8.1	7.8	7.9	7.9	7.6	7.5	8.6	8.2	8.5	9.5	7.6	7.7	9.5
Gricignano di Aversa	4.9	4.1	4.4	4.8	4	4.5	6.1	4.2	5.6	5.9	5.7	7.2	5.1
Lusciano	5	6	6.5	7.3	6.3	6.4	7.6	6.7	5.9	6.6	5.7	7.4	6.8
Maddaloni	7.6	8	7.2	8	8.4	7.2	8	7.1	8.5	8.3	8	8.9	9.3
Marcianise	6.4	6.6	6.4	7.4	6.9	7.3	8	7.1	7.6	7.9	6.9	7.6	9.3
Mondragone	7.8	9.6	8.5	8.6	9	7.6	8.9	8.8	9.1	9	8.8	10.1	10.7
Orta di Atella	3.9	3.8	3.9	3.4	4	4.5	4.7	4.6	4.7	4.6	4.5	5.2	5.3
Parete	6.2	7.4	7	5.7	6.7	6.3	6	6.6	7.1	6.7	6.2	7.8	7.5
Recale	6.6	6.8	6.2	6.4	6.1	8.8	7	8.4	8.5	6	7.7	8.4	8.9
San Cipriano d'Aversa	4.8	6.1	8.2	7.3	7.3	7.1	9	9.4	9	7.5	8.4	10.6	11.7
San Felice a Cancello	8.2	7.3	8.8	7.2	6.4	8.1	9	8.8	9.5	9.9	8.8	11.2	10.7
San Marcellino	5.2	7.5	6.3	7.5	5.7	6.7	6.6	6.3	6.7	7.4	7.3	7.6	7

Municipalities	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
San Marco Evangelista	5.7	6.2	5.6	7.8	6.4	6.8	6.5	6.6	7	5.8	8.3	8.7	9.3
San Nicola la Strada	7.5	7.7	7.8	6	7.3	7.4	7.4	6.9	7.7	8.1	7.9	8.9	8.6
San Tammaro	4.6	6.9	7.8	7.2	6.7	6.3	4.9	8.3	9.3	6.7	8.7	8.2	9.6
Santa Maria Capua Vetere	9	10	11.3	10.2	11.1	10.4	11	10.1	9.7	10.7	9.8	10.9	10.7
Santa Maria la Fossa	9.6	7.7	9.2	10.1	8.5	9.5	15.7	9.6	7.1	10.5	9.1	9	12.5
Sant'Arpino	6.8	5.3	6.5	6.4	6.2	5.9	6.8	6.5	7.4	5.8	7.2	8.1	9.3
Succivo	7.5	5.3	6.9	6.1	6.1	7.3	6.2	6.6	7.1	7.7	6.9	8.3	6.9
Teverola	4.6	4.9	5.9	4.9	5.9	4.7	6.2	5.6	5.8	5.8	7	7.4	5.9
Trentola Ducenta	6.4	5.1	5.5	5.4	6.7	5.3	6.4	5	6.3	6	6.8	6.6	7.5
Villa di Briano	6.5	5.3	5.2	6.7	4.8	6.5	2.8	8.1	8.1	7.1	5.6	8.3	9.7
Villa Literno	6.3	7.4	7.6	8.3	5.6	5.9	6.2	6.5	5.9	6.7	7.3	9.1	9.9

Appendix 2. Foreign population in the Land of Fires (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Municipalities	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Acerra	1,231	1,378	1,133	1,240	1,756	1,797	1,830	1,952	2,092	2,008	2,192	2,187	2,128	2,208	2,294
Brusciano	199	227	215	221	270	290	324	310	296	287	279	275	257	237	208
Caivano	552	637	605	663	692	667	708	756	800	864	850	858	813	818	780
Camposano	95	122	107	122	138	141	141	142	143	142	130	126	104	86	78
Casamarciano	53	52	56	62	66	62	60	51	55	51	43	43	40	40	46
Castello di Cisterna	122	150	127	131	152	154	152	161	163	170	178	173	178	163	144
Cicciano	228	282	243	242	315	322	341	341	357	374	355	340	245	243	245
Cimitile	120	142	134	187	198	210	232	242	247	262	275	246	254	232	208
Comiziano	46	56	37	35	47	48	49	54	54	54	52	50	46	49	53
Giugliano in Campania	3,470	3,974	2,702	3,393	4,555	5,229	6,098	6,512	6,980	6,908	6,914	6,087	6,569	6,184	5,844
Mariglianella	152	174	190	218	243	232	213	225	242	239	237	236	232	245	231
Marigliano	677	772	778	827	939	1,032	1,111	1,112	1,112	1,144	1,124	1,097	1,022	990	1,021
Melito di Napoli	348	401	296	393	446	596	585	678	750	815	771	722	739	714	632
Nola	907	979	887	931	1,046	1,138	1,201	1,248	1,357	1,440	1,497	1,524	1,425	1,283	1,290
Pomigliano d'Arco	575	648	646	714	840	870	911	943	960	960	1,042	1,016	935	919	954
Pozzuoli	1,638	1,768	1,254	2,071	1,899	2,045	2,056	2,151	2,176	2,220	2,273	2,263	2,199	1,931	1,889
Qualiano	519	607	497	575	685	867	1,038	1,055	1,108	1,130	1,195	1,128	1,075	1,023	1,025
Quarto	351	425	406	483	525	593	653	719	734	754	793	760	898	814	766
Roccarainola	137	148	139	176	184	184	193	194	202	176	213	205	143	143	150
San Paolo Bel Sito	76	96	73	79	87	92	85	80	81	74	75	74	74	70	79
San Vitaliano	88	109	108	117	117	109	99	95	106	128	145	144	132	126	128
Saviano	383	437	453	469	529	586	618	724	770	849	849	815	733	686	689
Scisciano	91	98	97	115	127	139	153	169	179	181	167	164	163	156	154
Tufino	53	48	48	51	48	54	64	64	50	54	49	49	33	37	31
Villaricca	454	504	503	544	639	685	703	690	799	792	704	721	699	703	683
Visciano	129	111	111	111	113	103	101	98	77	76	89	88	84	83	81
Aversa	1,939	2,100	2,248	2,530	2,747	2,914	2,963	3,037	3,099	3,203	3,103	3,019	3,030	2,876	2,951
Capodrise	241	278	213	190	240	247	252	267	290	287	327	313	289	293	295
Capua	749	874	747	813	927	972	1,067	1,069	1,117	1,159	1,266	1,178	1,236	1,337	1,518
Carinaro	266	270	230	255	311	320	315	312	309	312	306	299	354	333	344
Casal di Principe	617	718	660	815	913	988	1,052	1,171	1,164	1,164	1,317	1,234	1,327	1,409	1,482
Casaluce	345	401	421	494	522	553	503	486	439	473	370	350	370	418	445
Casapesenna	220	249	191	220	313	379	437	473	539	540	449	438	496	514	550
Caserta	2,997	3,345	2,568	2,735	3,402	3,575	3,605	3,632	3,793	4,007	4,048	3,955	3,825	3,775	3,916

Municipalities	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Castel Volturno	2,512	2,933	3,071	3,415	3,568	3,854	3,880	3,954	4,114	4,012	4,352	4,081	4,691	4,933	4,824
Cervino	111	135	77	88	141	155	143	151	168	184	183	174	158	167	182
Cesa	209	246	225	231	270	283	296	302	305	337	350	342	336	313	311
Francolise	182	224	201	216	243	266	280	300	305	289	296	282	292	288	348
Frignano	272	266	172	182	283	296	288	290	320	328	337	334	366	345	347
Gricignano di Aversa	403	461	384	431	513	388	484	522	544	599	870	853	881	806	807
Lusciano	362	431	457	578	577	655	656	705	730	772	793	779	719	734	764
Maddaloni	598	731	778	803	835	900	950	950	1,027	1,080	838	820	881	889	944
Marcianise	751	834	861	873	882	922	981	1,025	1,122	1,224	1,268	1,204	1,203	1,145	1,152
Mondragone	1,286	1,598	1,741	2,110	2,578	2,857	3,079	3,231	3,521	3,909	4,581	4,279	4,111	3,689	3,717
Orta di Atella	369	449	411	482	578	666	739	747	752	760	800	813	754	674	673
Parete	528	607	565	586	769	853	876	873	888	917	997	987	1,015	1,037	1,083
Recale	233	249	301	304	321	337	356	251	232	240	242	231	241	247	248
San Cipriano d'Aversa	529	627	453	520	615	721	736	796	917	972	1,034	1,009	869	845	826
San Felice a Cancello	424	483	315	338	418	438	438	469	502	485	498	474	515	543	563
San Marcellino	608	699	500	602	841	940	1,026	1,030	1,036	1,060	1,062	1,075	49	990	971
San Marco Evangelista	171	185	202	238	268	299	334	366	369	372	334	320	302	293	290
San Nicola la Strada	798	920	816	853	1,097	1,246	1,365	1,599	1,701	1,632	1,505	1,393	1,380	1,356	1,304
San Tammaro	99	107	56	76	100	88	94	104	99	93	162	154	161	176	194
Santa Maria Capua Vetere	1,198	1,349	1,068	1,107	1,403	1,453	1,478	1,560	1,739	1,819	1,729	1,695	1,729	1,629	1,692
Santa Maria la Fossa	74	111	89	108	120	168	191	173	167	163	127	135	136	143	162
Sant'Arpino	268	299	214	256	304	328	324	403	461	487	500	483	537	495	513
Succivo	179	226	200	242	278	300	336	341	322	365	369	371	407	371	338
Teverola	364	411	370	390	498	505	521	505	508	517	444	438	447	424	410
Trentola Ducenta	623	679	443	517	704	758	785	799	804	834	953	943	848	829	873
Villa di Briano	249	331	184	286	343	384	607	539	597	640	643	580	628	601	591
Villa Literno	743	588	349	430	752	900	919	960	1,085	1,274	1,336	1,275	1,214	1,428	1,572

Appendix 3. Potentially contaminated/unremediated sites in the Land of Fires (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Potentially contaminated/ unremediated sites	2017	2018	2019	2022
Acerra	1,623,710	1,642,711	1,502,449	1,419,196
Brusciano	60,634	60,641	60,641	58,251
Caivano	1,956,060	1,809,272	1,825,433	1,555,704
Camposano	2,967	2,968	2,968	2,968
Casamarciano	254,613	254,624	254,624	254,624
Castello di Cisterna	161,353	161,361	161,361	161,361
Cicciano	47,805	47,806	47,806	47,806
Cimitile	15,506	15,511	15,511	15,511
Comiziano	204,927	204,930	204,930	204,930
Giugliano in Campania	6,745,723	6,227,107	6,227,107	6,026,963
Mariglianella	62,874	62,878	64,418	62,418
Marigliano	339,325	339,337	334,521	302,341
Melito di Napoli	109,784	109,791	109,791	109,791
Nola	1,516,436	1,517,647	1,510,233	1,423,718
Pomigliano d'Arco	2,969,546	2,764,587	2,753,607	2,779,028
Pozzuoli	1,136,506	1,755,157	1,647,277	1,646,228
Qualiano	126,601	126,604	126,604	126,604

Potentially contaminated/ unremediated sites	2017	2018	2019	2022
Quarto	247,859	247,864	231,268	247,864
Roccarainola	194,532	194,535	194,535	194,535
San Paolo Belsito	838	839	839	839
San Vitaliano	202,069	202,074	183,030	182,439
Saviano	133,842	133,846	133,846	133,846
Scisciano	37,860	37,863	37,863	37,863
Tufino	534,917	534,925	534,925	534,925
Villaricca	284,988	285,251	285,251	285,251
Visciano	0	0	0	0
Aversa	96,603	99,238	84,238	83,548
Capodrise	68,047	68,050	42,838	40,976
Capua	2,463,009	2,468,933	2,460,209	2,308,087
Carinaro	174,472	182,170	182,170	182,170
Casal di Principe	36,988	41,091	37,991	36,700
Casaluce	22,593	22,594	22,594	20,660
Casapesenna	2,523	2,523	2,523	2,523
Caserta	1,246,361	1,239,682	1,627,890	1,535,614
Castel Volturno	3,973,000	3,982,183	3,982,183	3,972,524
Cervino	27,112	27,115	27,115	27,115
Cesa	8,805	9,266	9,266	6,807
Francolise	172,385	172,393	172,393	172,393
Frignano	58,542	58,545	58,545	58,545
Gricignano d'Aversa	179,818	179,820	179,820	179,820
Lusciano	3,907	3,907	3,907	3,907
Maddaloni	1,463,828	1,400,585	1,357,122	1,360,644
Marcianise	853,513	850,915	783,752	806,145
Mondragone	1,121,746	1,120,669	1,118,795	1,115,339
Orta di Atella	296,016	281,053	281,053	281,053
Parete	16,617	16,617	16,617	16,617
Recale	21,901	21,902	21,902	21,902
San Cipriano d'Aversa	1,187	1,187	1,187	1,187
San Felice a Cancello	237,554	237,565	237,565	237,565
San Marcellino	2,193	2,194	2,194	2,194
San Marco Evangelista	410,870	410,891	410,891	410,891
San Nicola La Strada	160,081	160,085	160,085	160,085
San Tammaro	703,837	703,849	703,849	703,849
Santa Maria Capua Vetere	400,209	396,163	381,641	381,641
Santa Maria La Fossa	417,560	405,642	405,642	405,643
Sant'Arpino	234	234	234	234
Succivo	48,360	48,361	48,361	48,361
Teverola	491,270	493,267	492,115	485,715
Trentola-Ducenta	57,710	57,712	57,712	57,712
Villa di Briano	119,787	119,790	119,790	119,790
Villa Literno	1,514,918	1,514,921	1,514,921	1,514,920

