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**Circular Economy
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and Italian NUTS 2
Regions: A Multi-Attribute
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Abstract

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Keywords

Circular economy; Dominance-based Rough Set Approach; Waste Index; Regional disparities; Economic, Social and Environmental Sustainability

JEL Codes

Q21, Q32, Q56, P48, R58

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1. Introduction

The circular economy (CE) is a complex concept that cannot be observed directly. It encompasses a multitude of dimensions and perspectives and is characterized by diverse types of actions at various stages in a product's life cycle. To measure cycles and flows of materials and environmental-related aspects the Material Flow Analysis (MFA) and the Life Cycle Assessment (LCA) (see, e.g., Baccini, 1996 and Hauschild et al. 2017) are largely used. MFA is an analytical method to study the flows of materials in a system, for example the exchanges between an economy and the natural environment. The value of materials is not considered, this way, it is not appropriate to quantify the economic value. On the contrary, LCA is a method to study the environmental impacts of a good or a service in each stage of its life.

In the context of territorial sustainability, the environmental dimension needs to be integrated with the economic and the social dimensions (Mamipour et al. 2019, Hondroyiannis et al. 2024). The most recurring economic aspects measured in the literature are income, GDP, wage, expenditure in research and development, number of firms operating in circular-related activities. These do not describe directly "how circular" economy is, but they have been used in the literature to understand the general economic outlook.

According to Raworth (2017) and by Mies and Gold (2021) the most social aspects that contribute to CE understanding are employment, education, awareness rising, health and safety and government involvement.

The need to collect knowledge by means of some tools that can provide indications is evident.

Among the tools, indicators play an important role in examining, comprehending, and quantifying the circular economy. Nevertheless, they require a certain level of background knowledge. When it comes to the circular economy, both institutions and academic research find it difficult to offer a single indicator capable of grasping the whole concept.

As noted by Moraga et al. (2019) different meanings and aspects require multiple

indicators. Therefore, indicators are incorporated in complete frameworks, for instance the *Circular Economy Monitoring Framework* associated with the corresponding *Action Plan* (European Commission, 2020) or organized to cover all actions required by the circular model (for example, reduce, reuse, recycle). After all, the CE is an integral component of the European Green Deal's growth strategy, aiming to boost economic performance and alleviate environmental strain (European Commission, 2019).

The *Global Circularity Metrics (GCM)* developed by the Circle Economy yearly, a not-for-profit organization, offers a single metrics for grasping the level of world resources (mineral, ores, fossil fuels and biomass) circularity.

The most recent report (Circle Economy Foundation, 2023) claims that from 9.1% in 2018 and 8.6% in 2020, only 7.2% is the percentage of total material inputs recycled in the world in 2023.

Building upon this foundation, our research question is to present the current state of the CE in NUTS 2 regions within France and Italy, aiming to highlight the relationships and patterns among the indicators used to describe the circular economy, and to identify opportune instruments/policies to keep materials and products in circulation for as long as possible and to ensure sustainable development.

France and Italy exhibit outstanding circularity performance, ranking as the top performers among the five major economies in the European Union, as reported by the Circular Economy Network (2021).

The choice to examine the CE of NUTS 2 regions aligns with the European cohesion policy's objective of diminishing disparities and inequalities across European regions, particularly at the NUTS 2 territorial level.

The achievement of our goal suggests the analysis and development of some preliminary steps: how do governments and private or public international institutions/researchers gauge the circular economy? Are there any recognized standards or certifications in place? Considering that products are manufactured using various processes, are there specialized approaches for measuring circularity within specific sectors?

This comprehensive framework implies that the analysis should be situated within the context of multi-attribute theory in which (condition and decision) attributes are indicators at regional level. The Eurostat indicators for reduction, reuse and economic and social aspects represent the condition attributes. As a decision attribute we propose a composite

index denoting the possible waste management capabilities of a region. It becomes a tool (the decision attribute) to evaluate other aspects and dimensions of the CE and to discover possible relationships among waste management capabilities and other sustainable indicators.

The paper is structured as follows. The second section presents data and includes an overview of frameworks of indicators adopted by some international institutions, as well as indicators by sector, drawn from a concise literature review on commonly used indicators. Section 3 focuses on the definition of the waste management capability index (Waste Index) and describes the adopted multi-attribute methodology, namely the Dominance-based Rough Set Approach. Section 4 is dedicated to the case study. Results and discussions are presented in Section 5, while Section 6 provides the conclusions of the paper.

2. Data

This section presents an overview of indicators adopted by some international institutions, as well as indicators by sector, drawn from a concise literature review on commonly used indicators.

2.1. China, EU and OECD

Governments and international institutions have been proposing their own frameworks of indicators. China was the first country to introduce CE policies within its plans; besides, China counts the higher number of publications and cited scholars (De Pascale et al., 2021). China's economic success, widely recognized, has come at the expense of its natural resources and environment. To address this issue, China adopted the CE as a national sustainable development policy. This country introduced national laws and regulations to support CE implementation, initiated demonstration projects, and established national CE indicators. These indicators provide valuable information for policymakers and can aid in achieving CE goals. However, this unique indicator system has not been shared with the international community (Geng et al., 2012).

The authors observe that the National Development and Reform Commission (NDRC) has chosen to highlight mainly environmental-related aspects like water and energy consumption or recycling rates of different materials and they highlight the lack of

indicators for social and economic aspects like employments, investments in R&D, level of awareness among citizens. Moreover, they remark that the NDRC does not provide any benchmark.

To fill these gaps, Geng et al. (2012) present a set of 22 indicators at national level (Table 2.1) related to the proposal within the NDRC.

Table 2.1: Chinese indicators on circular economy

Group	Indicator
<i>Resource output rate</i>	Output of main mineral resource ($10^4\text{¥}/\text{ton}$)
	Output of energy ($10^4\text{¥}/\text{ton sce}$)
<i>Resource consumption rate</i>	Energy consumption per unit of GDP ($\text{ton sce}/10^4\text{¥}$)
	Energy consumption per added industrial value ($\text{ton sce}/10^4\text{¥}$)
	Energy consumption per unit of product in key industrial sectors ($\text{ton sce}/\text{ton}$)
	Water withdrawal per unit of GDP ($10^4\text{m}^3/\text{¥}$)
	Water withdrawal per added industrial value ($10^3\text{m}^3/\text{¥}$)
	Water consumption per unit of product in key industrial sectors ($10^3\text{m}^3/\text{ton}$)
	Coefficient of irrigation
<i>Resource utilization rate</i>	Recycling rate of industrial solid waste
	Industrial water reuse ratio
	Recycling rate of reclaimed municipal wastewater
	Safe treatment rate of domestic solid waste
	Recycling rate of iron scrap
	Recycling rate of non-ferrous metal
	Recycling rate of waste paper
	Recycling rate of plastic
<i>Waste disposal and pollutant emission</i>	Recycling rate of rubber
	Total amount of industrial solid waste for final disposal (ton)
	Total amount of industrial wastewater Discharge (ton)
	Total amount of SO ₂ emission (Kg)
	Total amount of CO ₂ discharge (Kg)

¥ denotes of Chinese currency; sce represents the standard coal equivalent energy

Source: Geng et al. (2012)

The European Circular Economy Monitoring Framework was introduced in 2018 in support to the Circular Economy Action Plan (European Commission, 2019, European Commission, 2020). The indicators set is presented in Table 2.2.

The European Circular Economy Network (2021)'s selection of indicators is an interesting example of how CE can be measured on country basis. However, some states use a great variety of indicators. For example, Spain has developed its own national strategy (Spanish Strategy for Circular Economy) and prepared its own set of indicators.

The Organisation for Economic Cooperation and Development (OECD) has recently proposed a tool for organizing and managing the multitude of CE indicators.

The OECD's inventory (2021) comprises a comprehensive collection of 474 measures sourced from 29 studies and national monitoring systems. These measures are systematically categorized, offering insights into various aspects of the circular economy.

