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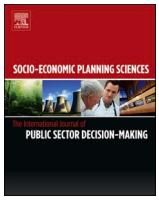

The role of the institutional supply chain in the transition from the linear to the circular paradigm: The Italian case

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ABSTRACT

Previous studies have highlighted the role of institutions among the drivers that favour the transition from the linear to the circular economy model. However, these studies tend to exclude the institutional supply chain and its correct functioning (i.e., 'good administration'). Thus, this study aims to analyse the effect of good administration on the two main phases of the circular economy paradigm in the waste sector in Italy. In this context, we propose an original good administration index (GAI) of public administration whose purpose is to capture the financial and organisational components of public administration staff. The analysis was conducted on data from 103 Italian provinces from 2008 to 2019. The results show that the GAI is key for achieving the upstream and downstream goals of the circular economy in the waste sector.

1. Introduction

Over the past fifteen years, European directives and national legislation on waste have set increasingly stringent environmental sustainability objectives. The primary aim of the legislation has been to reduce the amount of waste generated progressively and, when waste production is unavoidable, to promote its use as a resource to achieve high levels of recycling and low levels of landfill use.

The recycling of materials represents the primary means of reducing the consumption of primary resources and achieving self-sufficiency in terms of secondary materials while also providing the economy with additional benefits (economic, environmental, and social) inherent to the circular economy [1]. The circular economy model maximises the value of products, materials, and resources for as long as possible, thereby minimising waste [2]. A circular economy's ultimate goal is, in fact, to decouple environmental pressure from economic growth.

European environmental policies (adopted through various directives) have promoted the transition from a linear to a circular economy, aiming to reduce the impact of waste on the environment and human health by setting targets to achieve high recycling rates and reduce landfilling. In particular, in line with the principles of the circular economy, Directive 2008/98/EC introduces the waste hierarchy: 1) prevention, 2) reuse, 3) recycling, 4) recovery, and 5) disposal. Adhering to the hierarchy prioritises recycling, which can be achieved only through an appropriate system for collecting recyclable materials, while landfilling is at the bottom of the waste hierarchy. This is because landfills occupy substantial areas of land, potentially causing air, water, and soil pollution [3].

To achieve the objectives of the European directives, EU countries have adopted different policies, tools, and systems of administrative governance. Policy choices related to waste management, institutional quality, and the quality of governance can have significant effects on the upstream (separate waste collection) and downstream phases of the waste management process (such as landfill disposal). In particular, the economic literature has extensively investigated the role of institutions in waste management (see Ref. [4], Agovino et al., 2016; [5,6]). Mazzanti and Montini [7] showed that the waste crisis in many advanced countries is partly due to institutional failures. In particular, the

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literature indicates that high performance in separate waste collection (hereafter, SWC) production requires both effort from citizens and effective planning by local institutions (D'Amato et al., 2015; Agovino et al., 2019). An effective SWC system first and foremost requires local institutions to provide resources (monetary and real), policies, processes, technologies, and monitoring suited to specific local circumstances [6]. Matsumoto (2020) emphasised that the capacity for waste management and the time dedicated to waste management activities by citizens depend on the government's level of environmental protection and the level and quality of the policies they adopt.

However, when discussing the effects of institutions in the waste sector, these studies refer mainly to the ability of the public government to generate results (outputs or outcomes) and, thus, to institutional quality useful for achieving circular economy objectives (such as increasing recycling rates and reducing the rate of unsorted waste).[1] Agovino et al. [null] showed that in Italy, institutional quality has positive effects on the provincial efficiency of SWC. Other studies have shown that corruption, organised crime, and poor administration are significant factors that negatively affect the efficiency and effectiveness of waste management in Italy ([8]; Agovino et al., 2016; [9,10]). Recently, Romano et al. (2022) analysed waste management in 103 Italian provinces from 2007 to 2016, investigating the effects of various socioeconomic factors and institutional outcomes (corruption, crimes against public administration and the presence of women in municipal councils) on SWC. They reported positive effects on circular economy objectives in provinces where public administration (hereafter, PA) performance has better outcomes. In other words, PA performance in the waste sector is fundamentally influenced by how institutions evolve and the results they generate, or, in other words, by how they foster pro-environmental behaviours and enable individuals to access information. According to Tonglet et al. [11], citizens can be incentivised to adopt proenvironmental behaviours (institutional outcomes) if they have opportunities, facilities, and knowledge (outputs provided to citizens by institutions). However, for these outputs to be offered and these outcomes to be generated by institutions, they must function well, which is ensured by the monetary and real resources available to the PA.