Appendix 4. Number of toxic fires in the Land of Fires (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Municipalities	2014	2015	2016	2017	2018	2019	2020	2021
Acerra	5	8	5	3	47.26	81.79	73.28	53.29
Caivano	4	19	4	11	85.72	148.02	132.61	94.43
Castello di Cisterna	0	2	0	0	4.5	7.79	6.98	5.08
Giugliano in Campania	2	96	65	27	472.61	740.09	663.05	482.14
Marigliano	0	1	0	0	2.25	3.89	3.49	2.54
Melito di Napoli	0	0	0	1	2.25	3.89	3.49	2.54
Pozzuoli	0	10	1	2	29.26	50.64	45.37	32.99
San Vitaliano	0	0	0	0	0	0	0	0
Qualiano	0	12	9	6	60.76	105.17	94.22	68.51
Aversa	0	0	2	1	3.11	3.49	3.48	1.99
Capua	0	1	0	1	2.07	2.32	2.32	1.33
Carinaro	0	0	1	1	2.07	2.32	2.32	1.33
Casal di Principe	4	6	1	1	12.44	13.94	13.91	7.98
Casaluce	0	1	0	1	2.07	2.32	2.32	1.33
Castel Volturno	0	4	23	3	31.09	34.85	34.78	19.95
Frignano	0	2	2	2	6.22	6.97	6.96	3.99
Gricignano d'Aversa	0	3	2	3	8.29	9.29	9.27	5.32
Lusciano	0	1	0	0	1.04	1.16	1.16	0.66
Maddaloni	0	0	1	1	2.07	2.32	2.32	1.33
Marcianise	0	0	0	0	0	0	0	0
Mondragone	0	0	17	1	18.66	20.91	20.87	11.97
Orta di Atella	0	2	0	0	2.07	2.32	2.32	1.33
Parete	0	1	0	0	1.04	1.16	1.16	0.66
San Cipriano d'Aversa	0	1	0	1	2.07	2.32	2.32	1.33
San Felice a Cancello	0	0	0	0	0	0	0	0
San Marco Evangelista	0	0	0	0	0	0	0	0
San Tammaro	0	10	1	0	11.4	12.78	12.75	7.32
Santa Maria Capua Vetere	0	6	0	0	6.22	6.97	6.96	3.99
Succivo	0	2	0	1	3.11	3.49	3.48	1.99
Teverola	0	3	2	2	7.26	8.13	8.12	4.66
Trentola Ducenta	0	1	2	0	3.11	3.49	3.48	1.99
Villa Literno	0	5	11	6	22.8	25.56	25.51	14.63
Villa di Briano	0	0	2	1	3.11	3.48	3.48	1.99

Appendix 5. Consumption of land in hectares (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Municipalities	2012	2015	2016	2017	2018	2019	2020	2021
Acerra	1.040.27	1.049.54	1.050.65	1.053.00	1.053.67	1.058.77	1.158.86	1.179.91
Brusciano	202.33	202.55	202.69	202.74	202.87	202.87	211.56	216.94
Caivano	720.49	726.78	729.12	733.42	734.93	738.67	770.41	778.21
Camposano	104.15	105.73	105.73	105.73	105.90	105.90	108.80	109.19
Casamarciano	123.77	125.33	125.72	128.13	128.18	129.39	131.52	132.78
Castello di Cisterna	159.71	160.21	160.46	161.35	161.35	162.62	166.47	167.26
Cicciano	196.33	196.73	196.73	196.79	197.20	197.25	200.77	201.56
Cimitile	117.93	118.03	118.03	118.03	118.03	118.03	119.25	119.28
Comiziano	63.45	63.45	63.45	63.46	63.46	63.46	64.97	65.11
Giugliano in Campania	2.300.91	2.377.16	2.381.28	2.384.48	2.384.69	2.386.57	2.457.11	2.470.51
Mariglianella	127.69	128.03	128.03	128.04	128.44	129.12	133.68	135.75

Municipalities	2012	2015	2016	2017	2018	2019	2020	2021
Marigliano	566.02	568.38	570.06	570.96	571.35	571.91	602.02	608.51
Melito di Napoli	305.66	306.82	306.95	307.07	307.07	307.07	307.39	307.39
Nola	1.258.67	1.268.14	1.269.83	1.276.66	1.276.66	1.279.64	1.311.59	1.325.91
Pomigliano d'Arco	662.32	663.23	664.03	664.43	666.21	670.08	677.68	680.48
Pozzuoli	1.428.32	1.430.25	1.434.52	1.435.80	1.435.80	1.435.80	1.456.98	1.459.44
Qualiano	283.83	284.32	284.32	285.96	285.96	285.96	291.87	292.61
Quarto	570.49	573.69	576.46	578.59	578.59	578.59	596.54	607.04
Roccarainola	245.77	251.10	259.47	260.46	260.46	260.76	268.03	269.36
San Paolo Bel Sito	68.26	68.26	68.38	68.63	68.72	68.72	68.95	68.95
San Vitaliano	154.13	154.98	155.24	157.00	157.00	157.00	164.32	165.57
Saviano	412.51	414.59	415.62	416.38	416.38	417.67	424.26	429.29
Scisciano	160.11	160.31	161.34	162.06	162.42	162.48	167.75	172.69
Tufino	96.51	96.51	96.66	96.66	96.80	96.97	100.17	101.45
Villaricca	351.24	352.30	353.75	354.64	355.79	355.79	361.24	361.69
Visciano	86.32	86.48	86.55	86.62	86.80	86.80	87.81	87.81
Aversa	568.79	571.11	571.17	571.87	571.87	571.87	577.99	578.33
Capodrise	166.74	167.37	167.63	167.78	167.81	167.81	170.77	170.77
Capua	473.84	608.02	609.10	614.12	614.41	614.47	623.60	624.00
Carinaro	267.02	274.26	276.51	278.69	278.69	280.39	290.94	295.93
Casal di Principe	467.75	472.93	473.84	475.24	475.24	475.24	477.64	481.76
Casaluce	161.45	163.39	163.99	165.39	165.72	165.73	169.68	173.48
Casapesenna	152.21	152.91	153.56	153.56	153.56	153.56	155.13	155.26
Caserta	1.297.35	1.307.35	1.310.31	1.313.96	1.317.59	1.324.41	1.338.98	1.342.56
Castel Volturno	1.299.58	1.302.79	1.305.02	1.305.54	1.306.05	1.306.08	1.507.18	1.507.78
Cervino	107.29	108.07	108.33	108.33	108.41	108.41	110.89	110.89
Cesa	108.98	109.70	109.79	110.05	110.05	110.32	110.88	110.88
Francolise	239.08	242.68	244.51	245.71	246.16	246.16	252.12	255.22
Frignano	170.34	171.78	172.86	173.50	173.50	173.85	176.43	178.48
Gricignano d'Aversa	380.91	389.14	390.46	392.15	392.70	394.77	433.89	442.47
Lusciano	209.47	211.85	212.65	214.05	214.10	214.10	215.75	216.76
Maddaloni	917.81	928.39	930.61	930.82	932.81	952.91	998.29	1.005.89
Marcianise	1.117.58	1.127.17	1.129.59	1.143.71	1.158.98	1.160.59	1.175.43	1.170.60
Mondragone	663.56	669.44	670.03	670.28	670.42	670.42	713.55	713.55
Orta di Atella	286.12	286.57	287.12	287.26	287.26	287.74	298.46	299.73
Parete	158.80	160.09	160.58	161.97	162.29	164.00	171.61	175.25
Recale	110.58	112.91	113.11	113.14	113.17	113.17	114.00	114.84
San Cipriano d'Aversa	257.19	258.87	259.16	260.34	260.34	260.34	263.69	263.69
San Felice a Cancello	427.30	429.60	430.62	431.80	432.31	432.94	449.30	450.59
San Marcellino	207.17	209.03	210.33	210.86	210.86	210.86	215.71	219.04
San Marco Evangelista	209.15	211.15	211.23	212.08	212.85	217.38	221.44	223.16
San Nicola la Strada	268.95	269.83	270.60	270.72	270.92	271.74	274.89	273.65
San Tammaro	244.86	249.80	249.95	250.84	250.84	250.84	254.45	255.26
Santa Maria Capua Vetere	559.02	563.91	564.08	564.37	564.37	564.37	569.80	571.82
Santa Maria La Fossa	179.80	186.90	187.06	187.06	187.06	187.06	190.94	192.63
Sant'Arpino	180.90	183.77	184.69	186.20	186.20	186.20	189.12	189.12
Succivo	139.38	140.13	140.21	140.30	140.34	140.74	147.73	147.73
Teverola	291.40	301.10	301.78	303.40	303.40	304.87	315.40	316.70
Trentola Ducenta	277.48	279.80	280.17	281.06	281.06	281.06	283.87	285.51
Villa di Briano	159.05	160.64	160.73	160.82	160.82	160.82	162.31	163.13
Villa Literno	471.73	538.55	540.34	540.97	541.58	541.58	605.30	614.87

Appendix 6. Density of consumed land in relation to the total area (sqm/ha) (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Municipalities	Density of consumed land	Municipalities	Density of consumed land
Acerra	28.01	Casaluce	35.86
Brusciano	47.92	Casapesenna	17.78
Caivano	33.41	Caserta	19.84
Camposano	31.40	Castel Volturno	4.09
Casamarciano	39.55	Cervino	5.67
Castello di Cisterna	50.20	Cesa	16.38
Cicciano	7.99	Francolise	9.69
Cimitile	3.91	Frignano	18.88
Comiziano	2.32	Gricignano d'Aversa	78.05
Giugliano in Campania	38.27	Lusciano	41.98
Mariglianella	38.58	Maddaloni	57.74
Marigliano	23.48	Marcianise	48.46
Melito di Napoli	12.51	Mondragone	4.78
Nola	32.00	Orta di Atella	14.36
Pomigliano d'Arco	42.88	Parete	65.01
Pozzuoli	10.15	Recale	38.39
Qualiano	13.50	San Cipriano d'Aversa	19.03
Quarto	52.66	San Felice a Cancello	8.48
Roccarainola	19.75	San Marcellino	53.93
San Paolo Bel Sito	5.22	San Marco Evangelista	72.03
San Vitaliano	36.27	San Nicola la Strada	13.28
Saviano	30.33	San Tammaro	6.44
Scisciano	53.88	Santa Maria Capua Vetere	15.54
Tufino	12.42	Santa Maria La Fossa	10.46
Villaricca	26.10	Sant'Arpino	57.74
Visciano	2.00	Succivo	10.49
Aversa	14.25	Teverola	80.73
Capodrise	12.37	Trentola Ducenta	30.42
Capua	9.08	Villa di Briano	15.50
Carinaro	103.15	Villa Literno	45.08
Casal di Principe	17.29		

Appendix 7. Unitary real estate market values for the municipalities of the Land of Fires (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Municipalities	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Acerra	1618	1560	1475	1455	1400	1338	1273	1227	1218	1241
Brusciano	1625	1591	1444	1412	1464	1459	1455	1451	1615	1489
Caivano	1111	1321	1220	1168	1108	1100	1146	1052	1096	1061
Camposano	1409	1374	1161	1058	787	812	1077	1053	1034	1012
Casamarciano	1286	1296	1317	1154	1132	1112	1190	1156	990	1183
Castello di Cisterna	2144	1956	1884	1836	1795	1778	1573	1568	1564	1530
Cicciano	1648	1454	1341	1302	1209	1229	1206	1169	1197	1170
Cimitile	1532	1586	1478	1233	1268	1243	1320	1268	1184	1269
Comiziano	1218	1432	1418	1012	990	1010	1052	963	992	928
Giugliano in Campania	1864	1775	1670	1573	1497	1454	1413	1397	1395	1371
Mariglianella	1753	1632	1593	1468	1407	1491	1433	1355	1287	1416
Marigliano	1627	1523	1493	1484	1491	1441	1365	1337	1297	1262

Municipalities	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Melito di Napoli	1854	1725	1537	1403	1354	1334	1280	1298	1304	1265
Nola	1876	1741	1654	1529	1523	1492	1481	1440	1426	1377
Pomigliano d'Arco	2065	1984	1883	1810	1784	1770	1884	1853	1865	1913
Pozzuoli	3232	3050	2862	2870	2757	2578	2530	2454	2433	2392
Qualiano	1648	1518	1464	1359	1343	1360	1320	1301	1242	1213
Quarto	2227	2156	2061	1914	1821	1760	1732	1690	1666	1800
Roccarainola	1303	1138	1204	1221	1080	1024	1085	989	981	1142
San Paolo Bel Sito	1689	1528	1519	1526	1423	1381	1356	1218	1213	1095
San Vitaliano	2085	1914	1766	1718	1590	1581	1569	1499	1501	1517
Saviano	1356	1298	1332	1281	1236	1266	1236	1333	1386	1330
Scisciano	1660	1505	1479	1532	1500	1330	1396	1464	1432	1367
Tufino	1322	1309	1272	1202	1118	1052	1061	1061	1026	1036
Villaricca	1977	1869	1738	1587	1535	1572	1551	1499	1506	1456
Visciano	1274	1240	1203	1196	1123	1008	969	987	948	948
Aversa	1695	1729	1718	1669	1642	1579	1456	1429	1429	1411
Capodrise	1612	1450	1403	1308	1151	1249	1172	1173	1190	1203
Capua	1223	1162	1127	1048	1017	913	914	916	866	920
Carinaro	1280	1464	1361	1327	1198	940	1172	1170	1207	1169
Casal di Principe	1282	1293	1163	1102	954	764	851	934	972	951
Casaluce	1222	1345	1362	1265	1132	1030	1015	942	903	905
Casapesenna	1499	1486	1300	971	824	735	638	582	560	701
Caserta	2164	2239	2047	2189	1862	1752	1615	1549	1522	1513
Castel Volturno	663	910	901	762	662	608	623	599	572	556
Cervino	1251	1271	1036	561	748	794	743	750	687	757
Cesa	1264	1331	1254	1279	1421	1245	1201	1273	1212	1197
Francolise	713	763	715	812	812	818	698	699	708	682
Frignano	406	886	1067	1035	936	884	1072	874	741	937
Gricignano d'Aversa	1519	1345	1247	1309	1246	1244	1132	1234	1311	1217
Lusciano	1392	1498	1609	1523	1290	1309	1324	1363	1379	1552
Maddaloni	1383	1414	1261	1223	1113	1083	985	969	965	935
Marcianise	1285	1327	1072	958	952	983	920	928	902	981
Mondragone	848	764	771	790	824	821	782	745	749	771
Orta di Atella	1601	1577	1489	1430	1289	1192	1149	1146	1138	1081
Parete	1422	1492	1383	1423	1230	1135	1138	1193	1239	1323
Recale	1284	1381	1264	1304	1261	952	1005	1101	1017	1019
San Cipriano d'Aversa	1226	1306	1121	1026	871	701	761	811	840	839
San Felice a Cancello	1218	1274	1154	917	744	646	724	846	858	754
San Marcellino	1454	1458	1274	1272	1119	963	1048	1095	1090	1117
San Marco Evangelista	1208	1503	1646	1520	1235	1043	1035	1008	992	1084
San Nicola la Strada	1786	1768	1656	1545	1527	1395	1300	1222	1169	1150
San Tammaro	1330	1240	1234	1141	1075	944	938	977	1069	989
Santa Maria Capua Vetere	1550	1506	1407	1281	1184	1068	1104	1057	999	969
Santa Maria La Fossa	668	735	770	688	655	646	613	587	573	588
Sant'Arpino	1674	1639	1508	1446	1337	1328	1452	1453	1502	1525
Succivo	1472	1478	1470	1428	1336	1332	1380	1407	1373	1391
Teverola	1506	1443	1347	1296	1284	1263	1199	1293	1297	1293
Trentola Ducenta	1820	1679	1544	1503	1424	1361	1342	1424	1447	1367
Villa di Briano	1226	1305	1131	1102	999	775	796	896	910	903
Villa Literno	1392	1447	1188	1009	790	592	860	958	1045	870

Appendix 8. Dataset (blue: municipalities of Napoli's province; light blue: municipalities of Caserta's province).