Table 2.2: European indicators on circular economy

Circular Economy Aspect	Indicator
<i>Production and Consumption</i>	EU self-sufficiency for raw materials (%)
	Green public procurement (%)
	Generation of municipal waste per capita (million ton)
	Generation of waste per unit of GDP
	Generation of waste per unit of DMC*
	Food waste (million ton)
<i>Recycling Rates (%)</i>	Recycling rate of municipal waste
	Recycling rate of packaging
	Recycling rate of plastic packaging
	Recycling rate of wooden packaging
	Recycling rate of electric and electronic waste
	Recycling rate of bio waste
	Recycling rate of construction and demolition waste
<i>Secondary raw materials</i>	End-of-Life recycling of critical raw materials (%)
	Circular material use rate (%)
	Trade in recyclable materials (ton)
<i>Competitiveness and Innovation</i>	Gross investment in tangible goods in the recycling sector (% of GDP)
	Persons employed in the circular economy sectors (%)
	Gross value added in the circular economy sectors (%)
	Number of patents related to recycling and secondary raw materials

*DMC (Domestic Material Consumption)

Source: Eurostat. Online data codes: CEI_CIE, CEI_PC, CEI_SRM, CEI_WM

A significant portion of the indicators, accounting for 39%, pertains to environmental aspects. Another substantial portion, constituting 35%, delves into aspects related to government involvement in promoting circular practices. Economic and business-related indicators represent 14% of the inventory. These indicators cover a wide range of topics, including investments, savings, gains, and revenues associated with circular practices, as well as productivity metrics. Infrastructure and technology-related indicators make up 8% of the inventory, encompassing information about facilities, equipment, and areas dedicated to circular activities and projects. The final category in this inventory centres on social aspects and is characterized by a single prominent measure: employment levels linked to circular activities.

2.2 Indicators: a concise literature review

This paragraph aims to provide a very short literature review of key aspects within the agri-food sector, industrial production, and socio-economic dimensions relevant to the noteworthy aspects of the circular economy (Da Ronco, 2022).

For the *Agri-food sector*, Poponi et al. (2022) present an overview of 102 indicators relevant for the agri-food sector. They organized the collection in a number of areas of interest: air, soil, water, energy, waste, equality, economic aspects (cost, value, productivity), knowledge and innovation. Velasco-Muñoz et al. (2021) offer a selection of 41 indicators specific to agricultural sectors in order to provide a customized tool for decision-making processes related to the field. They highlight the need to find an internationally recognized standard for measuring circularity performance. Vasa et al. (2017) develop a system of indicators and sub-indicators to analyse circularity strategies of Western Balkans rural areas and make a comparison among Macedonia, Albania and Serbia. Authors attempted to take into account the concept of sustainability (with its economic, social and environmental dimensions) and the core ideas behind circularity. This involves a consideration of input quantities (such as energy or raw materials), the impact on resources, and their productivity.

Alba-Patiño et al. (2021) offer an intriguing perspective on the social aspects associated with CE practices. In their case study conducted in a rural Mediterranean area focused on almond tree cultivation, they discovered that restorative practices applied to local cultivations were perceived as beneficial for community wellbeing.

Finally, Santagata et al. (2021) offer a literature review concerning food waste conversion pathways.

Industrial sector meets many opportunities to improve circularity. In order to keep track and monitor circularity in each stage of products' life - including manufacture as well as second life - many indicators have been developed for measuring the so-called "micro" level. Pauliuk (2018) presents a dashboard of indicators aimed at completing the BS 8001:2017 guide (British Standards Institution, (2017)) and filling the gaps left by the standard.

Elia et al. (2017) suggest a reference framework for monitoring circular strategies at the micro-level, subsequent to the proposal of classifying primary environmental index-based models for measuring the CE.

Di Maio et al. (2017) introduce a value-based indicator to assess circular performances. In contrast with measures that account for material flow (MFA), this indicator aims to inform on the market value of resource that return in the cycle after their end-of-life. Bressanelli et al. (2019) offer an insight for durable good. They present a framework of indicators to evaluate impacts from economic, environmental and social perspectives. The environmental impact is mainly about CO₂ emissions and resource consumption, the economic aspects are related with costs and user perspective and finally, the social consequence accounted is the creation of employment opportunities. It is interesting that the framework is structured to highlight those areas where a decision maker can actually operate leverage: supply chain, product design, business model and digital technologies. Rossi et al. (2020) present a set of 18 indicators to assess business model from the triple perspective (economic, social, environmental). Ghisellini et al. (2018) focus on evaluating waste management in the construction and demolition sector.

Saidani et al. (2019) offer a comprehensive taxonomy of measures for the CE consisting of 55 indicators. De Pascale et al. (2021) provide a more recent systematic review encompassing 61 indicator systems. They have organized this collection based on indicator levels (micro, meso, macro) and circular strategies (reduce, reuse, recycle).

For what concerns *Economic-social aspects*, many studies (Lazell et al., 2018; Kovacic et al., 2019; Geng et al., 2012; Alba-Patiño et al., 2021; Ellen MacArthur Foundation, 2013; Padilla-Rivera et al., 2021, 2020; Mies and Gold, 2021) highlight the lack of social indicators as an important research gap. In fact, while the literature covers many technical and environmental implications, little has been said about the economic-social aspects related with the circular strategies (Llorente-González and Vence, 2020).

Llorente-González and Vence (2020) present an insight on the structural socio-economic characteristics of the activities that are generally considered "circular" because they contribute to the preservation of goods and products, and the maintenance of their functional value. The authors use Eurostat indicators for economic activities grouped by NACE Rev.2 to categorize activities based on labour and capital intensity. Repair and reuse are labour-intensive, while waste collection, recycling, and aircraft repair are more capital intensive. Promoting repair and reuse can boost job creation. The authors stress considering additional factors like working conditions, wages, learning opportunities, and equal treatment for a comprehensive analysis of the circular economy's economic and social

impact in Europe. Besides, authors point out the necessity to take into account other variables, for example working conditions, wage levels, learning and development opportunities, equal treatment, to provide a complete analysis of the economic and social effects of CE in Europe.

The most recurring (and often the only) socio-economic indicators in a number of frameworks (Kovacic et al., 2019; Circular Economy Network, 2021; OECD, 2021; Bressanelli et al., 2019) are "creation of job opportunities" and "employment" linked with CE strategies (recycling in particular). Employment gains particular attention even at the legislative level: CE has been presented by an opportunity to foster growth and job creation (European Commission, 2019, 2020). Another interesting and overlooked issue questions whether workers have the skills required by new green opportunities and next to this, whether they are willing to engage in these new jobs. Despite the dominance of job-related indicators, few researches attempt to fill this gap by embracing a more holistic view with respect to *Social dimension*. Poponi et al. (2022), reviewing circular indicators for agri-food sector, include measures for child labour, access and food security, employment, social inclusion, equal distribution, poverty and forced labour. In addition, Rossi et al. (2020) focus on jobs, employee participation, stakeholder involvement, and cultural change, Velasco-Muñoz et al. (2021) introduce a framework with an indicator for measuring changes in unpaid time spent by women and children and Padilla-Rivera et al. (2021) select and rank 12 key social indicators based on stakeholder input, covering areas like health, poverty, food security, governance.

There are fewer sources that offer a system of indicators to monitor the evolution and development of the CE at a regional level (Silvestri et al., 2020). The main sources of data can be identified in Eurostat, which presents several datasets according to NUTS classification, then, in national and regional statistical services (when allowed). The statistic service of the OECD is another source of data, even though significantly limited with respect to regional dimensions.

Consequently, studies on regional performance of CE are still rare in Europe and deserve a mention Avdiushchenko (2018), Avdiushchenko and Zajaç (2019), Scarpellini et al. (2019), Arsova et al. (2020) and Kruse and Wedemeier (2022).

The output featured in Avdiushchenko (2018) is a conceptual framework that includes five aspects (economic, social, environmental, cultural and spatial development) for CE based

regional development. On the basis of this conceptual model that identifies the connections between circular strategies and regional development, Avdiushchenko and Zajaç (2019) propose a single index, applying the proposed CE indicator to the Malopolska region in southern Poland.

Scarpellini et al. (2019) identify significant barriers to the CE in a Spanish region, including insufficient investment funding and a limited availability of recycled products. They suggest that implementing a waste-exchange system among companies could offer substantial incentives for regional planning and management. The study emphasizes the economic and social benefits of the circular economy.