The above economic literature has focused mainly on analysing the effects of institutional quality (understood as the outcomes achieved by the PA), excluding the organisational phase of monetary and real resources that the PA employs to achieve public interest objectives. These outcomes have implications for circular economy objectives in the waste sector. This study aims to fill this gap by addressing two steps of analysis. In the first step, we compute a PA good administration index (hereafter, GAI), which captures the organisational aspects of PA. In Italy, an organisational and management level is associated with the organisation of public offices on the basis of Article 97 of the Constitution, which is defined as 'good administration of the PA'. This requires a different measure from the theoretical and empirical literature's generalisation with the 'quality of institutions'. Second, the study analyses how the GAI impacts the various phases of the waste management cycle (upstream and downstream phases of the waste management process). The empirical analysis will be conducted on data from the 103 Italian provinces from 2008 to 2019.

The results show that the GAI has positive effects on the upstream phase, whereas the effects on the downstream phase depend on the GAI's aggregation method. Additionally, significant differences emerge when various geographical areas (i.e., northern, central and southern Italy) are compared.

The remainder of this paper is organised as follows: Section 2 examines the literature to reveal the gaps to be filled and the background and defines the research hypotheses. Section 3 presents the method used to construct the GAI. Section 4 presents the empirical investigation section. Section 5 presents the results and Section 6 provides a detailed discussion of the findings. Section 7 concludes.

2. Literature review, background and research hypotheses

A considerable portion of the economic literature, both theoretical and empirical, has investigated the effect of institutions on economic growth and development (Acemoglu et al., 2001; Acemoglu and Robinson 2008; Syverson 2011; Chanda and Dalgaard 2008; Easterly and Levine 2003). The results of these studies show that better institutions can create a business and legal environment conducive to economic growth, encouraging firms to invest in new technologies and research and development.

Mac [12] and Dubey et al. [13] demonstrate how institutional theory helps to understand sustainability by going beyond economic and technological aspects, emphasising the role of social norms, regulatory frameworks, and cognitive beliefs in driving sustainable behaviours in firms and society. Calzolari et al. [14] explore how institutional pressures (coercive, normative, and mimetic) influence the adoption of circular economy practices within firm's supply chains. Ranta et al. [15] provide a comparative analysis of institutional environments in China, the United States, and Europe, examining the drivers and barriers of the circular economy model in each region. The key drivers and obstacles are explored through an approach based on institutional theory, which considers regulatory, normative, and cultural-cognitive pillars as key factors in the implementation of circular economy policies. The findings show that a combination of all institutional pillars (regulatory, normative, and cultural) is necessary to create a supportive environment. The normative and cultural-cognitive pillars exert surprisingly strong influence and can nullify the effects of the regulatory pillar, as demonstrated in some regions where the social legitimisation of circular economy is still insufficient. Indeed, the authors highlight that while regulatory policies are important, they are not sufficient on their own to ensure the success of the circular economy transition.

For Italy, the empirical literature shows a link between institutional quality and economic development, as well as growth differentials among geographical areas ([16]; Lasagni et al., 2015). These studies highlight that the development delay in the Mezzogiorno is also due to lower institutional quality than in northern Italy.

In the waste sector, the link between institutions and the delay in achieving circular economy objectives across Italy's geographical macro-areas has been addressed by several authors [9,10]; [null]; [6, 10]. These studies show that institutional quality is crucial for achieving results that support the transition to a circular economy. Following this strand of the literature, institutions, owing to the quality of public goods and services generated by the action of the PA, allow achieving public utility objectives (for more details, see Ref. [17,18]). In other words, a public utility outcome depends on the PA performance, that is, on its ability to organise and combine public production inputs, for example, to reduce legal uncertainty and corruption ([8]; Agovino et al., 2016; [9, 10]), promote proenvironmental behaviours among citizens (Matsumoto, 2020), allow citizens to access information (through appropriate information campaigns) and, consequently, reduce inefficiencies in the provision of public services.

The empirical literature above on the waste sector has focused mainly on the relationship between institutional quality and public utility goals as a result of PA action while neglecting the '*institutional supply chain*'. In the case of the waste sector, establishing efficient urban waste management systems and achieving circular economy objectives depend, among other factors, on the system of administrative competencies (administrative governance) defined for the various stages of waste management and the actual functioning of the local institutional supply chain. In particular, the definition of administrative governance

[1] More specifically, economic literature mostly links the concept of institutional quality to a range of outcomes including: legal certainty that reduces illicit activities; low corruption; factors contributing to the formation of moral and social norms and good conduct among citizens who benefit from them (D'Amato et al., 2015; Romano et al., 2021).

leads to formulating the institutional supply chain. In European countries, the central government typically handles the adoption of directives and sets general policy guidelines in line with European regulatory requirements. It also oversees compliance with regulations and manages any fiscal transfers. Local governments (regional, provincial, and municipal) are responsible for providing recyclable material collection services and implementing intrinsic (informational campaigns) and/or extrinsic incentives, as well as defining funding mechanisms for the service, thereby constituting the actual institutional supply chain for service provision, including in the waste sector. In particular, at least half of the services, from primary waste collection to treatment and disposal, are managed by public entities, and approximately one-third involve public–private partnerships [19].