Municipalities	Δ mortality	Δ foreign population	Δ unreclaimed land	Δ landfills	Δ toxic fires	Δ land consumed	Δ real estate prices
Acerra	0.032	0.069	-0.018	0.250	6.899	0.014	-0.029
Camposano	0.020	-0.014	0.000	0.000	0.000	0.004	-0.025
Castello di Cisterna	0.021	0.037	0.000	0.000	0.726	0.005	-0.036
Cicciano	0.022	0.012	0.000	0.000	0.000	0.003	-0.036
Cimitile	0.036	0.035	0.000	0.000	0.000	0.001	-0.018
Giugliano in Campania	0.014	0.083	-0.019	-0.125	68.591	0.011	-0.033
Mariglianella	0.063	0.011	0.006	0.000	0.000	0.007	-0.022
Marigliano	0.016	0.026	-0.004	0.000	0.363	0.008	-0.028
Melito di Napoli	0.046	0.079	0.000	0.000	0.363	0.000	-0.041
Nola	0.011	0.050	-0.001	0.000	0.000	0.006	-0.033
Pomigliano d'Arco	0.033	0.033	-0.018	0.000	0.000	0.003	-0.008
Pozzuoli	0.026	0.008	0.121	0.000	4.713	0.002	-0.033
Qualiano	0.056	0.077	0.000	0.000	9.787	0.003	-0.033
Quarto	0.028	0.073	-0.017	0.000	0.000	0.007	-0.023
San Vitaliano	0.047	0.018	-0.024	0.000	0.000	0.008	-0.034
Scisciano	0.005	0.041	0.000	0.000	0.000	0.008	-0.020
Tufino	0.102	-0.034	0.000	0.000	0.000	0.006	-0.026
Villaricca	0.057	0.032	0.000	0.000	0.000	0.003	-0.033
Visciano	0.038	-0.026	0.000	0.000	0.000	0.002	-0.032
Aversa	0.016	0.021	-0.031	0.000	0.284	0.002	-0.020
Capodrise	0.043	0.052	-0.093	0.000	0.000	0.002	-0.030
Capua	0.001	0.049	0.000	0.000	0.190	0.023	-0.030
Casal di Principe	0.059	0.058	0.009	0.000	0.569	0.003	-0.027
Casaluce	0.069	-0.027	0.000	0.000	0.190	0.007	-0.031
Casapesenna	0.091	0.106	0.000	0.000	0.000	0.002	-0.072
Caserta	0.017	0.041	0.077	0.000	0.000	0.004	-0.037
Castel Volturno	0.001	0.038	0.001	0.000	2.850	0.018	-0.010
Cervino	-0.003	0.082	0.000	0.000	0.000	0.003	-0.030
Maddaloni	0.022	0.015	-0.019	0.000	0.190	0.010	-0.042
Marcianise	0.031	0.037	-0.020	-0.125	0.000	0.005	-0.026
Orta di Atella	0.053	0.054	-0.013	-0.250	0.190	0.005	-0.042
Recale	0.060	-0.019	0.000	0.000	0.000	0.003	-0.020
San Cipriano d'Aversa	0.062	0.063	0.000	0.000	0.190	0.002	-0.036
San Felice a Cancello	0.054	0.051	0.000	0.000	0.000	0.006	-0.044
San Nicola la Strada	0.044	0.061	0.000	0.000	0.000	0.002	-0.047
San Tammaro	0.066	0.111	0.000	0.000	1.046	0.004	-0.030
Santa Maria Capua Vetere	0.008	0.054	-0.012	0.000	0.570	0.002	-0.050
Teverola	0.036	0.020	0.000	0.000	0.666	0.008	-0.016
Trentola Ducenta	0.053	0.063	0.000	0.000	0.284	0.003	-0.030
Villa Literno	0.033	0.141	0.000	0.250	2.090	0.025	-0.030

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Complessità dell'agricoltura e saperi dell'agronomo[1]

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Abstract. The profession of the agronomist, in the hundred years of its history, is marked by the evolution of the notion of agriculture. Thus, initially holder of skills inherent to the land relevance of production structures, he finds himself later exercising more articulated tasks congenial to the profound transformation of production activities, once the biological cycle is removed from soil conditioning and the valorisation of the land becomes a qualifying parameter of a multifunctional vocation capable of involving management formulas integrated with the environment. A profession that requires a specialised cultural background but which rejects the fragmentation of knowledge, in a renewed commitment to compose from his point of view, how the agronomist can continue to be an interpreter of the productive leap characterising the sustainable dimension of development, improving the quality of life in the countryside with solutions placed at the service of common goods.

Keywords: agronomist, professional training, territory.
JEL code: K32.

1. QUALIFICAZIONE GIURIDICA E ASSETTO DELLA PROFESSIONE

Un'indagine sulla evoluzione della scienza *agroeconomica* ha un ruolo privilegiato di chiave interpretativa essenziale per descrivere e decifrare il profilo vario e vivo di una professione – rimasta a lungo priva di «un riconoscimento ufficiale» (Casadei, 2022, p. 9) – il cui sentiero è segnato dal progressivo consolidarsi ed assestarsi della nozione di agricoltura.

A partire dal r.d. 30 novembre 1924, n. 2172 *Ordinamento dell'istruzione superiore agraria e di medicina veterinaria*, il dialogo con le fonti che ne definiscono i titoli richiesti per l'iscrizione all'albo e l'elenco delle attività a cui sia abilitato, non si risolve, infatti, in una ricerca archivistica, ma punta lo sguardo sul continuo ricambio delle attitudini e della preparazione ed è in grado di offrire chiarimenti e indicazioni penetranti.

[1] Il presente scritto costituisce lo sviluppo dell'intervento tenuto al Convegno *Centenario dell'istituzione dell'esame di stato per l'abilitazione alla professione di Agronomo e di Perito Forestale. Regio decreto 30 novembre 1924, n. 2172* (Roma, 28 novembre 2024).

Anzi, viene da dire che, senza un esame che non sia anche specificamente tecnico-economico, la descrizione della figura dell'agronomo – lungo i cento anni di una esperienza corroborata dal necessario corredo del «complesso delle nozioni scientifiche e dei dati tecnici riflettenti l'attività agricola» (Tassinari, 2020) – rischierebbe di lasciare tracce sfocate e, comunque, non appaganti per identificare i tratti caratterizzanti impressi alla sua professionalità dalla messa a fuoco del movimento di fatti economici e dalla presa di coscienza di emergenti fatti sociali.

Fino agli esordi del '900, del resto, il rinnovamento dell'apparato tecnico e produttivo del settore era affidato all'ingegno di un ridotto drappello di autorevoli uomini di scienza piuttosto che all'efficienza delle strutture dedicate, a partire dai *comizi agrari*[2] e dalle *stazioni sperimentali* (Cossa, 1872)[3], in ragione della difficoltà di assumere direttori e sperimentatori con la preparazione dell'agronomo moderno. «E la ragione per la quale mancano in Italia agronomi preparati – scrive Antonio Saltini – è conseguenza delle vicende della cultura agronomica nazionale, della sua arretratezza nei decenni cruciali del Risorgimento, delle remore che ostacolano l'efficienza delle prime facoltà di agraria, che, create da spiriti lungimiranti, impiegano decenni per divenire autentici focolai di cultura agraria, risultando incapaci, alla fondazione delle istituzioni sperimentali e divulgative, di fornire i laureati che sarebbero necessari per dirigere comizi, stazioni sperimentali, cattedre ambulanti» (Saltini, 2002, p. 346).

L'importanza dell'agricoltura e gli interessi, tanto pubblici quanto privati, che si riconnettono al suo esercizio evidenziano, finalmente, la rivendicazione dello Stato corporativo di fare di essa il «fondamentale settore» nel «piano regolatore» dell'economia nazionale (Mussolini, 1936). Anche perché – nelle ulteriori parole di Giuseppe Bottai (Bottai, 1934) – l'agricoltura è da considerare depositaria di tutte le forze *conservatrici* che sempre si sprigionano nei momenti di pericolo per la società e di tutte le forze *innovatrici,* capaci di salvare, modificandola, una civiltà.

La prospettiva segnalata e le stesse citazioni solidaristicamente rinnovate nella concezione del diritto dedicato alla produzione agricola quale emanazione diretta dalla terra, dai solchi scavati, da intendere quasi come un prodotto del suolo, sono contenute nella corrispondente voce che Gian Gastone Bolla compone per *il Nuovo Digesto Italiano* (Bolla, 1937, p. 270). È lo stesso Autore – a cui Paolo Grossi ha riconosciuto il merito di «avere occhi e orecchi attenti, di capire che la grande architettura della codificazione civile, modellata su un individuo astratto ben rinserrato nella cintura dei suoi diritti soggettivi ma pensato avulso dai condizionamenti strutturali, doveva essere verificata alla luce delle esigenze di un mondo in trasformazione» (Bolla, 1922, p. 1) – ad avere intuito l'esigenza fondativa di una *Rivista* (anche essa, oggi, centenaria) il cui programma indulgeva sulla «influenza che il diritto ha sul progresso agrario», tanto da richiedere «la collaborazione degli economisti-agrari affinché i diversi problemi siano esaurientemente studiati anche nei loro presupposti, nelle loro relazioni ed attinenze tecniche» (Goldoni, 2021).

Nell'anno terzo della sua pubblicazione, in quel 1924, in cui prende forma giuridica l'ordinamento dell'istruzione superiore, al fine di promuovere, secondo l'art. 1 del r.d. 2172 cit., «il progresso delle scienze agrarie e di impartire la cultura scientifica necessaria per l'esercizio degli uffici e delle professioni agrarie e forestali» (Casadei, 2022, p. 18), l'evolversi del pensiero giuridico conosce la propria torsione metodologica nell'acquisizione di una coscienza che nasce dal confronto con una esperienza viva, ne sottolinea le differenze, mettendo a nudo soluzioni in grado di tener conto dell'ambiente che le ha prodotte. È il Brugi, autorevole civilista, a titolare il rinvio al valore giuridico e all'importanza delle consuetudini, osservando che: «ogni regione di Italia ha il suo notevole aspetto e i suoi propri bisogni: a quello e a questi rispondono usi diversi» (Brugi, 1934, p. 3), per questa via, preparando l'opera di rinnovamento della materia, che avverte i limiti del ricorso ai soli strumenti della tradizione e si affaccia a realizzare l'adeguamento tra forma giuridica e sostanza economico-sociale degli istituti attinenti all'esercizio delle attività di coltivazione e allevamento.

2. ATTRIBUZIONI DELL'AGRIMENSORE E DIVISIONE PROFESSIONALE DEL LAVORO

Con una precisazione necessaria: non c'è da meravigliarsi che la strutturazione del reale facesse riferimento al fondo inserito nel meccanismo della produzione con una matrice, appunto, consuetudinaria.

Lo sguardo fortemente legato alla concreta realtà terrena richiedeva un sapere tecnico intrecciato, in modo saldo, con la rilevanza fondiaria delle strutture produttive, così che la professione di agronomo dovesse attagliarsi a quella risalente di coloro che esercitavano un'attività di individuazione e di terminazione della proprietà

[2] Cfr. r.d. 23 dicembre 1866, n. 3452 *Che instituisce in ogni Capo-luogo di Circondario un Comizio agrario per l'utilità e l'incremento dell'agricoltura.*

[3] La successiva disciplina è opera del r.d. 30 dicembre 1923, n. 3203 *Provvedimenti per le stazioni e gli istituti sperimentali agrari e per la creazione di un istituto di economia e statistica agraria.*

terriera magari anche in qualità di arbitri incaricati di risolvere controversie insorte tra confinanti. In proposito, non può passare inosservato il ritaglio dell'oggetto della professione rispetto a quella del geometra, che il già citato Gian Gastone Bolla individua, nella voce riguardante l'*Agrimensore*, constatando che, in base alle sue conoscenze, «che concernono la terra e le costruzioni, si occupa anche della gestione del patrimonio agrario considerato come mezzo di produzione, e delle costruzioni edilizie civili e rurali» (Bolla, 1939, p. 282).

Nel delimitare l'ambito delle competenze, il r.d. 25 novembre 1929, n. 2248 *Regolamento per l'esercizio professionale dei dottori per le scienze agrarie* conferma la comune attitudine a regolare, insieme ai geometri, la divisione dei fondi rustici condividendo le attribuzioni, tra l'altro, in ordine a: tracciamento di strade poderali e consorziali; stima di aree e di fondi rustici anche ai fini della concessione di mutui e della dichiarazione di espropriazione e stima dei danni prodotti ai fondi rustici dalla grandine e dagli incendi; stima di scorte morte, operazioni di consegna e riconsegna di beni rurali e relativi bilanci e liquidazione, stima per la costituzione ed eliminazione di servitù rurali e stima di acque irrigue nei rapporti dei fondi serviti; funzioni contabili e amministrative nelle piccole e medie aziende non che progetto per la direzione, sorveglianza e liquidazione di costruzioni rurali e di edifici per uso di industrie agricole.