Arsova et al. (2020) present a similar goal, namely, to offer a regional framework to monitor the advancement of CE for an evidence-based regional policy.

Kruse and Wedemeier (2022) elaborated an index on the basis of some selected indicators in order to compare German regions according to their circular performance.

An interesting contribution to regional knowledge of CE is presented by Silvestri et al. (2020). Relying on Eurostat data, they compare 169 NUTS 2 European regions according to their performance in terms of circularity. In order to investigate how EU areas differ in terms of implementation of circular principles they developed two indexes: Circular Economy Static Index (CESI) and Circular Economy Dynamic Index (CEDI). The first one is meant to provide a static picture of regional performance in a given year; the second one is built to show pace of development (growth rates from a starting year). Both indexes are built with the same 11 variables, clustered in the three sustainability dimensions.

The 31 indicators used in our work (listed in Annex A) refer to “reduce” (4 indicators), “reuse” (11 indicators), waste management capabilities (6 indicators) and economic and social aspects (10 indicators). Eurostat and OECD are the sources.

3. Methods

Recognizing that a linear production model, where waste inevitably ends up in landfills or incinerators, is unsustainable in the long term (Boulding, 1966; Murray et al., 2017), in order to break the link between resource consumption and production, the Ellen MacArthur Foundation, among others, suggests several strategies summarized as the 3R approach: Reduce, Reuse, Recycle.

The assumption that circularity should reduce the pressure on the natural resources,

preserve the properties of ecosystems and, ultimately, decouple growth from resource depletion, may suggest an indicator for tracking the production or the extraction of raw materials. But this kind of data is not available at regional level.

Ultimately, a core aspect of circularity has been identified with recycling and waste management practices. The choice is motivated by few reasons: in the European Union the first policies proposals (European Commission, 2014) regarded mainly waste management. Even though, the CE is not just recycling, and if encouraged, it could make a significant difference (Ellen MacArthur Foundation, 2013).

To capture waste management capabilities of each region, in this paper we propose a single index, not to be considered as a single index of circularity, obtained by the number of disposal (landfills and incinerators, with negative impact) and recovery facilities (energy recovery and backfilling, both with negative impact, recycling with positive impact) present in the territory. This choice is motivated because in the European Union the waste management is a crucial aspect (European Commission, 2014). Even though the CE is not just recycling, this aspect is crucial to "close the loop": if encouraged it could make a significant difference (Ellen MacArthur Foundation, 2013).

In order to assess waste management capabilities at a regional level, data available from Eurostat are categorized based on the specific activities being performed: energy recovery from waste, recycling, backfilling, or disposal of waste in landfills, incineration and collection, treatment and disposal activities. From a CE standpoint, it is evident that certain practices should be promoted while others need to be reconsidered. For instance, encouraging recycling centres can enhance overall waste recovery rates, whereas landfills result in a depletion of valuable materials and their associated value.

Following the suggestions of Kruse and Wedemeier (2022), Silvestri et al. (2020) and Avdiushchenko and Zajaç (2019), the index we propose, which for simplicity will be called Waste Index (*WI*), is built in two steps.

Step 1: The indicators were normalized in an interval between 0 and 1: variables (indicators) with positive impact on circular performance are normalized as:

$$Y_{jk} = T_k(X_{jk}) = \frac{X_{jk} - \min\{X_{1k}, \dots, X_{jk}\}}{\max\{X_{1k}, \dots, X_{jk}\} - \min\{X_{1k}, \dots, X_{jk}\}}$$

while, variables with a negative impact:

$$Y_{jk} = T_k(X_{jk}) = \frac{\max\{X_{1k}, \dots, X_{jk}\} - X_{jk}}{\max\{X_{1k}, \dots, X_{jk}\} - \min\{X_{1k}, \dots, X_{jk}\}}$$

X_{jk} denotes the value of the k -th indicator for the region j and Y_{jk} is the corresponding normalized value obtained by the equation.

Step 2: The index is the result of the simple average of the normalized values Y_{jk} ($k = 1, \dots, K$)

$$WI = \frac{1}{K} \sum_{k=1}^K Y_{jk}$$

This index describes the possible waste management capabilities of a region. Values going towards 1 should suggest better waste management capabilities, especially regarding recycling activities (which is the only indicator with a positive impact). Values close to 0 denote exactly the opposite.

To capture waste management capabilities of each region, we considered the number of disposal and recovery facilities present in the territory, distinguished according to the type of activity they perform: energy recovery from waste, recycling, backfilling, or disposal of waste in landfills or incinerators and materials recovery-firms. Clearly, from a circular perspective, some practices should be encouraged other discarded: recycling hubs may improve the overall level of recovery, while landfills and incinerators represent a loss in terms of materials and value.

To determine the factors that characterize circular economy, we utilized the Dominance-based Rough Set Approach (DRSA) (Słowiński et al., 2009) as a model for our study. This approach was selected because it can handle the absence of structured data collection methods, does not rely on statistical assumptions, and can accommodate both categorical and numerical data. Moreover, as it is widely recognized, in order to present ideas and solutions that can support policymakers (Frederiksen et al., 2012 and Santagata et al., 2020 among others), it is crucial to present meaningful and understandable results obtained through explicit analysis techniques: this confirm our choice to use DRSA to generate decision rules in the form of "if... then" statements so as to aid in the evaluation process.

The essential definitions of DRSA refer to the information system $IS = (\mathcal{U}, Q, V, f)$, a 4-tuple decision table. $\mathcal{U} = \{x_1, x_2, \dots, x_N\}$ denotes the finite set of records: in our analysis, we consider the European NUTS 2 regions of the countries (France and Italy) with the best performances in terms of circularity according to the Circular Economy Network (2021).

$Q = \{q_1, q_2, \dots, q_M\}$ denotes the set of selected criteria (criteria describing different aspects of circularity), V is the domain set, i.e. the union set of all the domain sets V_{q_j} , each of them contains all the values assumed by each criterion $q_j \in Q$. Finally, f is the information function, with $f(x_i, q_j) \in V_{q_j}$, that is the function through which it is possible to associate, to each region, the value assumed in correspondence with each criterion.

A criterion can be considered either as an attribute characterizing the region (i.e., a condition attribute) or as data that specifies the category of the element, called decision attribute, in our case a criterion that could distinguish among different levels of overall circularity with respect to territories. This way, the set Q of all the attributes may be considered partitioned into the sets of condition and decision criteria Q_C and Q_D respectively, that is $Q = Q_C \cup Q_D$.

Note that if a domain V_{q_j} is completely preordered by an outranking relation $\succeq_{q_j}$, that is, $x \succeq_{q_j} y$ if x is at least as ‘good’ as y with respect to criterion q_j , and if the domain V_{q_j} is real-valued, then the information function represents the preordering relation $x \succeq_{q_j} y$ through the inequality $f(x, q_j) \geq f(y, q_j)$. For a complete illustration of the basic definition, the main elements and results of DRSA see Słowiński et al., 2009, some basic definitions are recalled in Appendix A.

4. The case study

The circular economy of France and Italy NUTS 2 regions (21 and 22¹, respectively, see Annex B), our case study, is described by the set of attributes/indicators listed in Table 4.1. The definition of the related information system (*IS*) is quite complex, because indicators represent different aspects of circularity. Clearly, this is not unexpected, given that the CE has often been described as an "umbrella" concept, which embraces many aspects, many strategies and actions and it could be evaluated through the different dimensions of sustainability. In our case study, we focus on four aspects of circularity: three dimensions of circularity are considered as condition attributes, namely reduction, reuse, and economic and social aspects; the last, recycling, represented by *WI*, is assumed as decision attribute.

¹Due to data restrictions, overseas regions (Martinique, Guyana, Guadalupe, La Reunion, Mayotte) are not included.