Nel complementare r.d. 11 febbraio 1929, n. 274 *Regolamento per la professione di geometra*, a cui era abilitato colui che avesse conseguito il diploma di agrimensore, era soltanto fatta salva, con riguardo a talune prestazioni di notevole importanza economica e caratterizzate dalla complessità di elementi di valutazione, la competenza dell'agronomo in ragione delle *speciali cognizioni scientifiche e tecniche*.

In effetti, si è osservato come il libero dispiegarsi della professione fosse ancora limitato quando il r.d. n. 2248 cit. era intervenuto a configurarne il più preciso inquadramento in un campo già dominato da ingegneri e geometri, mentre dalla stessa complessità e varietà delle applicazioni tecniche in agricoltura hanno avuto origine molteplici occasioni di interferenza con altre professioni se non di contrasto con le rispettive categorie (Petroni, 1968, p. 301).

A mano a mano che gli effettivi rapporti economici venivano a richiedere tecniche progredite al fine di cogliere la più matura organizzazione aziendale della produzione attraverso una valutazione dell'esercizio rispetto all'appropriazione patrimoniale, la figura dell'agronomo si avviava a diventare, con alcuni tratti tipici, garante della sua continuità secondo un piano e uno scopo determinato. Tra le più notevoli mansioni riconosciute si citano: la direzione e l'amministrazione di azienda; l'assistenza ai contratti agrari; il progetto, la condotta e la stima dei lavori per miglioramenti, trasformazioni e bonificamenti di fondi rustici; i giudizi di accertamento di qualità, quantità e valore delle produzioni dell'agricoltura e delle industrie agrarie; i lavori riguardanti la coltivazione, il commercio e l'utilizzazione di piante agrarie e dei relativi prodotti.

3. IMPORTANZA DEL FATTORE DI CAMPAGNA QUALE AUSILIARIO DELL'AGRICOLTORE

In realtà, nella tradizione, l'esperto di tecnica agricola più conosciuto è stato il fattore di campagna che, «provvisto più di esperienza e di cognizioni empiriche che non di una formale qualificazione professionale, espletava per conto del proprietario una serie di mansioni di carattere tecnico, amministrativo e gestorio insieme» (Carrara e Ventura, 1961, p. 133). Ma l'importanza di questa figura di agronomo viene gradualmente a ridursi rispetto al consolidamento dei temi legati alle nuove frontiere economiche, così come alle conquiste tecnologiche e alle ricadute sociali, con lo scorporo degli usi che ne fotografavano l'ambito di operatività all'insegna dell'immobilismo. Tanto che, nella voce ad esso dedicata nel *Digesto delle Discipline Pubblicistiche,* si sottolinea come sia difficile attribuire la qualifica «anche in senso lato, ad un tecnico agricolo che non sia laureato in scienze agrarie o quanto meno diplomato di istituto tecnico dello specifico settore» (Ercoli, 1987, p. 152).

Invero, all'esame di Stato per l'abilitazione all'esercizio della professione di agronomo (*recte*: dottore agronomo e dottore forestale) erano ammessi i laureati della facoltà di agraria il cui ordinamento didattico successivamente riformato con il d.p.r. 19 aprile 1982, n. 299 *Modificazioni all'ordinamento didattico universitario*[4], risultava articolato in tre distinti indirizzi (produzione vegetale; tecnico-economico e zootecnico) attraverso la ricognizione di discipline comuni e caratterizzanti, se non con l'intento di esaurire sul piano degli insegnamenti la formazione di uno specialista, di istruire «un neo-laureato dotato di preparazione professionale indirizzato verso determinati settori della produzione agricola» (Ercoli, 1987, p. 154).

Va sottolineato anche che i contenuti dei corsi avessero subito previsto un approfondimento dei profili di diritto agrario all'interno dell'area economico-estimativa, al fine di consentire – come si legge nell'avvertenza formulata da Giovanni Galloni in un volume apposi-

[4] Tale ordinamento sostituisce il precedente di cui alla tabella XXI del r.d. 30 settembre 1938, n. 1652.

tamente destinato agli studenti delle facoltà di scienze agrarie – a questi ultimi e agli stessi tecnici, che operano nei settori della produzione, di impossessarsi di «un punto di riferimento e di orientamento sui problemi di natura legislativa» che, ad ogni passo, si trovano di fronte all'esercizio dell'attività professionale (Galloni, 1988, p. VI).

La sommatoria di saperi anche di notevole diversità conduce, anzi, in una fase incerta segnata dall'aspettativa di dare un razionale assetto alla materia dei contratti agrari, a reinventare la stessa competenza dei laureati (o diplomati) di qualsiasi scuola di indirizzo agrario attraverso la equiparazione ai coltivatori diretti, favorendo il ricambio generazionale nella gestione produttiva dei fondi rustici in quanto siano anche capaci di soddisfare il terzo del fabbisogno di lavoro (Germanò, 1990, p. 241).

4. NUOVI ORIZZONTI DELL'AGRICOLTURA E MODERNIZZAZIONE DELLA PROFESSIONE

La sensibilità a procedere lungo itinerari in precedenza non calpestati si impone, per altro, come un dato insopprimibile. Il 28 marzo 1976, tenendo la prolusione inaugurale innanzi a questa Accademia, «portatrice e avanguardia in campo agricolo non solo di dottrina e di genialità creativa ma di idee e di cultura», Giovanni Marcora, nel tornare ad occuparsi, rispetto al riordinamento delle strutture produttive, dell'*osso* e della *polpa* dell'agricoltura italiana (Rossi-Doria, 2003; 2005), osserva, in chiusura, che, se ci venga offerta la possibilità di muoversi con razionalità avendo chiari gli obiettivi dello sviluppo produttivo in un equilibrato disegno di utilizzazione del territorio, «ciò noi spesso lo dobbiamo agli esami, alle analisi, agli approfondimenti che gli stessi ambienti della scienza, della ricerca, della professione più impegnata, portano avanti prevedendo e prevenendo le necessità» (Marcora, 2003, p. 222) .

Ora, proprio nello stesso anno, l'*Ordinamento della professione di dottore agronomo e di dottore forestale* viene riformato con la l. 7 giugno 1976, n. 3, recependo un'estensione delle competenze che abilitano il professionista ad incidere nella sfera dello studio, progettazione, direzione, sorveglianza, liquidazione, misura, stima, contabilità e collaudo delle opere di trasformazione e miglioramento fondiario, non che di bonifica e di sistemazione idraulica e forestale ovvero di opere inerenti a rimboschimenti e di lavori relativi alle costruzioni rurali e, ancora, di tutte le operazioni di estimo anche in ambiti congeniali all'emergere, procedere e consolidarsi delle esigenze di direzione, amministrazione, gestione, contabilità, curatela, consulenza di imprese nelle fasi della produzione e in quelle successive, in contesti imprenditoriali e dello scambio sul mercato.

Anche per l'influenza che, nel frattempo, viene ad esercitare il legislatore europeo, l'agricoltura conferma l'attualità di un percorso che, in tempi accelerati, porta ad una profonda trasformazione delle strutture sia sul piano dell'efficienza che dell'equità. Da un lato, sottratta al rischio biologico e sottoposta ad un controllo tecnologico delle fasi di allevamento di piante e animali, abbandona il suolo come base produttiva dello sfruttamento, dall'altro lato, sotto l'impulso di nuove aspettative, che maturano nella società, relative alla tutela dell'ambiente e alla salvaguardia delle risorse naturali, assume il territorio come parametro qualificante di una spiccata vocazione multisettoriale capace di ricomprendere tanto la fornitura di plurimi servizi quanto l'impegno sociale di rafforzare l'asse dei rapporti città-campagna.

L'agricoltura come attività economica a sé stante cede il passo ad una visione più ampia e integrata, che si riassume nelle politiche di sviluppo rurale: *diversificazione, multifunzionalità* e *pluriattività* sono i nuovi meccanismi di un processo di sviluppo che rimodula il ruolo degli agricoltori nelle campagne. Ad essi ci si riferisce «non solo per la produzione di alimenti, tradizionali beni privati oggetto di mercato, ma anche per le esternalità positive assicurate ai cittadini, attraverso la realizzazione di beni e servizi ambientali e ricreativi e per il rafforzamento della coesione sociale e dei valori culturali nel mondo rurale (Adornato, 2007, p. 5).

La distanza rispetto al *lessico* in precedenza utilizzato appare in tutta la sua latitudine con riguardo a chi tradizionalmente «applica le conoscenze agronomiche alla pratica agraria, quindi nella direzione di aziende, industrie, ecc. agrarie o quale funzionario in uffici pubblici o privati». Di questa trasformazione non poteva non risultare investita anche la valutazione complessiva delle attività di competenza dell'agronomo che, con l'entrata in vigore della l. 10 febbraio 1992, n. 152, *Modifiche e integrazioni alla legge 7 gennaio 1976, n. 3, e nuove norme concernenti l'ordinamento della professione di dottore agronomo e di dottore forestale*, conosce un ulteriore accrescimento di funzioni in quanto chiamato ad applicarsi in ordine alla differenziata strumentazione dell'intervento pubblico diretto a regolare l'impatto dei comportamenti umani e il mantenimento degli equilibri con le diverse componenti del territorio e alla segnalata ricchezza delle esperienze di una produzione volàno di buona qualità per la vita delle persone e moltiplicatrice di relazionalità e convivialità delle comunità.

Oltre tutto, ai fini della attribuzione e gestione delle risorse, gli atti di pianificazione e programmazione del settore agricolo come supporto allo sviluppo del territorio, prevedendo differenti scelte a livello delle Regioni,

implicano che all'agronomo sia richiesto di stimolare la competizione geo-economica in base alle caratteristiche specifiche delle aree rurali con l'offerta di prestazioni adattate alla realtà dei modelli.

Non si può, infatti, far riferimento all'esercizio uniforme di un'attività proprio in ragione della pluralità di agricolture e delle tipologie di soggetti destinatari di politiche diversificate (Adornato, 2010, p. 85).

È l'agronomo a farsi carico, inoltre, degli studi di assetto territoriale, dei piani zonali, urbanistici e paesaggistici; della programmazione relativa alle componenti agro-forestali e ai rapporti città-campagna; della redazione, nei piani regolatori, di specifici studi per la classificazione del territorio rurale, agricolo e forestale. E, ancora, dei piani ecologici per la tutela dell'ambiente; della valutazione dell'impatto ambientale e del successivo monitoraggio con riguardo agli effetti sulla flora e sulla fauna; dei piani paesaggistici e ambientali per lo sviluppo dei siti naturali, urbani ed extraurbani; dei piani ecologici e dei rilevamenti del patrimonio agricolo e forestale. E rientrano tra i nuovi profili distintivi della professione anche le attitudini che accreditano – come già osservato – l'ottimale utilizzazione del territorio in chiave non solo produttivistica: dalla progettazione, direzione, sorveglianza, liquidazione, misura, contabilità e collaudo di lavori relativi al verde pubblico anche sportivo, ai parchi naturali urbani ed extraurbani al recupero paesaggistico e naturalistico; alla conservazione di spazi rurali, agricoli e forestali, fino al recupero di cave e discariche.

Una lista di attività innovative che evidenziano numerose implicazioni tra territorio e società dipendenti dalla *prossimità urbana*, «rendendo le aree rurali attraenti per i ceti urbani e mostrando le aree urbane carenti per alcune risorse legate alla qualità della vita quotidiana» (Di Iacovo, 2003, p. 9).

L'agricoltura che, fino a non molto tempo addietro era confinata nel *contado*, arriva a insediarsi in città (Adornato, 2013, p. 9) e la nuova delimitazione geografica, che mostra forme ed economie integrate, alimenta, sul versante professionale, il coinvolgimento dell'agronomo in molteplici ambiti.

5. CONSIDERAZIONE DEL TERRITORIO TRA INTERESSE ALLA PRODUZIONE E DIMENSIONE AMBIENTALE

Non c'è dubbio che l'agronomo, in linea con la moderna evoluzione del fenomeno agricolo, flessibile nella diversificazione delle attività e, allo stesso tempo, unificato nell'occupazione dello spazio territoriale, sia, perciò, chiamato a supportare, insieme allo sviluppo delle capacità concorrenziali del sistema agroalimentare (Albisinni, 2009, p. 479), anche la gestione delle risorse naturali e, più in generale, dell'ambiente rurale. Se le relative mansioni possano ricondurci alla professione di un vero e proprio *agro-ecologo* è una valutazione che interroga non tanto in ordine al progressivo completamento del sistema legislativo finora codificato, con la conseguenza di attendere la formalizzazione di successive modifiche, quanto l'indispensabile consapevolezza intorno al posto occupato nelle campagne con una libertà di azione mai prima conosciuta.

Chiaro è il punto di *ri-partenza*, così come è stato espresso, in termini sintetici, da Giulio Andreotti, in un'altra importante prolusione inaugurale tenuta a questa Accademia: «non possiamo fare a meno di una razionale agricoltura e nello stesso tempo conservare l'ambiente» (Andreotti, 1991, p. 358).

Munito della conoscenza degli strumenti di programmazione europea e capace di orientare i fattori economici e sociali dello sviluppo territoriale, l'approccio professionale dell'agronomo sembra far leva sull'idea di complessità del sistema di produzione e di consapevolezza della gravità delle sfide: dalla sicurezza dell'approvvigionamento alimentare al cambiamento climatico, mettendo in campo una serie di competenze inedite.

Occorre, del resto, rendersi conto di un quadro inseparabile di interferenze che si manifestano nella complementarietà della rete di relazioni tra viventi, la cui rilevanza non è sfuggita neppure al legislatore europeo che, nel campo dei controlli (Albisinni, 2018, p. 1) ha articolato un più ampio strumentario di verifica della conformità delle complessive condizioni della produzione, seguendo l'itinerario dei passaggi di filiera senza, però, affrancarsi dall'insieme dei profili che mostrano la formula di gestione dell'agricoltura integrata con il territorio, la natura, la coesione delle comunità e la stessa architettura dei centri abitati.