Table 4.1: List of used indicators

Abbr.	Indicator (reference unit)	Source	Year
	REDUCE		
<i>AIR.POL</i>	Air Pollution in PM2.5 (µg/m³)	OECD	2019
<i>FERT.VAL</i>	Fertilizers and soil improvers (Million €)	EUROSTAT	2019
<i>PESR.VAL</i>	Plant protection products, herbicides, pesticides (Million €)	EUROSTAT	2019
<i>ARTF.LND</i>	Artificial land (%)	EUROSTAT	2018
<i>SOIL.EER</i>	Soil erosion by water (%)	EUROSTAT	2016
	REUSE		
<i>N77.F</i>	Rental and leasing activities - firms (number)	EUROSTAT	2019
<i>C33.F</i>	Repair and installation of machinery and equipment - firms (number)	EUROSTAT	2019
<i>C33.E</i>	Repair and installation of machinery and equipment - employees (number)	EUROSTAT	2019
<i>S95.F</i>	Repair of computers and personal and household goods - firms (number)	EUROSTAT	2019
<i>S95.E</i>	Repair of computers and personal and household goods - employees (number)	EUROSTAT	2019
<i>G45.F</i>	Wholesale, retail and repair of motor vehicles and motorcycles - firms (number)	EUROSTAT	2019
<i>G45.E</i>	Wholesale, retail and repair of motor vehicles and motorcycles - employees (number)	EUROSTAT	2019
<i>G452.F</i>	Maintenance, repair of motor vehicles - firms (number)	EUROSTAT	2019
<i>G452.E</i>	Maintenance, repair of motor vehicles - employment (number)	EUROSTAT	2019
<i>G452.G</i>	Maintenance, repair of motor vehicles - growth rate of employment (%)	EUROSTAT	2019
<i>G454.F</i>	Sale, maintenance, repair of motorcycles, related parts and accs- firms (number)	EUROSTAT	2019
	ECONOMIC and SOCIAL ASPECTS		
<i>HHINC</i>	Income of households - euros per inhabitants (€ per inhabitant)	EUROSTAT	2019
<i>EMPL</i>	Employment rate (% 15-74 years)	EUROSTAT	2019
<i>UNEMPL</i>	Unemployment rate (% 15-74 years)	EUROSTAT	2019
<i>BBACCESS</i>	Household with broadband access (% of total households)	OECD	2019
<i>EDUTER</i>	Population (from 15 to 74 years) with tertiary education (%)	EUROSTAT	2019
<i>R&D</i>	R&D expenditure as percentage of GDP (%)	EUROSTAT	2018
<i>LIFEEXP</i>	Life expectancy (years)	EUROSTAT	2019
<i>C33.W</i>	Repair and installation of machinery and equipment (€ per worker)	EUROSTAT	2019
<i>G45.W</i>	Wholesale, retail trade and repair of motor vehicles and motorcycles (€ per worker)	EUROSTAT	2019
<i>G452.W</i>	Maintenance and repair of motor vehicles (€ per worker)	EUROSTAT	2019
	WASTE MANAGEMENT CAPABILITIES		
<i>LANDFILL</i>	Disposal facilities - landfills (number)	EUROSTAT	2018
<i>INCENC</i>	Disposal facilities- incineration (number)	EUROSTAT	2018
<i>ENREC</i>	Recovery facilities - energy recovery (number)	EUROSTAT	2018
<i>RECYC</i>	Recovery facilities - recycling (number)	EUROSTAT	2018
<i>BACKFILL</i>	Recovery facilities - backfilling (number)	EUROSTAT	2018
<i>E38.F</i>	Waste collection, treatment and disposal activities; materials recovery-firms (number)	EUROSTAT	2019

Accordingly, three information tables² are considered. The first table contains indicators for aspects of circularity grouped under 'reduce', primarily environmental indicators. The second table displays attributes related to leasing, remediation, and repair activities, which are used to represent reuse, while the last table presents indicators mainly pertaining to the economic and social aspects associated with the circular economy as a whole.

The Waste Index serves as the common decision attribute in all information tables.

The DRSA method, selected for analyzing these indicators related to the circular economy, reveals relationships and patterns among them.

The decision rules, logical statements given by a composed condition component (*if*) and a decision component (*then*), are extracted using jMAF software (Błaszczynski et al. 2013, Da Ronco, 2022), multiple decision rules have been identified for each information system, enabling the identification of specific region characteristics.

Additionally, the information systems furnish knowledge regarding several noteworthy properties concerning a specific rule: these include Learning Positive Examples (LPE), strength, coverage factor, and support.

Learning Positive Examples (LPE) pertain to all regions falling within the decision class, and they may be characterized by one or more of the rules associated with their class; supporting examples for a decision rule encompass all regions for which that rule holds true; strength is the ratio of the number of supporting examples to the total number of regions (43); the coverage factor is determined by the ratio between the number of supporting examples and the number of regions that satisfy a decision.

5. Results and discussion

As known, the application of DRSA for the analysis of the CE aims to reveal relationships and patterns within the indicators, this way the analysis results can help address some questions, in particular:

- How are NUTS2 regions characterized by higher waste management capabilities?
- What relationships and patterns exist among waste management capabilities (decision attribute) and other indicators (condition attributes)?
- Which indicators and rules describe the largest number of regions?

The rules extracted using the jMAF software are 33 (reduce), 35 (reuse), and 26 (economic

² For details, please contact the corresponding author

and social aspects) (Annex C), in relation to each information table.

The rules with waste management capabilities index *WI* at least equal to 0.64, tied to the median value, are presented in detail and discussed in this paragraph.

Eleven regions meeting this criterion have been selected (see Annex B), and they will be referred to as regions with higher waste management capabilities. This designation implies that the chosen decision rules fall under the jMAF category "at least." The paragraph presents and deliberates on rules categorized under Reduce (5 out of 33), Reuse (5 out of 35), and Economic and Social aspects (9 out of 26).

Reduce

One of the aims of the CE is reducing the pressure on the environment and protecting the resource. (Ellen MacArthur Foundation, 2013). Consequently, in the information table some indicators account for quality of air and of soil.

Some of the 33 extracted decision rules describe a greater number of Italian regions compared to the French ones.

However, it is worth noting that Lombardia, Veneto, and Piemonte, among the most industrialized Italian regions, do not satisfy any decision rule. In contrast, the Provincia of Bolzano, Valle d'Aosta, and the southern Italian regions frequently recur.

As for France, the agricultural and poorly populated region of Limousin is more often mentioned, appearing in 19 out of the 33 extracted rules.

The condition attribute that occurs most frequently is related to fertilizers (FERT.VAL) with *WI* ranging between 0.52 and 0.63, followed by soil erosion by water (SOIL.EER).

Table 5.1 displays the first five rules³ according to “reduce” (the complete list of rules and their properties is available in Annex C). Note that in the five selected decision rules, the FERT.VAL attribute clearly does not appear.

Table 5.1: Decision rules for "Reduce": a selection

	AIR.POL	ARTF.LND	SOIL.EER	WI
<i>RULE 1</i>			≤ 0.02	≥ 0.71
<i>RULE 2</i>		≤ 2.4		≥ 0.67
<i>RULE 3</i>	≤ 6.93			≥ 0.66
<i>RULE 4</i>	≤ 9.45	≤ 3.5		≥ 0.65
<i>RULE 5</i>		≤ 2.9	≤ 48.13	≥ 0.64

³ Attributes “Fertilizers and soil improvers” (FERT.VAL) and “Plant protection products, herbicides, pesticides” (PESR.VAL) are not present in the selected rules.

From the outcome of the analysis, it can be observed that according to rule 1, the region with the highest *WI* value (Île-de-France, FR10) is characterized by the lowest level of soil erosion ($\leq 0.02\%$). Rule 5 states that a region classified with a $WI \geq 0.64$ presents a percentage of artificial land and soil erosion lower or equal to 2.9% and 48.13%, respectively. This case requires both conditions to be true⁴, as seen in rule 4.

Rule 2, satisfied by Provincia di Bolzano (ITH1), is characterized by the lowest percentage of artificial land ($\leq 2.4\%$) and rule 3, by Corse (FRM0), showing the smallest air pollution average value ($PM_{2.5} \leq 6.93 \mu g/m^3$). Therefore, it can be inferred that a hypothetical region with lower percentages of artificial land or air pollution must be classified at least in the set of territories with $WI \geq 0.66$.

Reuse

The CE suggests to "reuse" objects, namely to enhance all those practices that allow to repair, share and provide maintenance (Stahel, 2019).

The extracted rules are 35 (detailed in Annex C2.a). All regions are represented by these rules, confirming, however, a more complex description of Italian regions compared to French ones. In the case of Italy, Southern regions are more prevalent, and for France, the Limousin region appears in 11 out of the 35 rules, although the condition attributes concerning the "reuse" case are entirely different. Nevertheless, the greater representativeness of regions described by at least one decision rule remains. Regarding attribute frequencies, the indicator C33.F (Repair and installation of machinery and equipment firms) does not appear in any rule, while S95.F (Repair of computers and personal and household goods - firms), G452.F (Maintenance, repair of motor vehicles - firms), and G45.F (Wholesale, retail and repair of motor vehicles and motorcycles - firms) appear infrequently.

Table 5.2 shows the first five rules describing the dimension of "reuse"⁵.

⁴ Provincia di Bolzano (ITH1) and Provincia di Trento (ITH2) support rule 5.

⁵ Indicators "Repair and installation of machinery and equipment: number of firms" (C33.F), "Repair of computers and personal and household goods - firms (number)" (S95.F), "Wholesale, retail and repair of motor vehicles and motorcycles – employees" (G45.E), "Repair of computers and personal and household goods - firms" (G45.F), "Repair of motorcycles: number of firms" (G452.F) "Sale, maintenance, repair of motorcycles, related parts and accs-firms" (G454.F) were deleted since they do not describe any regions among the first five rules.

Table 5.2: Decision rules for "Reuse": a selection

	N77.F	C33.E	S95.E	G452.E	G452.G	WI
<i>RULE 1</i>	≥ 11484					≥ 0.71
<i>RULE 2</i>	≥ 1544				≥ 9.0	≥ 0.71
<i>RULE 3</i>			≥ 0.27	≥ 0.63		≥ 0.66
<i>RULE 4</i>		≥ 1.04		≥ 0.85		≥ 0.66
<i>RULE 5</i>				≥ 1.19		≥ 0.65

Rule 1 highlights that a number of renting and leasing activities (N77.F) higher or equal to 11484 units characterizes Île-de-France region (FR01), which shows $WI \geq 0.71$. Rule 2 states that if a region shows a number of leasing and renting activities higher or equal to 1544 units and a growth in employment in repairing activities (G452.G) higher or equal to 9%, it will have a WI value at least equal to 0.71. Rule 5 asserts that percentages of employment in repairing activities (G452.E) equal or higher than 1.19% are associated with higher capacity of waste management capabilities (i.e. $WI \geq 0.65$).

Economic and social aspects

Here we consider the indicators focusing on economic and social dimension, such as, for example, wages, education, income, life expectancy, employment and unemployment.

In the 26 rules extracted (see Annex C3.a), the southern regions of Italy do not appear (the southernmost region is Lazio, a central region), and the most represented regions are those in the central part. Additionally, 13 out of 21 are the described regions for Italy, 10 out of 22 regions for France. The France regions that appear most frequently in the rules are Île-de-France, followed to a lesser extent by Corsica and Auvergne.

The most frequent condition attributes in the decision rules are: household with broadband access (% of total households) (BBACCESS), population (from 15 to 74 years) with tertiary education (%) (EDUTER), and unemployment rate (% 15-74 years) (UNEMPL).

Never appearing is employment rate (% 15-74 years) (EMPL).

Table 5.3 presents the first nine rules⁶.

Table 5.3: Decision rules for "Economic and social aspects": a selection

	HHINC	UNEMPL	BBACCESS	EDUTER	LIFEEXP	C33.W	G45.W	WI
<i>RULE 1</i>	≥ 32700							≥ 0.71
<i>RULE 2</i>	≥ 29100							≥ 0.67
<i>RULE 3</i>			≥ 91	≥ 22.12				≥ 0.67
<i>RULE 4</i>			≥ 89	≥ 22.12				≥ 0.66

⁶ "Employment rate" (EMPL), "R&D expenditure as percentage of GDP" (R&D) and "Maintenance and repair of motor vehicles" (G452.W) are not included in the table since they do not describe any region among the first nine rules.

RULE 5			≥ 89	≥ 18.55		≥ 24586		≥ 0.66
RULE 6		≤ 6.3		≥ 22.73	≥ 84			≥ 0.66
RULE 7				≥ 18.65	≥ 84.5			≥ 0.65
RULE 8					≥ 84.5			≥ 0.64
RULE 9			≥ 91	≥ 13.91			≥ 17434	≥ 0.64

Different rules describe regions with higher WI. For example, rule 1 states that regional average household income (HHINC) equal or higher than 32700 € per inhabitants is a condition according to which a region can be classified among those with the highest WI ($WI \geq 0.71$). This is the case of Île-de-France. However, rule 2 suggests that even a smaller household income (higher or equal to 29100 €) can describe regions with a relative lower WI (in this case, $WI \geq 0.67$). This rule is supported by Île-de-France and the Provincia di Bolzano.

Rule 3 and rule 4 describe two situations almost equivalent highlighting the same condition attributes, the percentage of houses having a broadband access (BBACCESS) and the percentage of people with tertiary education (EDUTER).

Rule 5, considering the same minimum value of broadband connection (89%) as Rule 4 but with a slightly lower percentage of people with a minimum tertiary education (threshold 18.55%), additionally requires that the salary of workers engaged in repair costs (C33.W) be equal to or greater than 24.6 thousand euros in order to obtain the same relationship, that is, $WI \geq 0.66$. The Île-de-France and Liguria regions are described by this rule.

In rules 6, 7, and 8, life expectancy (LIFEEXP) features nearly identical threshold values. Tertiary education serves as a condition attribute in rules 6, 7 and 9, and in 9, with a significantly lower threshold value compensated by the presence of two additional requirements: access to broadband and the salary of workers in the wholesale, retail trade, and repair of motor vehicles and motorcycles sector (G45.W). The final four rules display a WI ranging from 0.66 to 0.64.

As a result, Italian and French regions can be compared in different ways. Considering the waste management capabilities, Italian regions show better result, with most of them placed in the highest half (Annex B). This outcome is reflected in the decision rules obtained from the analysis. The rules that describe regions with a higher value of the decision attribute are supported by a larger number of Italian regions. While, for lower WI values supporting example are more equally distributed between France and Italy.

6. Conclusions

Despite the growing interest in the CE among public and private entities, and scholars and researchers (Arruda et al. 2021), certain aspects of the CE remain insufficiently established and shared (Ghinoi et al. 2020). Among these, notable challenges include difficulties in measuring the CE across different territories, limited and unbalanced availability of territorial data (Lazell et al., 2018), multitude of adopted methodologies, and the complexity of the production processes involved.

Our article is exploratory and aims to pave the way for new research avenues in understanding the CE, along with proposing a methodology capable of highlighting the relationships among indicators describing the CE at different territorial levels.

CE widespread is a prerequisite to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss. This way requires adoption of specific legislative changes and instruments like incentives and/or penalties, such as cost reduction or increased revenues, currently not yet sufficiently present. Besides, public policies should be implemented at the regional/local level considering the different starting conditions and availability of resources of the various territorial areas.

While we have been able to capture the main territorial relationships, through the DRSA methodology using indicators related to reduce, reuse, and socio-economic aspects, it is not easy to identify the different forms of the CE (Niang et al., 2023).

It is important to note that within the realm of sustainability, alongside the circular economy, other concepts such as green economy and bio economy are encountered within public policies, which may require different support tools (D'Amato et al., 2017).

Another aspect requiring particular attention pertains to the education and training of human resources capable of applying the appropriate techniques. Lastly, but no less important, it is worth noting the need to identify sustainable finance tools, given the high cost of investments required for the implementation and widespread adoption of the circular economy.

From the perspective of recommendations for territorial policymakers, our research has revealed complex and heterogeneous results that call for tailor-made and sector-specific policies. This is considering the multifaceted nature of the circular economy, encompassing various aspects such as material flows, environmental, social, and economic factors.

Furthermore, it is worth noting that specific indicators carry more significance. This becomes evident in the "reduce" analysis when examining the relationships between fertilizers and water-induced soil erosion. In the "reuse" context, relationships and patterns are less evident and pronounced.