Si tratta, in effetti, di avanzare sul terreno della conoscenza degli intrecci instaurati nell'evoluzione del modello organizzativo dell'impresa agricola, che produce e distribuisce una varietà aumentata di beni e servizi – si pensi, da ultimo, alla produzione di energia elettrica, di biogas e di combustibili ricavati dai prodotti e residui o all'assorbimento delle emissioni di anidride carbonica – contribuendo alla promozione di processi di trasformazione sostenibile e prestando assistenza all'evoluzione di tecniche e saperi di cui l'agricoltore è portatore, per cogliere le opportunità progettuali che il mercato rende disponibili.

La posta in gioco per l'agronomo è, in altri termini, quella di vedersi chiamato a spiegare, in un contesto completamente rivisitato, il funzionamento delle dinamiche della catena di produzione con una dotazione tecnica adattata al riconoscimento dei nuovi processi e delle

nuove possibilità che indicano «un altro modo di pensare all'agricoltura, ai soggetti che la praticano» (Adornato, 2014, p. 23).

Scrive un filosofo francese, in un'indagine legata alle grandi questioni politiche del presente, che il maggior deficit che si avverte nella conversione imposta dall'involuzione dello sviluppo quantitativo e tecnologico sia da individuare nel sistema educativo: «Perché il nostro insegnamento disciplinare è a compartimenti stagni; i saperi sono insegnati in una logica che separa le conoscenze invece di collegarle» (Morin, 2023, p. 141). Da cui l'auspicio che gli obiettivi e le categorie relative agli studi, finora separati, entrino in sincronia e confluiscano in una unità di pensiero.

Questa esigenza, almeno per la formazione dell'agronomo, sembra, in realtà, soddisfatta avendo avuto precedente consapevolezza che: «Il pensiero che taglia, riduce e isola porta certo gli esperti e gli specialisti a essere molto produttivi nei loro campi. Ma oggi la frammentazione dei saperi, la moltiplicazione dei sottosettori di singole discipline, la proliferazione dei linguaggi formali creano ostacoli e impedimenti» (Ceruti, 2011, pp. 19-20) ai fini dell'ampliamento dello sguardo in un mondo in continuo divenire.

6. SAPERI E PERCORSI FORMATIVI: VERSO UNA NUOVA FONDAZIONE DELLA PROFESSIONE

Ripartire dal *curriculum* del dottore in scienze agrarie e forestali conserva, allora, il significato di ritagliare una convincente e originale risposta, così alle necessità dell'approvvigionamento alimentare rispetto all'offerta di prestazioni avanzate, come alle esigenze della società in termini di salvaguardia dell'ambiente e della natura, da parte di chi svolge la propria attività in vista del supporto alle diverse tipologie aziendali agrarie ai fini dell'adempimento di (ormai) plurime funzioni.

Non occorre, tanto, insistere sull'esclusività nell'attribuzione di competenze in aree vaste della conoscenza nell'ambito della scienza agraria o forestale, dell'agronomia e dell'estimo rurale. Anche se un esplicito parere del Consiglio di Stato riguardo all'attività di pianificazione urbanistica ha motivato che, se una professione intellettuale sia *tipizzata* dalla legge, essa possa essere svolta soltanto dagli iscritti agli albi ed elenchi istituiti in forza della legge medesima, ammettendo che l'istituzione di tali albi possa configurare «un transito da un regime di libertà ad uno di esclusiva, nel senso che in capo agli iscritti, sussista una sorta di "privativa" per lo svolgimento delle attività tipizzate»[5].

Piuttosto, pare utile osservare che quella dell'agronomo, per la peculiarità delle cognizioni apprese nel percorso formativo, resta al centro di una complessa disciplina delle professioni, nel senso che non si possa fare a meno del bagaglio culturale specialistico, ma sempre in una prospettiva d'insieme, nelle aree in cui si articola la sua funzione, crocevia tra interesse alla produzione e interesse alla conservazione dell'ambiente (Capizzano, 1988, p. 1).

La linea che demarca la professione rispetto a quella riservata ad altri professionisti, che esercitano attività simili, è data, così, dal *punto di vista*[6] e, cioè, dal fatto che compito primario dell'agronomo si intende sempre di più quello di sciogliere i nodi dei fenomeni complessi riflessi dalle strutture di produzione e lavoro, mostrando i vantaggi che un'adeguata organizzazione territoriale presenta, in un rapporto *non predatorio* e sostenibile di attività che forniscano beni e servizi ad elevato contenuto relazionale.

Un significativo precedente è offerto da una recente decisione del Consiglio di Stato a proposito di una pretesa sovrapposizione delle competenze assegnate all'agronomo o all'agrotecnico in quanto iscritti al diverso albo professionale che, facendo leva sull'inciso contenuto nell'ultimo comma dell'art. 2 della l. n. 3 cit., stabilisce che la relativa elencazione non possa, comunque, pregiudicare l'esercizio di ogni altra attività professionale, in un ambito più esteso, come quello pertinente alla pianificazione, progettazione, manutenzione e gestione delle alberature cittadine, mentre le competenze dell'agrotecnico restano confinate «alla gestione economico-aziendale e amministrativa delle aziende agricole e zootecniche»[7].

Appare, dunque, essenziale non solo la scelta di iscrizione all'albo dei soli laureati, rimuovendo eventuali dubbi sulla equiparazione con il percorso di accesso ad altre professioni che ammettano anche non

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[5] Cfr. Cons. Stato, sez. II, 29 gennaio 1997, oggetto*: Ministero dei Lavori Pubblici-ricorso straordinario al Presidente della Repubblica proposto dall'Ordine degli Architetti e dall'Ordine degli Ingegneri avverso la delibera di conferimento ad un urbanista dell'incarico di elaborazione di P.G.R. intercomunale.*

[6] Il *punto di vista* è il criterio che la Corte Costituzionale, sentenza (12 luglio) 21 luglio 1995, n. 345, in *Giur. cost.,* 1995, I, 2595, individua a proposito della determinazione delle competenze del biologo. Nella sentenza si precisa, tra l'altro, che alla «concorrenza parziale e interdisciplinarità che appaiono sempre più necessarie in una società, quale quella attuale, i cui interessi si connotano in ragione di una accresciuta e sempre maggiore complessità ed alla tutela dei quali ... è, in via di principio, preordinato e subordinato l'accertamento e il riconoscimento nel sistema degli ordinamenti di categoria della professionalità specifica di cui all'art. 33, comma 5, Cost. Il che porta ad escludere una interpretazione delle sfere di competenza professionale in chiave di generale esclusività monopolistica (cfr. ad esempio le zone di attualità mista (...) degli ingegneri in scienze forestali nell'ambito di talune sistemazioni montane)».

[7] Così Cons. Stato, sez. III, 22 febbraio 2024, n. 4520, in www.dejure.it.

laureati che siano in possesso del diploma di istruzione superiore ad indirizzo agrario perché, ancor di più, rileva la vicenda della formazione universitaria: destinata a precedere le trasformazioni economiche e a riflettere l'evoluzione delle tecnologie e svincolata, per così dire, da una lista cognitiva dei saperi ripetitivi per proporre le sfide di una sperimentazione continua e spesso imprevedibile.

L'aggiornamento degli obiettivi culturali, dei contenuti disciplinari e delle competenze trasversali non disciplinari richieste per i corsi delle corrispondenti classi di laurea[8], consente sicuramente di affinare lo sguardo sul processo di modificazione dei problemi applicativi aziendali oltre che sull'emersione di nuovi criteri di sviluppo integrato dei settori agrario, agroambientale e forestale, consegnando al laureato, che intende affrontare le prove dell'esame abilitante alla professione, di comporre, rappresentare e immaginare come, dopo cento anni, si possa continuare a tirare le fila di ciò che si fa nelle campagne e nei boschi, valorizzando l'interazione delle conoscenze tecniche con la consapevolezza di indirizzo gestionale.

Nel passaggio dalla visuale fondiaria propria della risalente figura dell'agrimensore ad una più moderna, in grado di rendere conto dell'aspetto vitale dei bisogni umani, individuali e collettivi, assolti dal lavoro degli agricoltori, è imposta la responsabilità di diventare interpreti del *salto produttivo* generato dalle sopravvenute competenze agronomiche e forestali in vista dell'approccio caratterizzante la dimensione territoriale ed ecologica dello sviluppo.

La transizione che stiamo, ancora, attraversando – e che condurrà inevitabilmente ad un modo diverso di produrre – richiede, dunque, nuove carte da giocare in termini di capacità professionale che, se emarginano il lavoro replicativo, concorrono anche a promuovere l'apporto determinante di un lavoro cognitivo che contribuisce a scommettere sul futuro possibile, cambiando l'organizzazione della produzione e migliorando la qualità degli agro-eco-sistemi messi al servizio di beni comuni.

Trascorsi cento anni, il profilo caratterizzante la professione dell'agronomo *postmoderno* è riposto nell'esperienza di saper marcare la conclusione del progetto di un'agricoltura armonizzata al contesto di vita, capace di valorizzare le singole identità e promuovere lo sviluppo nel rispetto delle differenze.

[8] Cfr. d.m. 16 marzo 2007 *Determinazione delle classi delle lauree universitarie* e d.m. 16 marzo 2007 *Determinazione delle classi di laurea magistrale.*

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Rassegna giurisprudenziale I semestre 2025

a cura di Nicola Lucifero

AGRICOLTURA

Consiglio di Stato, Sez. VI, Sentenza, 18/03/2025, n. 2219
Agricoltura – pagamenti – creazione artificiale delle condizioni – revoca
Non sono erogati pagamenti ai beneficiari che risultino aver creato artificialmente le condizioni necessarie per ottenere tali pagamenti al fine di trarne un vantaggio contrario agli obiettivi del regime di sostegno. L'accertamento della creazione artificiosa delle condizioni per beneficiare delle provvidenze economiche giustifica l'applicazione dell'art. 30 del Reg. CE n. 73/2009, comportando la decadenza dalla totalità dei contributi erogati per l'annualità in questione.

T.A.R. Torino, (Piemonte) sez. II, 12/03/2025, n. 487
Agricoltura – Quote latte – Prelievo supplementare – Natura.
Gli importi dovuti a titolo di prelievo supplementare e i relativi interessi non sono debiti da pagarsi periodicamente, ma misure a carattere patrimoniale imposte per salvaguardare il sistema delle quote latte e applicate sul presupposto dello sforamento delle quote individuali, talché la prescrizione rilevante è quella decennale.

T.A.R. Torino, (Piemonte) sez. II, 12/03/2025, n.487
Natura del prelievo supplementare delle quote latte
Agricoltura – Quote latte – Prelievo supplementare – Natura.
Gli importi dovuti a titolo di prelievo supplementare e i relativi interessi non sono debiti da pagarsi periodicamente, ma misure a carattere patrimoniale imposte per salvaguardare il sistema delle quote latte e applicate sul presupposto dello sforamento delle quote individuali, talché la prescrizione rilevante è quella decennale.

ALIMENTAZIONE

CGUE, V Sez., 30 aprile 2025, C-386/23, *Novel Nutriology GmbH contro Verband Sozialer Wettbewerb eV.*
Rinvio pregiudiziale – Tutela dei consumatori – Regolamento (CE) n. 1924/2006 – Indicazioni nutrizionali e sulla salute fornite sui prodotti alimentari – Articolo 10, paragrafi 1 e 3 – Condizioni specifiche applicabili

alle indicazioni sulla salute – Articoli 13 e 14 – Elenco delle indicazioni sulla salute consentite – Articolo 28, paragrafi 5 e 6 – Misure transitorie – Pubblicità che effettua la promozione di un integratore alimentare impiegando indicazioni sulla salute relative a sostanze botaniche che rientrano nella composizione di tale integratore – Indicazioni sulla salute la cui valutazione è stata sospesa dalla Commissione europea – Applicabilità del regolamento n. 1924/2006

L'articolo 10, paragrafi 1 e 3, del regolamento (CE) n. 1924/2006 del Parlamento europeo e del Consiglio, del 20 dicembre 2006, relativo alle indicazioni nutrizionali e sulla salute fornite sui prodotti alimentari, come modificato dal regolamento (CE) n. 109/2008 del Parlamento europeo e del Consiglio, del 15 gennaio 2008, deve essere interpretato nel senso che: esso osta a che, nell'ambito della pubblicità commerciale effettuata per un integratore alimentare composto da «sostanze botaniche», ai sensi del regolamento (UE) n. 432/2012 della Commissione, del 16 maggio 2012, relativo alla compilazione di un elenco di indicazioni sulla salute consentite sui prodotti alimentari, diverse da quelle facenti riferimento alla riduzione dei rischi di malattia e allo sviluppo e alla salute dei bambini, sia consentito, finché la Commissione europea non abbia portato a termine l'esame delle indicazioni sulla salute relative alle sostanze botaniche ai fini del loro inserimento negli elenchi delle indicazioni sulla salute consentite, di cui agli articoli 13 e 14 del regolamento n. 1924/2006, come modificato, impiegare indicazioni specifiche sulla salute relative a tali sostanze e che descrivano o menzionino funzioni psicologiche o comportamentali, o fare riferimento a benefici generali e non specifici di una sostanza siffatta sullo stato di salute generale e sul benessere derivante dallo stato di salute, senza che tale riferimento sia accompagnato da un'indicazione specifica sulla salute che figuri in tali elenchi, a meno che l'impiego di tali indicazioni non sia autorizzato a norma dell'articolo 28, paragrafo 6, di tale regolamento.