Surprisingly, the number of businesses related to computer, personal, and household goods repair, as well as motor vehicle maintenance and repair, and wholesale, retail, and repair of motor vehicles and motorcycles, appears infrequently. However, when considering economic and social aspects, attributes such as the household broadband access, the population (15 to 74 years) with tertiary education, and the unemployment rate are involved in more rules than expected, while the employment rate never appears.

Lastly, further research could be conducted on other NUTS 2 EU regions with diverse productive structures and specializations, highlighting the varying potential of the CE in different sectors through the utilization of different methodologies and distinct common indicators.

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ANNEX A. Basic concept of Dominance-based Rough Set Approach

With reference to a decision criterion in Q_D (in our case study we consider the decision criterion WI), each element in $\mathcal{U}$ is assigned one class Cl_t ($t \in \mathbb{N}$) such that the classes are preference-ordered, namely when $r > s$, each element in Cl_r is preferred to each element in Cl_s . Let us suppose that m denotes the finite number of decision classes. The preference can be either strict or weak. More precisely, if $r > s$ and it is $x \in Cl_r$ and $y \in Cl_s$, then ' x is at least as good as y ' and not ' y is at least as good as x ' with respect to the decision criterion.

Related to the previous assumption are the definitions of upward and downward unions of classes⁷ Cl_s : $Cl_t^{\geq} = \bigcup_{s \geq t} Cl_s$; $Cl_t^{\leq} = \bigcup_{s \leq t} Cl_s$. Therefore, $x \in Cl_t^{\geq}$ implies that x belongs to at least class Cl_t , while $x \in Cl_t^{\leq}$ means that x belongs to at most class Cl_t .

With reference to condition criteria in Q_C , it is possible to define a partial preordering D_P (i.e. reflexive and transitive) for each condition criterion in $P \subseteq Q_C$, with the following meaning: $x D_P y$ if $x \succeq_{q_j} y$ for each criterion $q_j \in P$. In this way, each element x in $\mathcal{U}$ is related to two sets: the P -dominating set and the P -dominated set, respectively

$$D_P^+(x) = \{y \in U: y D_P x\}; \quad D_P^-(x) = \{y \in U: x D_P y\}.$$

If x dominates y on all the condition criteria in $P \subseteq Q_C$, it also dominates y on the decision (i.e. element x should be assigned to at least as good a decision class as y). In our study, decision-makers satisfying the dominance principle were consistent, while those violating the dominance principle were classified as inconsistent.

The P -dominating and P -dominated sets represent the basis of knowledge, in fact, knowledge is approximated by the upward and downward unions of decision classes; the P -lower approximation of $Cl_t^{\geq}$ with respect to $P \subseteq Q_C$ is $\underline{P}(Cl_t^{\geq}) = \{x \in U: D_P^+(x) \subseteq Cl_t^{\geq}\}$, while the P -upper approximation of $Cl_t^{\geq}$ with respect to $P \subseteq Q_C$ is $\bar{P}(Cl_t^{\geq}) = \{x \in U: D_P^-(x) \cap Cl_t^{\geq} \neq \emptyset\}$.

Analogous are the definitions for the P -lower and P -upper approximations of $Cl_t^{\leq}$ with respect to $P \subseteq Q_C$:

$$\underline{P}(Cl_t^{\leq}) = \{x \in U: D_P^-(x) \subseteq Cl_t^{\leq}\} \quad \text{and} \quad \bar{P}(Cl_t^{\leq}) = \{x \in U: D_P^+(x) \cap Cl_t^{\leq} \neq \emptyset\}.$$

Accordingly, the lower approximations are composed of elements belonging to the upward and downward unions of classes, whereas the upper approximations contain elements that could belong to the upward and downward unions of classes.

Finally, the upward and downward unions of classes are related to the upward and downward unions of decision classes by set inclusion relations:

⁷ In the case of $Cl_t^{\geq}$, $t = 2, \dots, m$; in the case of $Cl_t^{\leq}$, $t = 1, \dots, m - 1$.

$$\underline{P}(Cl_t^{\geq}) \subseteq Cl_t^{\geq} \subseteq \bar{P}(Cl_t^{\geq}) \text{ and } \underline{P}(Cl_t^{\leq}) \subseteq Cl_t^{\leq} \subseteq \bar{P}(Cl_t^{\leq})$$

and on these inclusion properties are based the definitions of the P -boundaries of $Cl_t^{\geq}$ and of $Cl_t^{\leq}$:

$$B_{nP}(Cl_t^{\geq}) = \bar{P}(Cl_t^{\geq}) - \underline{P}(Cl_t^{\geq}) \quad B_{nP}(Cl_t^{\leq}) = \bar{P}(Cl_t^{\leq}) - \underline{P}(Cl_t^{\leq}).$$

The related logical statements given by a composed condition component (*if...*) and a decision component (*then...*), i.e. decision rules, in DRSA are formalised as $D_{\leq}$ -decision rules, $D_{\geq}$ -decision rules, and $D_{\leq\geq}$ -decision rules, given that the information system can be described by decision rules based on dominance relations and associated approximations and the related rules can be certain, possible, or approximate. Certain rules follow from lower approximations, possible rules are linked to upper approximations, and approximate rules refer to the boundary regions.

Step 5 in the methodology we applied (see Section 3) was performed using the VC-DomLEM algorithm implemented with jMAF software (Błaszczyński *et al.*, 2013) developed by Laboratory of Intelligent Decision Support Systems at the Poznan University of Technology (<http://www.idss.cs.put.poznan.pl>).

ANNEX B. List of NUTS 2 Regions (the list follows the geographical position)

Region	NUTS 2 Code	Number	WI
Île-de-France	FR10	1	0.71
Centre - Val de Loire	FRB0	2	0.5
Bourgogne	FRC1	3	0.54
Franche-Comté	FRC2	4	0.52
Basse-Normandie	FRD1	5	0.58
Haute-Normandie	FRD2	6	0.61
Nord-Pas-de-Calais	FRE1	7	0.62
Picardie	FRE2	8	0.57
Alsace	FRF1	9	0.63
Champagne-Ardenne	FRF2	10	0.56
Lorraine	FRF3	11	0.56
Pays-de-la-Loire	FRG0	12	0.49
Bretagne	FRH0	13	0.4
Aquitaine	FRI1	14	0.53
Limousin	FRI2	15	0.6
Poitou-Charentes	FRI3	16	0.5
Languedoc-Roussillon	FRJ1	17	0.54
Midi-Pyrénées	FRJ2	18	0.44
Auvergne	FRK1	19	0.54
Rhône-Alpes	FRK2	20	0.36
Provence-Alpes-Côte d'Azur	FRL0	21	0.47
Corse	FRM0	22	0.66
Piemonte	ITC1	23	0.6
Valle d'Aosta	ITC2	24	0.62
Liguria	ITC3	25	0.66
Lombardia	ITC4	26	0.5
Provincia di Bolzano	ITH1	27	0.67
Provincia di Trento	ITH2	28	0.64
Veneto	ITH3	29	0.55
Friuli-Venezia Giulia	ITH4	30	0.6
Emilia-Romagna	ITH5	31	0.55
Toscana	ITI1	32	0.61
Umbria	ITI2	33	0.65
Marche	ITI3	34	0.61
Lazio	ITI4	35	0.67
Abruzzo	ITF1	36	0.66
Molise	ITF2	37	0.63
Campania	ITF3	38	0.71
Puglia	ITF4	39	0.59
Basilicata	ITF5	40	0.65
Calabria	ITF6	41	0.64
Sicilia	ITG1	42	0.63
Sardegna	ITG2	43	0.61

ANNEX C

Table C.1a: Decision rules for "reduce"