AMBIENTE

CGUE, Grande Sezione, 21 gennaio 2025, C-188/23, *Land Niedersachsen contro Conti 11. Container Schiffahrts-GmbH & Co. KG MS "MSC Flaminia"*

Rinvio pregiudiziale – Ambiente – Spedizione di rifiuti – Direttiva 2006/12/CE – Direttiva 2008/98/CE – Nozione di "rifiuti" – Convenzione di Basilea sul controllo dei movimenti transfrontalieri di rifiuti pericolosi e del loro smaltimento – Articolo 1, paragrafo 4 – Regolamento (CE) n. 1013/2006 – Rifiuti soggetti alla procedura di notifica e autorizzazione preventive scritte – Spedizioni di rifiuti all'interno dell'Unione europea – Articolo 1, paragrafo 3, lettera b) – Validità – Interpretazione conforme alla Convenzione di Basilea – Rifiuti prodotti a bordo di una nave a seguito di avaria in alto mare – Nozione di "sbarco dei rifiuti" – Sbarco parziale dei rifiuti in un porto sicuro

L'articolo 1, paragrafo 3, lettera b), del regolamento (CE) n. 1013/2006 del Parlamento europeo e del Consiglio, del 14 giugno 2006, relativo alle spedizioni di rifiuti, dev'essere interpretato nel senso che l'esclusione dall'ambito di applicazione di tale regolamento prevista da tale disposizione, riguardante i rifiuti prodotti a bordo di una nave a seguito di avaria avvenuta in alto mare finché non siano sbarcati per essere recuperati o smaltiti, non si applica più ai rifiuti rimasti a bordo di tale nave per essere spediti, insieme alla nave, a fini di recupero o smaltimento, dopo che una parte di tali rifiuti è stata sbarcata in un porto sicuro a fini di recupero o smaltimento; tale interpretazione è conforme all'articolo 1, paragrafo 4, della Convenzione sul controllo dei movimenti transfrontalieri di rifiuti pericolosi e del loro smaltimento, firmata a Basilea il 22 marzo 1989, approvata, a nome della Comunità economica europea, con la decisione 93/98/CEE del Consiglio, del 1 febbraio 1993.

CGUE, VII Sez., 20 marzo 2025, C-809/23, *Sumitomo Chemical Agro Europe SAS contro Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (ANSES) e Compagnie européenne de réalisations antiparasitaires SAS France (CERA).*

Domanda di pronuncia pregiudiziale proposta dal Conseil d'État (Francia).

Rinvio pregiudiziale – Biocidi – Direttiva 98/8/CE – Regolamento (UE) n. 528/2012 – Applicabilità ratione temporis – Norme transitorie – Accesso alle informazioni – Articoli 66 e 67 – Domanda di accesso a una relazione di equivalenza tecnica tra principi attivi contenuti in biocidi redatta dall'autorità competente di uno Stato membro – Tutela degli interessi commerciali – Direttiva 2003/4/CE – Applicabilità ratione materiae – Articolo 4, paragrafo 2 – Nozione di "informazioni sulle emissioni nell'ambiente".

1) Gli articoli 96 e 97 del regolamento (UE) n. 528/2012 del Parlamento europeo e del Consiglio, del 22 maggio 2012, relativo alla messa a disposizione sul mercato e all'uso dei biocidi, come modificato dal regolamento (UE) n. 334/2014 del Parlamento europeo e del Consiglio, dell'11 marzo 2014, devono essere interpretati nel senso che:

una domanda di accesso alle informazioni relative a un principio attivo contenuto in un biocida autorizzato e, in

particolare, alla sua equivalenza tecnica con un principio attivo approvato, che è stata presentata dopo la data in cui tale regolamento è divenuto applicabile, deve essere valutata alla luce delle disposizioni di detto regolamento, quand'anche una siffatta domanda riguardi un biocida autorizzato a norma della direttiva 98/8/CE del Parlamento europeo e del Consiglio, del 16 febbraio 1998, relativa all'immissione sul mercato dei biocidi, o, se del caso, in forza del medesimo regolamento sulla base di un'equivalenza tecnica stabilita da un'autorità competente designata conformemente all'articolo 26 di tale direttiva.
2) L'articolo 66, paragrafo 3, lettera j), del regolamento n. 528/2012, come modificato dal regolamento n. 334/2014, deve essere interpretato nel senso che: una volta concessa l'autorizzazione all'immissione sul mercato di un biocida, l'autorità competente non può rifiutare l'accesso richiesto alle informazioni relative ai metodi di analisi che hanno consentito di stabilire l'equivalenza tecnica dei principi attivi contenuti in tale prodotto. Tali informazioni devono essere precise e complete, ma non si estendono ai risultati o alle conclusioni ottenuti a seguito dell'applicazione di tali metodi.
3) L'articolo 67, paragrafo 1, lettera h), l'articolo 67, paragrafo 3, lettera e), e l'articolo 67, paragrafo 4, lettera b), del regolamento n. 528/2012, come modificato dal regolamento n. 334/2014,devono essere interpretati nel senso che: non rientra nell'ambito di applicazione di tali disposizioni la comunicazione di una relazione che stabilisca l'equivalenza tecnica tra un principio attivo contenuto in un biocida autorizzato e un principio attivo approvato, elaborata dall'autorità competente di uno Stato membro in occasione dell'istruzione di una domanda di autorizzazione all'immissione in commercio di tale prodotto.
4) L'articolo 66 del regolamento n. 528/2012, come modificato dal regolamento n. 334/2014, deve essere interpretato nel senso che: esso non definisce un regime specifico ed esaustivo di accesso alle informazioni detenute dalle autorità competenti di uno Stato membro relative ai biocidi e, in particolare, all'equivalenza tecnica tra il principio attivo ivi contenuto e un principio attivo approvato, tale da escludere l'applicazione, da parte di dette autorità, delle disposizioni nazionali che recepiscono l'articolo 4, paragrafo 2, secondo comma, della direttiva 2003/4/CE del Parlamento europeo e del Consiglio, del 28 gennaio 2003, sull'accesso del pubblico all'informazione ambientale e che abroga la direttiva 90/313/CEE del Consiglio.
5) L'articolo 4, paragrafo 2, secondo comma, della direttiva 2003/4 deve essere interpretato nel senso che: la nozione di «informazioni sulle emissioni nell'ambiente», ai sensi di tale disposizione, non è, in linea di principio, applicabile alle informazioni contenute in una relazione redatta dall'autorità competente di uno Stato membro a seguito della valutazione dell'equivalenza tecnica di un principio attivo, contenuto in un biocida autorizzato, con un principio attivo approvato.
5) L'articolo 4, paragrafo 2, secondo comma, della direttiva 2003/4 deve essere interpretato nel senso che: la nozione di «informazioni sulle emissioni nell'ambiente», ai sensi di tale disposizione, non è, in linea di principio, applicabile alle informazioni contenute in una relazione redatta dall'autorità competente di uno Stato membro a seguito della valutazione dell'equivalenza tecnica di un principio attivo, contenuto in un biocida autorizzato, con un principio attivo approvato.

Cassazione Penale, sez. III, 13 febbraio 2025, n. 12514
Inquinamento ambientale – Prova del danno – Condotte riparatorie
L'art. 452-bis c.p. individua un reato di danno, la cui prova non richiede l'espletamento di accertamenti tecnici, essendo sufficiente il riscontro empirico delle conseguenze negative della condotta. L'attenuante del ravvedimento operoso può essere integrata solo da condotte riparatorie che si siano tradotte in un concreto aiuto all'ambiente.

Cassazione Civile, sez. I, 13 marzo 2025, n. 6675
Sanità pubblica – Igiene del suolo e dell'abitato – Danno ambientale – Nozione – Commissione di un reato a protezione dell'ambiente – Necessità – Esclusione
1) La condotta generativa del danno ambientale, come configurata sia dall'art. 18 della l. n. 349 del 1986 che dall'art. 311 del d.lgs. n. 152 del 2006, non si identifica necessariamente nella commissione di uno specifico reato a protezione dell'ambiente, potendo la stessa consistere nella violazione di una qualunque prescrizione riferita ad attività umana da cui possa derivare un'alterazione di quest'ultimo, desumibile dall'insieme delle regole dell'ordinamento, tra le quali rientrano sicuramente quelle relative all'illecito aquiliano ed alla responsabilità derivante dall'esercizio di attività pericolose.
2) In materia di danno ambientale, in relazione a fattispecie sussumibili *ratione temporis* nell'art. 2043 c.c., anziché nell'art. 18 della l. n. 349 del 1986, il comportamento idoneo ad integrare l'illecito consiste in una condotta dolosa o colposa di danneggiamento dell'ambiente (non richiedendosi anche la violazione di disposizioni di legge o di provvedimenti adottati in base a legge, secondo le previsioni della suddetta *lex specialis*), destinata a persistere sino a quando il suo autore mantenga, in base a libera determinazione sempre reversibile, le condizioni di lesione ambientale, sicché la prescrizione del diritto al

risarcimento decorre solo dalla cessazione di tale contegno, sia essa volontaria ovvero dipendente dalla perdita di disponibilità del bene danneggiato.

Cassazione Civile, Sez. V, Ordinanza, 05/05/2025, n. 11723
Consorzio – piano di classifica – inclusione – benefici – esclusione – onere della prova.
L'adozione del piano di classifica delle opere di bonifica da parte del consorzio genera una presunzione juris tantum di vantaggiosità per i fondi inclusi nel perimetro del comprensorio, che può essere superata dal proprietario attraverso prova contraria. L'onere della prova del beneficio specifico incombe sul consorzio solo in caso di specifica impugnativa del piano di classifica da parte del consorziato. Ove vengano in considerazione opere di difesa idraulica del territorio, il beneficio si deve considerare intrinseco alle opere stesse, essendo evidente che i fondi difesi da tali opere acquistano di per sé un maggior valore per effetto delle opere stesse.

Consiglio di Stato, sez. IV, 7 gennaio 2025, n. 68
Legittimo il divieto della giunta regionale di realizzare impianti eolici vicino a un sito Natura 2000 di importanza comunitaria
È legittimo il divieto imposto dalla giunta regionale alla realizzazione in prossimità di un sito Natura 2000 di importanza comunitaria (SIC), designato anche quale zona speciale di conservazione (ZSC), di impianti eolici di qualsiasi tipologia, inclusi singoli aereogeneratori, fatti salvi gli impianti di autoproduzione con potenza non superiore a 20 kilowatt, avendo l'amministrazione considerato la stessa fascia di rispetto prevista dal precedente atto di indirizzo al piano energetico regionale e per questa fascia costruito una carta del rischio per gli uccelli in transito con criteri non illogici. Né in senso contrario rileva la circostanza che detto atto di indirizzo non vieti in assoluto di installare impianti eolici nella fascia di rispetto considerata, non potendosi considerare illegittimo l'operato della regione stessa nel momento in cui essa, sulla base di una motivazione congrua, abbia reso questa norma più severa per un sito ben individuato.

Consiglio di Stato, sez. VI, 22 gennaio 2025, n. 483
Ambiente – Danno ambientale – Principio 'chi inquina paga' – Fallimento – Curatore – Applicabilità – Limiti
Il principio 'chi inquina paga' non vale ad esonerare la curatela fallimentare dagli obblighi di ripristino e di smaltimento dei rifiuti. La curatela fallimentare, che ha la custodia dei beni del fallito, infatti anche quando non prosegue l'attività` imprenditoriale, non può` evidentemente avvantaggiarsi dell'esimente di cui all'art. 192, lasciando abbandonati i rifiuti risultanti dall'attività` imprenditoriale dell'impresa cessata. Nella qualità` di detentore dei rifiuti, sia secondo il diritto interno, ma anche secondo il diritto comunitario (quale gestore dei beni immobili inquinati), il curatore fallimentare è perciò` senz'altro obbligato a metterli in sicurezza ed a rimuoverli, avviandoli allo smaltimento o al recupero.

Consiglio di Stato, sez. IV, 24 febbraio 2025, n. 1568
Ambiente – Autorizzazione integrata ambientale (A.I.A.) – Valutazioni – Sindacabilità – Limiti
Le valutazioni sottese al rilascio dell'autorizzazione integrata ambientale e alle relative modifiche implicano il ricorso a nozioni tecnico scientifiche in materia ambientale, connotate da un'ampia discrezionalità in merito ai possibili effetti ambientali o sanitari della modifica proposta, sindacabili dalla giurisdizione amministrativa di legittimità nei soli casi di esiti abnormi o manifestamente illogici.

Consiglio di Stato, sez. IV, 22 aprile 2025, n. 3465
Ambiente – Valutazione di impatto ambientale (V.I.A.) – Procedimento – Conclusione -Termini – Natura
L'art. 8, comma 1, d.lg. n. 152 del 2006 non può essere inteso come una deroga al principio della perentorietà dei termini di conclusione dei procedimenti di valutazione di impatto ambientale.

T.A.R. Ancona (Marche) sez. II, 12 marzo 2025, n. 165
Ambiente – Autorizzazione paesaggistica – Disparità di trattamento – Limiti
L'illegittimità per disparità di trattamento in materia paesaggistica è configurabile solo in casi macroscopici e presuppone un'assoluta identità delle situazioni di fatto prese in considerazione.

Corte Appello Napoli, sez. III, 13 gennaio 2025, n. 15807
Il giudizio di comparazione tra circostanze di segno opposto, previsto dall'art. 69 c.p. mira a realizzare una valutazione complessiva del fatto delittuoso e della personalità del reo, garantendo la proporzionalità tra reato e pena
In tema di giudizio di comparazione tra circostanze di reato, l'art. 69 c.p. impone una valutazione complessiva del fatto e della personalità del reo, al fine di determinare una pena proporzionata. Qualora concorrano circostanze aggravanti soggette a comparazione e circostanze "privilegiate" che la escludono, le attenuanti devono essere preliminarmente confrontate con le prime. In caso di equivalenza, si applica la pena prevista per il reato aggravato dalla circostanza "privilegiata".

Tribunale Frosinone, 15 gennaio 2025, n. 50
Reati ambientali e responsabilità penale: delega ai dipendenti
In materia di reati ambientali, la responsabilità penale per violazioni connesse alla gestione di un'impresa grava sui soggetti titolari di poteri decisionali e di spesa. La delega di funzioni, per essere valida ed efficace, deve essere espressa, inequivoca e conferire reali poteri di gestione. In assenza di specifiche deleghe o poteri societari formalmente attribuiti, un dipendente privo di ruoli dirigenziali non può essere ritenuto penalmente responsabile per le violazioni ambientali dell'azienda.

CACCIA

Cassazione Penale, Sez. III, Sentenza, 23/01/2025, n. 8863
Caccia – Contravvenzione di uccellagione – Detentore di esemplare di fauna selvatica – Dimostrazione della sua provenienza non illegittima – Onere della prova – Indicazione
In tema di reati venatori, il detentore di un esemplare di fauna selvatica è tenuto a dimostrarne la provenienza non illegittima per escludere la propria responsabilità in ordine alla contravvenzione di uccellagione, di cui al combinato disposto degli artt. 2, comma 1, lett. c), e 30, comma 1, lett. b), legge 11 febbraio 1992, n. 157, incombendo su di lui, e non sulla pubblica accusa, l'"onus probandi", posto che la regola generale sancita dall'art. 21, comma 1, lett. e), della legge citata è quella del divieto di detenzione di esemplari di fauna selvatica.