Certain at least rules
1: (SOILEER <= 0.02) => (WI >= 0.71)
2: (ARTFLND <= 2.4) => (WI >= 0.67)
3: (AIRPOL <= 6.93) => (WI >= 0.66)
4: (AIRPOL <= 9.45) & (ARTFLND <= 3.5) => (WI >= 0.65)
5: (ARTFLND <= 2.9) & (SOILEER <= 48.13) => (WI >= 0.64)
6: (AIRPOL <= 10.81) & (FERTVAL <= 11.85) => (WI >= 0.63)
7: (FERTVAL <= 29.6) => (WI >= 0.62)
8: (FERTVAL <= 144.02) & (SOILEER <= 0.26) => (WI >= 0.62)
9: (FERTVAL <= 39.02) => (WI >= 0.61)
10: (FERTVAL <= 140.24) & (SOILEER <= 0.34) => (WI >= 0.61)
11: (FERTVAL <= 61.99) => (WI >= 0.6)
12: (FERTVAL <= 73.75) & (SOILEER <= 2.36) => (WI >= 0.6)
13: (PESRVAL <= 93.86) & (SOILEER <= 0.49) => (WI >= 0.58)
14: (FERTVAL <= 140.24) & (SOILEER <= 0.5) => (WI >= 0.56)
15: (FERTVAL <= 148.43) & (SOILEER <= 0.49) => (WI >= 0.56)
16: (FERTVAL <= 348.45) & (ARTFLND <= 4.2) & (SOILEER <= 0.22) => (WI >= 0.56)
17: (FERTVAL <= 69.32) => (WI >= 0.54)
18: (ARTFLND <= 3.6) => (WI >= 0.54)
19: (PESRVAL <= 42.89) & (SOILEER <= 2.36) => (WI >= 0.54)
20: (AIRPOL <= 10.21) & (FERTVAL <= 148.43) => (WI >= 0.54)
21: (AIRPOL <= 8.42) & (ARTFLND <= 5.6) => (WI >= 0.53)
22: (FERTVAL <= 111.65) => (WI >= 0.52)
23: (AIRPOL <= 10.7) & (FERTVAL <= 148.43) => (WI >= 0.52)
24: (FERTVAL <= 144.02) & (SOILEER <= 7.19) => (WI >= 0.52)
25: (FERTVAL <= 348.45) & (ARTFLND <= 4.2) => (WI >= 0.52)
26: (PESRVAL <= 53.32) => (WI >= 0.5)
27: (ARTFLND <= 5.0) & (SOILEER <= 8.86) => (WI >= 0.5)
28: (ARTFLND <= 6.5) & (SOILEER <= 0.19) => (WI >= 0.5)
29: (SOILEER <= 0.6) => (WI >= 0.49)
30: (ARTFLND <= 6.7) & (SOILEER <= 8.86) => (WI >= 0.49)
31: (FERTVAL <= 148.43) => (WI >= 0.47)
32: (ARTFLND <= 5.8) => (WI >= 0.44)
33: (SOILEER <= 0.88) => (WI >= 0.4)

Table C.1b: Decision rules for "reduce": supporting regions, strength and coverage factor

Rule	S *	Supporting Regions: France	Supporting Regions: Italy	Strength	Coverage factor
1	1	1		0.0233	0.5000
2	1		27	0.0233	0.2500
3	1	22		0.0233	0.1429
4	3	22	27, 40	0.0698	0.3333
5	2		27, 28	0.0465	0.1818
6	2		27, 37	0.0465	0.1429
7	9	22	24, 25, 27, 28, 33, 37, 40, 41	0.2093	0.5625
8	2	1, 7		0.0465	0.1250
9	12	22	24, 25, 27, 28, 33, 34, 36, 37, 40, 41, 43	0.2791	0.6000
10	2	1, 6		0.0465	0.1000
11	15	15, 22	24, 25, 27, 28, 30, 33, 34, 36, 37, 38, 40, 41, 43	0.3488	0.6522
12	2	9, 15		0.0465	0.0870
13	3	1, 5, 15		0.0698	0.1200
14	4	1, 6, 11, 15		0.0930	0.1429
15	5	1, 5, 6, 7, 15		0.1163	0.1786
16	1	10		0.0233	0.0357
17	16	15, 17, 22	24, 25, 27, 28, 30, 33, 34, 36, 37, 38, 40, 41, 43	0.3721	0.4848
18	6	3, 22	24, 27, 28, 40	0.1395	0.1818
19	3	9, 15, 19		0.0698	0.0909
20	8	5, 15, 17, 19, 22	27, 40, 43	0.1860	0.2424
21	3	14, 15, 22		0.0698	0.0882
22	22	1, 4, 9, 15, 17, 22	24, 25, 27, 28, 30, 32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43	0.5116	0.6286
23	10	4, 5, 6, 15, 17, 19, 22	27, 40, 43	0.2326	0.2857
24	9	1, 4, 6, 7, 9, 11, 15, 19	39	0.2093	0.2571
25	9	3, 4, 10, 22	24, 27, 28, 40, 43	0.2093	0.2571
26	19	4, 9, 15, 19, 22	24, 25, 26, 27, 28, 30, 32, 33, 34, 36, 37, 40, 41, 43	0.4419	0.5000
27	7	2, 3, 4, 10, 14, 15, 19		0.1628	0.1842
28	3	2, 8, 16		0.0698	0.0789
29	12	1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 15, 16		0.2791	0.3077
30	13	2, 3, 4, 5, 6, 8, 10, 11, 14, 15, 16, 19	39	0.3023	0.3333
31	30	1, 4, 5, 6, 7, 9, 11, 15, 17, 19, 21, 22	23, 24, 25, 27, 28, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43	0.6977	0.7500
32	26	2, 3, 4, 10, 11, 14, 15, 16, 17, 18, 19, 21, 22	24, 25, 27, 28, 37, 40, 41, 42, 43	0.6047	0.6341
33	14	1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 19		0.3256	0.3333

*: |S| denotes the cardinality of NUTS 2 regions set satisfying the considered rule

Table C.2a: Decision rules for "reuse"

#: Certain at least rules
1: (N77F >= 11484) => (WI >= 0.71)
2: (N77F >= 1544) & (G452G >= 9.0) => (WI >= 0.71)
3: (S95E >= 0.27) & (G452E >= 0.63) => (WI >= 0.66)
4: (C33E >= 1.04) & (G452E >= 0.85) => (WI >= 0.66)
5: (G452E >= 1.19) => (WI >= 0.65)
6: (S95E >= 0.6) => (WI >= 0.63)
7: (N77F >= 1423) & (G45F >= 10617) & (G45E >= 1.78) => (WI >= 0.63)
8: (C33E >= 1.04) & (S95E >= 0.21) & (G454F >= 382) => (WI >= 0.63)
9: (G452E >= 1.16) => (WI >= 0.61)
10: (G452G >= 9.0) => (WI >= 0.61)
11: (S95E >= 0.21) & (G452E >= 0.85) => (WI >= 0.61)
12: (G452E >= 1.02) & (G454F >= 621) => (WI >= 0.61)
13: (S95E >= 0.19) & (G45E >= 1.91) => (WI >= 0.6)
14: (S95E >= 0.21) & (G452E >= 0.84) => (WI >= 0.6)
15: (G45F >= 10617) & (G45E >= 1.78) => (WI >= 0.6)
16: (S95E >= 0.21) & (G452G >= -11.0) => (WI >= 0.58)
17: (S95E >= 0.25) & (G45E >= 1.62) & (G452G >= -18.5) => (WI >= 0.58)
18: (G45E >= 1.88) => (WI >= 0.57)
19: (G452E >= 0.88) => (WI >= 0.55)
20: (C33E >= 1.09) & (G452E >= 0.84) => (WI >= 0.55)
21: (S95F >= 4707) => (WI >= 0.53)
22: (S95E >= 0.25) & (G452G >= -18.5) => (WI >= 0.53)
23: (G45E >= 1.78) & (G452G >= -26.9) => (WI >= 0.52)
24: (G452G >= 0.5) => (WI >= 0.5)
25: (G45E >= 1.54) & (G452G >= -26.9) => (WI >= 0.5)
26: (S95E >= 0.19) & (G452E >= 0.63) => (WI >= 0.5)
27: (G45E >= 1.6) & (G454F >= 367) => (WI >= 0.5)
28: (G45E >= 1.49) & (G452G >= -9.6) => (WI >= 0.49)
29: (G452G >= -15.0) => (WI >= 0.47)
30: (C33E >= 0.74) => (WI >= 0.47)
31: (C33E >= 0.41) & (G452G >= -18.5) => (WI >= 0.47)
32: (G452G >= -19.8) => (WI >= 0.44)
33: (G452F >= 9237) => (WI >= 0.44)
34: (G45E >= 1.6) => (WI >= 0.4)
35: (S95E >= 0.27) => (WI >= 0.4)