CONTRATTI AGRARI E PRELAZIONE

Corte d'Appello L'Aquila, Sentenza, 21/02/2025, n. 231
Prelazione – qualifica affittuario – prova
In tema di contratti agrari, la prova della qualità di affittuario dei fondi rustici non può essere offerta mediante testimonianza qualora il valore del canone ecceda il limite fissato dall'art. 2721 c.c., salvo la discrezionalità del giudice di ammettere tale prova in deroga al limite fissato dalla norma

Corte d'Appello Genova, Sez. III, Sentenza, 18/01/2025, n. 67
Prelazione – riscatto – condizioni – onere della prova
In materia di prelazione agraria e retratto agrario, il diritto di riscatto del coltivatore diretto può essere esercitato solo se ricorrono tutte le condizioni previste dalle normative specifiche (art. 8 L. n. 590 del 1965 e art. 7 L. n. 817 del 1971), inclusi la qualifica di coltivatore diretto, la coltivazione biennale dei terreni agricoli confinanti, il possesso della forza lavorativa adeguata, e il non aver effettuato vendite di fondi rustici nel biennio precedente. Il soggetto che agisce per il riscatto agrario è tenuto a fornire la prova delle condizioni positive e negative previste dalla legge.

CONTRIBUTI E AGEVOLAZIONI

CGUE, VII sez., 13 febbraio 2025, C-625/23**,** *Società Agricola Circe di OL Società Semplice contro ST e Agenzia per le Erogazioni in Agricoltura (AGEA)*
Rinvio pregiudiziale – Agricoltura – Politica agricola comune – Regolamento (CE) n. 1782/2003 – Regime di pagamento unico – Articolo 33 – Regolamento (CE) n. 795/2004 – Diritti all'aiuto – Ammissibilità al beneficio dell'aiuto – Articolo 15 – Nozione di "scissione" – Riduzione di superfici agricole dopo l'assegnazione provvisoria dei diritti all'aiuto – Rilevanza di tale riduzione ai fini dell'assegnazione definitiva dell'aiuto
L'articolo 33, paragrafo 3, secondo comma, del regolamento (CE) n. 1782/2003 del Consiglio, del 29 settembre 2003, che stabilisce norme comuni relative ai regimi di sostegno diretto nell'ambito della politica agricola comune e istituisce taluni regimi di sostegno a favore degli agricoltori e che modifica i regolamenti (CEE) n. 2019/93, (CE) n. 1452/2001, (CE) n. 1453/2001, (CE) n. 1454/2001, (CE) n. 1868/94, (CE) n. 1251/1999, (CE) n. 1254/1999, (CE) n. 1673/2000, (CEE) n. 2358/71 e (CE) n. 2529/2001, in combinato disposto con l'articolo 15, paragrafo 2, del regolamento (CE) n. 795/2004 della Commissione, del 21 aprile 2004, recante modalità di applicazione del regime di pagamento unico di cui al regolamento (CE) n. 1782/2003 del Consiglio che stabilisce norme comuni relative ai regimi di sostegno diretto nell'ambito della politica agricola comune e istituisce taluni regimi di sostegno a favore degli agricoltori, deve essere interpretato nel senso che: la nozione di «scissione», ai sensi di tali disposizioni, comprende una situazione in cui operazioni giuridiche connesse avvenute tra diversi agricoltori nel corso del periodo di riferimento, che includono una cessione di quote societarie e di superfici agricole coltivate, comportano che il patrimonio iniziale di un agricoltore e l'insieme di tali superfici siano attribuiti a due nuovi agricoltori distinti, anche qualora una simile situazione non costituisca una «scissione» ai sensi del diritto societario dell'Unione e, in particolare, della direttiva (UE) 2019/2121 del Parlamento europeo e del Consiglio, del 27 novembre 2019, che modifica la direttiva (UE) 2017/1132 per quanto riguarda le trasformazioni, le fusioni e le scissioni transfrontaliere.

CGUE, VI Sez., 20 marzo 2025, C-116/24, *Porcellino Grasso SRL contro Ministerul Agriculturii și Dezvoltării Rurale e a.*

Rinvio pregiudiziale – Politica agricola comune – Finanziamento da parte del Fondo europeo agricolo per lo sviluppo rurale (FEASR) – Programma nazionale di sviluppo rurale 2007-2013 – Misure di sviluppo rurale – Pagamenti per il benessere degli animali – Errori di calcolo – Riduzione di tali pagamenti da parte delle autorità nazionali senza aspettare una decisione definitiva della Commissione europea – Incidenza della scadenza del termine impartito per modificare tale programma e delle decisioni della Commissione che approvano o modificano detto programma – Assenza di contraddizione tra una sentenza della Corte e una sentenza del Tribunale dell'Unione europea – Responsabilità dello Stato membro di cui si tratta in caso di violazione del diritto dell'Unione.

1) L'articolo 19 del regolamento (CE) n. 1698/2005 del Consiglio, del 20 settembre 2005, sul sostegno allo sviluppo rurale da parte del Fondo europeo agricolo per lo sviluppo rurale (FEASR), come modificato dal regolamento (CE) n. 74/2009 del Consiglio, del 19 gennaio 2009, e l'articolo 9, paragrafo 3, del regolamento (CE) n. 1974/2006 della Commissione, del 15 dicembre 2006, recante disposizioni di applicazione del regolamento (CE) n. 1698/2006 del Consiglio sul sostegno allo sviluppo rurale da parte del Fondo europeo agricolo per lo sviluppo rurale (FEASR) come modificato dal regolamento di esecuzione (UE) n. 335/2013 della Commissione, del 12 aprile 2013, devono essere interpretati nel senso che: essi non ostano a che le autorità nazionali coinvolte nell'attuazione di una misura di sostegno finanziario non rimborsabile adottino, a seguito di errori di calcolo constatati dalla Corte dei conti europea, atti che impongono una riduzione dell'importo dell'aiuto finanziario concesso dal programma di sviluppo rurale del Fondo europeo agricolo per lo sviluppo rurale (FEASR) per la Romania per il periodo di programmazione 2007-2013, come approvato e modificato da decisioni della Commissione europea, laddove detto programma non poteva più essere riveduto né modificato alla data della constatazione di tali errori. Le considerazioni esposte dal Tribunale dell'Unione europea nella sentenza del 18 gennaio 2023, Romania/Commissione (T 33/21, EU:T:2023:5), sono irrilevanti al riguardo.

2) Il principio di responsabilità degli Stati membri in caso di violazione del diritto dell'Unione non trova applicazione qualora le aliquote di sostegno relative a aiuti finanziari concessi in forza di un programma di sviluppo rurale del Fondo europeo agricolo per lo sviluppo rurale (FEASR) siano state determinate in modo non conforme al diritto dell'Unione e i beneficiari degli aiuti in parola abbiano ottenuto pagamenti a titolo di questi ultimi, calcolati sulla base di tassi rettificati, conformi a tale diritto.

CGUE, VII sez., 10 aprile 2025, C-657/23, *M. K. contro Ministerstvo zemědělství*

Rinvio pregiudiziale – Politica agricola comune (PAC) – Finanziamento, gestione e monitoraggio della PAC – Regolamento (UE) n. 1306/2013 – Finanziamento da parte del Fondo europeo agricolo per lo sviluppo rurale (FEASR) – Articolo 54 – Tutela degli interessi finanziari dell'Unione europea – Regolamento (CE, Euratom) n. 2988/95 – Articolo 3 – Recupero degli importi indebitamente versati di una sovvenzione – Termine di prescrizione – Termine ordinatorio.

L'articolo 54, paragrafo 1, del regolamento (UE) n. 1306/2013 del Parlamento europeo e del Consiglio, del 17 dicembre 2013, sul finanziamento, sulla gestione e sul monitoraggio della politica agricola comune e che abroga i regolamenti del Consiglio (CEE) n. 352/78, (CE) n. 165/94, (CE) n. 2799/98, (CE) n. 814/2000, (CE) n. 1290/2005 e (CE) n. 485/2008, in combinato disposto con l'articolo 3, paragrafo 1, primo comma, del regolamento (CE, Euratom) n. 2988/95 del Consiglio, del 18 dicembre 1995, relativo alla tutela degli interessi finanziari delle Comunità, deve essere interpretato nel senso che: esso non osta a che la procedura di recupero degli importi indebitamente versati di una sovvenzione rientrante nel Fondo europeo agricolo per lo sviluppo rurale (FEASR) nei confronti del beneficiario di quest'ultima possa essere avviata dopo la scadenza del termine di 18 mesi decorrente dall'approvazione e, se del caso, dal ricevimento da parte dell'organismo pagatore o dell'ente incaricato del recupero di una relazione di controllo o di un documento analogo, che indichi che vi è stata un'irregolarità.

Cassazione Civile, sez. II, 18 marzo 2025, n. 7196

Nelle relazioni finanziarie tra agricoltori e l'Amministrazione, è ammissibile la compensazione atecnica tra contributi PAC e debiti per quote latte

Nel contesto dei rapporti finanziari tra agricoltori e l'Amministrazione in relazione ai contributi derivanti dalla Politica agricola comune (PAC) dell'Unione europea e ai debiti connessi al prelievo supplementare per le quote latte, emerge il principio di ammissibilità della compensazione impropria o atecnica. Tale meccanismo si concretizza quando, pur in assenza di una connessione giuridica diretta tra le due posizioni creditorie, si procede alla loro estinzione reciproca. Affinché la compensazione sia operante, è necessario che il controcredito

vantato dall'Amministrazione sia caratterizzato da certezza e liquidità, elementi che devono essere valutati dai giudici di merito e che non sono suscettibili di censura in sede di legittimità.

ESPROPRIAZIONE

Cassazione Civile, sez. I, 22 febbraio 2025, n. 4673
Calcolo dell'indennità aggiuntiva per espropriazione di area coltivata: sul valore del soprassuolo e dei frutti pendenti
Ai fini del calcolo dell'indennità aggiuntiva di cui *ex* artt. 40 e 42 d.P.R. n. 327/2001, ovvero spettante al proprietario coltivatore diretto o imprenditore agricolo, deve tenersi conto dell'aumento di valore di cui il suolo viene a beneficiare in ragione del soprassuolo. È esclusa la possibilità di determinare tale indennità sulla sola base del valore tabellare previsto per i suoli agricoli e per quelli non aventi vocazione edificatoria, trattandosi di un criterio di computo astratto, che non soddisfa il requisito del «ragionevole legame» con il valore di mercato del bene, ponendosi dunque in contrapposizione con il concetto di «serio ristoro» di cui all'art. 42 Cost.

Cassazione Civile, Sez. Un., 22 gennaio 2025, n. 1625
Giurisdizione civile – Giurisdizione ordinaria e amministrativa: determinazione e criteri – Fondo ricompreso in area naturale protetta – Vincoli ambientali ablativi delle facoltà del diritto dominicale – Domanda di indennizzo ex art. 15 l. n. 394 del 1991 – Giurisdizione del g.o. – Sussistenza – Fondamento – Fattispecie
Appartiene alla giurisdizione del giudice ordinario la controversia con la quale il proprietario di un fondo rientrante in un'area naturale protetta invoca la liquidazione dell'indennizzo *ex* art. 15 della l. n. 394 del 1991, in ragione dell'imposizione, da parte della P.A., di vincoli ambientali di natura sostanzialmente espropriativa, dal momento che, in tal caso, il *petitum* sostanziale non involge l'esercizio del potere pubblico, limitandosi a prospettare la lesione di un diritto soggettivo in conseguenza della conformazione legale del diritto di proprietà. (Nella specie, la S.C. ha cassato la pronuncia con cui il giudice di merito aveva declinato la giurisdizione ordinaria, in relazione alla domanda con la quale i titolari di alcuni terreni rientranti nel Parco nazionale del Pollino avevano dedotto la lesione del loro diritto di proprietà in conseguenza della previsione, nel piano di cui all'art. 12 della l. n. 394 del 1991, di vincoli che determinavano l'impossibilità di svolgere qualsivoglia attività agro-silvo-pastorale e il taglio silvicolturale).

IMPRESA

Cassazione Civile, Sez. I, Ordinanza, 24/01/2025, n. 1718
Concordato preventivo – privilegio – conferimento
Per beneficiare del privilegio previsto dall'art. 2751-bis c.c., è necessario non solo provare che il latte o i prodotti agricoli venduti siano stati conferiti dai soci, ma in caso contrario, dimostrare il nesso di strumentalità delle operazioni di acquisto da terzi con la finalità mutualistica della cooperativa. In mancanza di tale prova, il credito non può essere considerato privilegiato.

Cassazione Civile, Sez. I, Sentenza, 14/05/2025, n. 12949
Consorzio – amministratori – responsabilità – azione
L'art. 2608 cod. civ. preclude la possibilità che il consorzio stesso possa esercitare un'azione di responsabilità verso i propri amministratori, attribuendo esclusivamente ai consorziati il potere di agire per il risarcimento dei danni derivanti da condotte degli amministratori, secondo le norme del mandato, preservando così la tutela degli interessi individuali rispetto al fondo consortile.

LAVORO E PREVIDENZA

CGUE, X Sez., 8 maggio 2025, Cause riunite C-212/24, C-226/24 e C-227/24, *L.T. s.s., A.M., XXX, c. Istituto nazionale della previdenza sociale (INPS),*
Rinvio pregiudiziale – Politica sociale – Lavoro a tempo determinato – Direttiva 1999/70/CE – Accordo quadro CES, UNICE e CEEP sul lavoro a tempo determinato – Clausola 4, punto 1 – Principio di non discriminazione dei lavoratori a tempo parziale – Ambito di applicazione – Nozione di "condizione di impiego" – Operai agricoli a tempo determinato – Contributi previdenziali calcolati in funzione delle retribuzioni – Retribuzioni degli operai agricoli a tempo determinato stabilite in funzione delle ore di lavoro giornaliere prestate – Retribuzioni degli operai agricoli a tempo indeterminato stabilite in funzione di un orario di lavoro giornaliero forfettario
La clausola 4, punto 1, dell'accordo quadro sul lavoro a tempo determinato, concluso il 18 marzo 1999, allegato alla direttiva n. 70/1999/CE, relativa all'accordo quadro CES, UNICE e CEEP sul lavoro a tempo determinato, deve essere interpretata nel senso che essa osta a una normativa nazionale, come interpretata da un giudice nazionale supremo, in forza della quale i contributi previdenziali dovuti da datori di lavoro, che impiegano operai agricoli a tempo determinato, al fine di finanziare prestazioni di un regime professionale di sicurezza sociale, sono calcolati in funzione delle retribuzioni versate a tali operai per le ore di lavoro giornaliere che essi hanno

effettivamente svolto, mentre i contributi previdenziali dovuti dai datori di lavoro che impiegano operai agricoli a tempo indeterminato sono calcolati sulla base di una retribuzione stabilita per un orario di lavoro giornaliero forfettario, come fissato dal diritto nazionale, a prescindere dalle ore effettivamente prestate.

PARTECIPAZIONE

CGUE, X Sez., 6 marzo 2025, C-41/24, *Waltham Abbey Residents Association contro An Bord Pleanála e a.*
Rinvio pregiudiziale – Ambiente – Direttiva 2011/92/UE – Valutazione dell'impatto ambientale di determinati progetti pubblici e privati – Articolo 2, paragrafo 1, e articolo 4, paragrafo 2 – Progetti rientranti nell'allegato II – Lavori di pianificazione urbana – Articolo 4, paragrafi 4 e 5 – Obblighi del committente e dell'autorità competente qualora lo Stato membro interessato decida di richiedere la determinazione di cui ai paragrafi 4 e 5 per tali progetti – Presa in considerazione delle osservazioni presentate da terzi da cui risulti un impatto potenziale del progetto in questione su una specie animale soggetta alla rigorosa tutela prevista dall'articolo 12 della direttiva 92/43/CEE
L'articolo 4, paragrafi da 4 a 6, della direttiva 2011/92/UE del Parlamento europeo e del Consiglio, del 13 dicembre 2011, concernente la valutazione dell'impatto ambientale di determinati progetti pubblici e privati, come modificata dalla direttiva 2014/52/UE del Parlamento europeo e del Consiglio, del 16 aprile 2014, dev'essere interpretato nel senso che: nell'ipotesi in cui, nell'ambito di una procedura di verifica preliminare condotta ai sensi di tale disposizione, un terzo abbia fornito all'autorità competente elementi oggettivi in merito a un potenziale impatto ambientale significativo di tale progetto, in particolare su una specie protetta ai sensi della direttiva 92/43/CEE del Consiglio, del 21 maggio 1992, relativa alla conservazione degli habitat naturali e seminaturali e della flora e della fauna selvatiche, come modificata dalla direttiva 2013/17/UE del Consiglio, del 13 maggio 2013, tale autorità deve chiedere al committente di fornirle informazioni supplementari e tenerne conto prima di decidere se una valutazione d'impatto ambientale sia necessaria o meno per detto progetto. Per contro, nell'ipotesi in cui, nonostante le osservazioni presentate a detta autorità da tale terzo, si possa escludere, sulla base di elementi oggettivi, che tale progetto possa avere un impatto ambientale significativo, la stessa autorità può decidere che una valutazione d'impatto ambientale non è necessaria, senza che essa sia tenuta a chiedere al committente di fornirle informazioni supplementari.

Consiglio di Stato, sez. IV, 7 gennaio 2025, n. 68
Coinvolgimento degli attori economici e sociali per l'introduzione delle misure di conservazione in materia ambientale
L'art. 2 del decreto del Ministro dell'ambiente e della tutela del territorio e del mare 17 ottobre 2007, nella parte in cui per introdurre le misure di conservazione richiede di assicurare la concertazione degli attori economici e sociali del territorio coinvolto, in quanto norma di rango regolamentare e quindi sublegislativo, costituisce una norma eccezionale, introdotta per rimediare all'inerzia manifestata dalle regioni nell'adottare le misure di conservazione necessarie per designare la zona speciale di conservazione (ZSC) e la zona di protezione speciale (ZPS). Detto disposto normativo non si applica pertanto nella regione Piemonte che ha superato detta inerzia con la previsione degli artt. 39 e 40 della legge regionale 29 giugno 2009, n. 19, che prevedono che i SIC si individuino su parere degli enti locali interessati e che si tenga conto delle segnalazioni delle amministrazioni dello Stato, degli enti locali, degli enti di gestione, senza richiedere un coinvolgimento degli operatori economici comunque considerati.

PRELAZIONE AGRARIA

Corte Appello Napoli, sez. IV, 12 aprile 2025, n. 1871
Prelazione agraria del confinante
In tema di prelazione agraria spettante al proprietario coltivatore diretto confinante, l'insediamento stabile di un affittuario coltivatore diretto sul fondo oggetto di vendita, anche in base a contratto non registrato o privo di data certa, costituisce causa ostativa all'esercizio del retratto. Ciò che rileva è l'effettiva, concreta e abituale attività di coltivazione, anche desumibile da elementi presuntivi, documentali e testimoniali.

Tribunale Ferrara, 13 maggio 2025
Preliminare di vendita e clausole inopponibili al prelazionario agrario
Qualora a seguito della stipula di un preliminare di vendita il titolare del diritto di prelazione agraria, *ex* art. 8 l.n. 590/1965, eserciti il suo diritto subentrando al promissario acquirente, il prelazionario non è tenuto ad onorare obbligazioni estranee alla causa astratta del contratto di compravendita in virtù di clausole negoziali poste nel preliminare nell'interesse delle altre parti o abusivamente inserite per danneggiarlo o pregiudicarne la libera determinazione di esercizio del diritto.

TRIBUTI

Cassazione Civile, sez. trib., 11 gennaio 2025, n. 719
Imposte in genere – Esenzioni ed agevolazioni – Agevolazione ex art. 2, comma 4-bis, del d.l. n. 194 del 2009 – Ambito di applicazione – Terreni e relative pertinenze – Distinzione tra pertinenza civile e pertinenza fiscale – Conseguenze
In tema di agevolazione per la piccola proprietà contadina, prevista dall'art. 2, comma 4-bis, del d.l. n. 194 del 2009, conv. con modif. dalla l. n. 25 del 2010, la nozione fiscale di pertinenza dei terreni agricoli differisce da quella civile, in quanto, prevalendo nella prima una visione economico-funzionale, il rapporto di pertinenzialità si configura in funzione dell'attività di impresa, tale da ricomprendere tutti i fabbricati funzionali all'attività agricola e alle costruzioni strumentali destinate ad uso ufficio dell'azienda agricola e agrituristica ed i fabbricati abitativi rurali.

Cassazione Civile, sez. trib., 18 febbraio 2025, n. 4164
Reddito agricolo forfetario – Attività art. 2135 c.c.
Nell'ambito delle attività agricole, la legge prevede che la quantificazione forfetaria del reddito si fondi sulla riconducibilità delle operazioni effettuate alle categorie di attività esplicitamente elencate e descritte dall'art. 2135 c.c. Risultano quindi connesse all'impresa agricola quelle attività che si rapportano direttamente alla manipolazione, alla conservazione, trasformazione, commercializzazione e valorizzazione dei prodotti agricoli ottenuti prevalentemente dalla coltivazione del fondo, del bosco o dall'allevamento di animali. Sono comprese anche le attività che comportano l'offerta di beni e servizi sfruttando prevalentemente le attrezzature o le risorse aziendali abitualmente impiegate nell'attività agricola, così come quelle finalizzate alla valorizzazione del territorio e del patrimonio rurale e forestale, incluse le attività di accoglienza e ospitalità qualificate dalla legge. L'individuazione del perimetro di applicabilità del regime forfetario per le attività agricole esige un'interpretazione che integri le disposizioni tributarie con le normative civilistiche, assicurando che l'applicazione della misura forfetaria sia coerente con la natura e la sostanza delle attività realmente svolte dall'imprenditore agricolo.

Cassazione Civile, sez. trib., 23 febbraio 2025, n. 4735
Imposta reddito persone fisiche (Irpef) – Oggetto dell'imposta – Redditi diversi – Operazioni speculative – Cessione di terreni edificabili con destinazione agricola – Plusvalenze tassabili ex art. 81 t.u.i.r. – Valore iniziale determinato ex art. 7 l. n. 448 del 2001 – Perizia sul valore asseverata in data successiva all'accertamento notificato – Utilizzabilità – Esclusione – Fondamento
In tema di imposte sui redditi, la determinazione delle plusvalenze, di cui all'art. 81, comma 1, lettere a) e b), del d.P.R. n. 917 del 1986, per i terreni edificabili e con destinazione agricola, a norma dell'art. 7 della l. n. 448 del 2001, non può avvenire assumendo come valore iniziale, in luogo del costo o del valore di acquisto, quello determinato sulla base di una perizia giurata asseverata in data successiva alla notifica dell'avviso di accertamento, poiché contrario alla finalità della norma, volta ad assicurare al contribuente un regime opzionale più favorevole, con riferimento all'anno d'imposta, entro il termine effettivamente previsto dalla norma primaria.

Cassazione Civile, sez. trib., 22 marzo 2025, n. 7664
Imposta reddito persone fisiche (I.r.p.e.f.) – Redditi agrari – Reddito agrario – Attività agricole connesse – Condizioni – Limiti
In tema di reddito agrario, la tassazione secondo il regime *ex* art. 34 TUIR si applica alle "attività agricole connesse", in base alla definizione di cui all'art. 2135, comma 3, c.c., purché ricorrano i presupposti previsti dall'art. 32, comma 2, lett. c), TUIR e "nei limiti della potenzialità del terreno" di cui all'art. 32, comma 1, TUIR, nel testo vigente *ratione temporis*.

Cassazione Civile, sez. trib., 7 marzo 2025, n. 6172
Contratti agrari – Piccola proprietà contadina – Agevolazioni tributarie – --- Agevolazioni tributarie – Imprenditore agricolo professionale – Società agricole – Qualifica iap – Condizioni – Limitazione di cui all'art. 1, comma 3 bis, d.lgs. n. 99 del 2004 – Ambito di applicazione – Riferibilità alle sole società di capitali – Fondamento
Imposte in genere – Esenzioni ed agevolazioni – Agevolazioni varie – --- In genere.
Le agevolazioni tributarie dell'imprenditore agricolo professionale (cd. IAP) si estendono alle società agricole, purché ricorrano le condizioni previste dall'art. 1, comma 3, d.lgs. n. 99 del 2004; pertanto, la limitazione di cui al comma 3-bis, quale deroga alla rilevanza delle attività dell'amministratore per la qualifica di IAP, al fine di contrastare il fenomeno abusivo del cd. IAP "itinerante" (ove un soggetto IAP assume il ruolo di amministratore di più società), si applica solo alle società di capitali e non anche a quelle di persone, giacché per queste ultime la responsabilità solidale e illimitata del socio IAP per le obbligazioni sociali è idonea ad arginare tale abuso.

USI CIVICI

Cassazione Civile, sez. trib., 12 gennaio 2025, n. 769
Usi civici – Accertamento – Terra facente parte di un demanio universale – Presunzione di demanialità – Sussistenza – Prova contraria – Oggetto ed onere
In tema di usi civici, la dimostrazione che una terra fa parte di un demanio universale comporta la presunzione della demanialità della stessa, salvo che sussista un preciso titolo da cui risulti per essa la trasformazione del demanio in allodio, con onere della prova a carico del privato che eccepisce la natura allodiale.

Cassazione Civile, Sez. Un., 15 gennaio 2025, n. 1008
Giurisdizione civile – Giurisdizione ordinaria e amministrativa – Usi civici – Giurisdizione del commissario regionale per la liquidazione degli usi civici – Oggetto – Fattispecie
La giurisdizione del Commissario regionale per la liquidazione degli usi civici sussiste con riguardo ad ogni controversia relativa all'esistenza, natura ed estensione dei diritti di uso civico e degli altri diritti di promiscuo godimento delle terre spettanti agli abitanti di un comune o di una frazione, comprese quelle nelle quali sia contestata la qualità demaniale del suolo o l'appartenenza a titolo particolare dei beni delle associazioni, nonché tutte le questioni a cui dia luogo lo svolgimento delle operazioni affidate ai commissari. (Nella specie, la S.C., pronunciandosi in sede di regolamento preventivo di giurisdizione, ha ritenuto competere alla suddetta giurisdizione la domanda con la quale un Comune aveva invocato l'accertamento della natura allodiale di alcuni fondi, inseriti nel P.R.G. senza alcuna opposizione dell'Università agraria, escludendo la configurabilità di un'inammissibile iniziativa officiosa nell'ordinanza con cui il Commissario aveva disposto la chiamata in giudizio della suddetta Università agraria e della Regione).

Cassazione Civile, Sez. V, Sentenza, 29/01/2025, n. 2139
Demanio e patrimonio dello stato e degli enti pubblici – usi civici – imposte e tasse in genere – avviso di accertamento
I terreni gravati da usi civici di bosco e pascolo permanente, facenti parte del patrimonio demaniale dell'ente territoriale ai sensi dell'art. 826 c.c., sono soggetti al pagamento della TOSAP in quanto beni appartenenti al demanio o al patrimonio indisponibile dei comuni e delle province.

Cassazione Civile, Sez. I, Sentenza, 31/01/2025, n. 2295
Usi civili – procedimento civile – Legittimazione attiva e passiva
Nelle comunioni familiari montane, come le Regole, la legittimazione ad agire per il risarcimento dei danni derivanti da atti gestori o deliberativi illegittimi spetta esclusivamente alla collettività stessa rappresentata dall'organizzazione sociale, non ai singoli soci. Solo l'assemblea dell'ente può adottare le decisioni relative alle azioni di responsabilità contro gli amministratori o i regolieri.

Cassazione Civile, Sez. V, Sentenza, 15/02/2025, n. 3861
Demanio e patrimonio dello Stato e degli enti pubblici – usi civici – prova in genere in materia civile – onere della prova
I terreni comunali gravati da usi civici, destinati a bosco o pascolo permanente, rientrano nel patrimonio indisponibile del Comune e sono assoggettati alla tassa per l'occupazione di spazi ed aree pubbliche (TOSAP). In tali casi, è onere del contribuente dimostrare la sdemanializzazione dei beni per sottrarli alla tassazione.

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