Table C.2b: Decision rules for "reuse": supporting regions, strength and coverage factor

Rule	S	Supporting examples: France	Supporting examples: Italy	Strength	Coverage factor
1	1	1		0.0233	0.5000
2	1		38	0.0233	0.5000
3	1	22		0.0233	0.1429
4	1		25	0.0233	0.1429
5	1		33	0.0233	0.1111
6	1	9		0.0233	0.0714
7	1		42	0.0233	0.0714
8	1		25	0.0233	0.0714
9	2		33, 34	0.0465	0.1000
10	2		38, 43	0.0465	0.1000
11	3		25, 32, 34	0.0698	0.1000
12	1		42	0.0233	0.0500
13	3	15	23, 33	0.0698	0.1304
14	4		25, 30, 32, 34	0.0930	0.1739
15	2		23, 42	0.0465	0.0870
16	6	15, 22	25, 30, 32, 34	0.1395	0.2400
17	3	5, 15, 22		0.0698	0.1200
18	5	8, 15	23, 33, 34	0.1163	0.1923
19	15		23, 24, 29, 31, 32, 33, 34, 36, 37, 38, 39, 40, 41, 42, 43	0.3488	0.5000
20	1		30	0.0233	0.0333
21	2	1, 14		0.0465	0.0588
22	4	5, 14, 15, 22		0.0930	0.1176
23	10	4, 8, 15	23, 29, 31, 33, 34, 39, 42	0.2326	0.2857
24	22	6	23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43	0.5116	0.5789
25	25	2, 4, 5, 8, 15, 16, 17, 22	23, 26, 27, 28, 29, 31, 32, 33, 34, 36, 37, 38, 39, 40, 41, 42, 43	0.5814	0.6579
26	13	3, 22	23, 24, 25, 26, 29, 30, 31, 32, 33, 34, 36	0.3023	0.3421
27	10	7, 17	23, 26, 29, 31, 32, 38, 39, 42	0.2326	0.2632
28	21	12, 15, 17	23, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43	0.4884	0.5385
29	32	2, 6, 8, 10, 11, 12, 15, 17, 19, 21, 22	23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43	0.7442	0.8000
30	11	6, 7, 21	25, 26, 29, 30, 31, 33, 38, 39	0.2558	0.2750
31	28	3, 5, 6, 8, 10, 11, 12, 14, 16, 19, 21	23, 25, 26, 27, 29, 30, 31, 32, 33, 34, 35, 36, 38, 39, 40, 42, 43	0.6512	0.7000
32	38	2, 3, 5, 6, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 21, 22	23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42,	0.8837	0.9268

			43		
33	2	1	26	0.0465	0.0488
34	24	2, 4, 5, 7, 8, 13, 15, 17, 22	23, 26, 28, 29, 31, 32, 33, 34, 36, 37, 38, 39, 40, 41, 42	0.5581	0.5714
35	4	1, 9, 13, 22		0.0930	0.0952

Table C.3a: Decision rules for "eco_soc"

#: Certain at least rules
1: (HHINC $\geq$ 32700) $\Rightarrow$ (WI $\geq$ 0.71)
2: (HHINC $\geq$ 29100) $\Rightarrow$ (WI $\geq$ 0.67)
3: (BBACCESS $\geq$ 91.0) & (EDUTER $\geq$ 22.12) $\Rightarrow$ (WI $\geq$ 0.67)
4: (BBACCESS $\geq$ 89.0) & (EDUTER $\geq$ 22.12) $\Rightarrow$ (WI $\geq$ 0.66)
5: (BBACCESS $\geq$ 89.0) & (EDUTER $\geq$ 18.55) & (C33W $\geq$ 24586) $\Rightarrow$ (WI $\geq$ 0.66)
6: (UNEMPL $\leq$ 6.3) & (EDUTER $\geq$ 22.73) & (LIFEEXP $\geq$ 84.0) $\Rightarrow$ (WI $\geq$ 0.66)
7: (EDUTER $\geq$ 18.65) & (LIFEEXP $\geq$ 84.5) $\Rightarrow$ (WI $\geq$ 0.65)
8: (LIFEEXP $\geq$ 84.5) $\Rightarrow$ (WI $\geq$ 0.64)
9: (BBACCESS $\geq$ 91.0) & (G45W $\geq$ 17434) $\Rightarrow$ (WI $\geq$ 0.64)
10: (C33W $\geq$ 43889) $\Rightarrow$ (WI $\geq$ 0.63)
11: (LIFEEXP $\geq$ 84.4) $\Rightarrow$ (WI $\geq$ 0.61)
12: (HHINC $\geq$ 21600) & (C33W $\geq$ 42261) $\Rightarrow$ (WI $\geq$ 0.61)
13: (BBACCESS $\geq$ 90.0) & (EDUTER $\geq$ 17.53) & (LIFEEXP $\geq$ 84.1) $\Rightarrow$ (WI $\geq$ 0.61)
14: (BBACCESS $\geq$ 91.0) $\Rightarrow$ (WI $\geq$ 0.6)
15: (BBACCESS $\geq$ 87.0) & (C33W $\geq$ 24586) $\Rightarrow$ (WI $\geq$ 0.6)
16: (BBACCESS $\geq$ 87.0) & (RD $\geq$ 2.18) $\Rightarrow$ (WI $\geq$ 0.6)
17: (BBACCESS $\geq$ 90.0) & (RD $\geq$ 1.56) & (LIFEEXP $\geq$ 84.1) $\Rightarrow$ (WI $\geq$ 0.6)
18: (G45W $\geq$ 36881) $\Rightarrow$ (WI $\geq$ 0.57)
19: (C33W $\geq$ 42261) $\Rightarrow$ (WI $\geq$ 0.56)
20: (BBACCESS $\geq$ 87.0) & (RD $\geq$ 1.35) $\Rightarrow$ (WI $\geq$ 0.55)
21: (UNEMPL $\leq$ 6.3) & (EDUTER $\geq$ 22.73) $\Rightarrow$ (WI $\geq$ 0.54)
22: (BBACCESS $\geq$ 86.0) $\Rightarrow$ (WI $\geq$ 0.5)
23: (UNEMPL $\leq$ 6.5) $\Rightarrow$ (WI $\geq$ 0.5)
24: (G452W $\geq$ 30593) $\Rightarrow$ (WI $\geq$ 0.49)
25: (UNEMPL $\leq$ 6.7) $\Rightarrow$ (WI $\geq$ 0.44)
26: (UNEMPL $\leq$ 6.9) $\Rightarrow$ (WI $\geq$ 0.4)

Table C.3b: Decision rules for "eco_soc": supporting regions, strength and coverage factor

Rule	S	Supporting examples: France	Supporting examples: Italy	Strength	Coverage factor
1	1	1		0.0233	0.5000
2	2	1	27	0.0465	0.5000
3	1		35	0.0233	0.2500
4	2	1	35	0.0465	0.2857
5	2	1	25	0.0465	0.2857
6	1	22		0.0233	0.1429
7	2	1	33	0.0465	0.2222
8	4	1	27, 28, 33	0.0930	0.3636
9	2		28, 35	0.0465	0.1818
10	2	1, 9		0.0465	0.1429
11	5	1	27, 28, 33, 34	0.1163	0.2500
12	3	1, 6, 9		0.0698	0.1500
13	2		28, 32	0.0465	0.1000
14	3		28, 30, 35	0.0698	0.1304
15	3	1	25, 30	0.0698	0.1304
16	2	1	23	0.0465	0.0870
17	2		28, 32	0.0465	0.0870
18	2	1, 8		0.0465	0.0769
19	4	1, 6, 9, 11		0.0930	0.1429
20	9	1	23, 25, 28, 29, 30, 31, 32, 35	0.2093	0.3000
21	2	19, 22		0.0465	0.0606
22	13	1	23, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35	0.3023	0.3421
23	9	19, 22	24, 26, 27, 28, 29, 30, 31	0.2093	0.2368
24	1	12		0.0233	0.0256
25	10	18, 19, 22	24, 26, 27, 28, 29, 30, 31	0.2326	0.2439
26	12	13, 18, 19, 22	24, 26, 27, 28, 29, 30, 31, 32	0.2791	0.2857