In Italy, administrative functions for waste management are divided between the central state and local governments (as regions, provinces). The central government defines the general policies and criteria for waste management, including the target system for SWCs. Regions play a planning and control role by setting regional waste management plans for organising SWCs and managing disposal and recovery plants (Legislative Decree (LD) 152/2006 art.195 and 196). Provinces have operational functions, as they coordinate and oversee all the actions related to collection and transport services, as well as the hygienic-sanitary protection measures to be followed during the various phases of waste management (LD 152/2006 art.198). Provinces generally correspond to areas where integrated public services such as waste collection and disposal are organised. National legislation typically organises urban waste management services into optimal territorial areas (ATOs) to achieve cost efficiency and service effectiveness by overcoming management fragmentation.

The waste management system can be divided into various heterogeneous phases (collection and transport, treatment, energy recovery, and recycling/disposal of materials). Specifically, it is necessary to define the upstream phase (SWC versus undifferentiated waste collection) and the downstream phase of waste management (green waste treatment methods versus landfill use). Both phases represent the beginning and end of any production process. The collection and transport of separated waste concern the outputs that PAs (provinces) must manage operationally through expenditures on implementing collection methods, using and purchasing transport vehicles, etc. In this initial phase, various inputs (primarily capital and labour) are employed by the local PA. The PA organises activities and services (such as containers, door-to-door services, and collection days). To initiate these activities, the public actor also enters into agreements with local suppliers (public–private or private companies). Therefore, it is reasonable to expect that the organisation of services in the upstream phase is influenced by the efficiency and proper functioning of the institutional chain.

In the downstream phase, disposal is the final stage of the waste cycle, because the waste management hierarchy defined by the European Directive stipulates that landfill use should be reserved only for materials that cannot be otherwise recovered. Waste remaining after the treatment phase is sent to landfills. The downstream phases are characterised by a predominance of capital input over labour input, leading to high initial investment costs (sunk costs) and long amortisation periods. This phase is, therefore, primarily concerned with managing facilities for various treatment and disposal methods, as well as the investments required to create these facilities. Thus, in this phase, the effective functioning of the institutional supply chain may determine the development of alternative disposal methods to landfills and the reduction in landfill use that facilitates transitioning to a circular economy. In other words, for the entire urban waste management process to function correctly (from the upstream to the downstream phase), local institutions must ensure that a series of real and monetary elements are properly coordinated and operationally effective (institutional supply chain). This is necessary to achieve an effective and efficient system for SWCs, an effective waste collection system, informative campaigns for active and informed citizen engagement, infrastructure suitable for waste composition, and appropriate funding systems and economic incentives.

Therefore, we test the following two research hypotheses.

H1. *Good PA administration impacts the upstream phase of waste management, specifically the increase in SWC.*

H2. *Good PA administration affects the downstream phase of waste management, specifically the reduction in landfill use.*

3. Measuring the GAI

This section calculates a composite indicator of good PA administration. We aim to provide a measure of the functioning level of public offices in relation to their nominal (or financial) and real (staff) components. Our objective is positioned as an upstream phase relative to downstream results associated with institutional quality.[2] Thus, institutional quality is understood as the outcome of the effective organisation and management of PAs. The objectives of public interest certainly depend on the economic, infrastructural, civic, and social provisions of a public entity, but they also depend on the organisational capacity (upstream phase) to achieve these objectives. The concept of good administration in Italy is articulated in relation to Article 97 of the Italian Constitution, which states, "*Public offices are organised according to the provisions of law, in such a way as to ensure the proper conduct and impartiality of the administration*." To achieve this, administrative action must be guided not only by the principle of legality but also by the principles of effectiveness and efficiency. The principle of efficiency, or economicity, refers to the means the administration employs (nominal and real) in its activities.

The principle of efficiency is supported by Legislative Decree 150/2009, which introduces the performance cycle of the PA: planning, measurement–evaluation, and utilisation of performance results. According to Legislative Decree 150/2009, performance encompasses both organisational and individual components, which cannot be separated since the former is achieved through the contribution of the latter. As stipulated by the Decree, performance planning is based on defining objectives, indicators, and targets, which must be linked to the resources necessary to achieve them. In other words, the PA should be viewed similarly to a company composed of a complex of individuals who perform given activities aimed at predetermined results set by its economic entity. These activities, and consequently the duties and tasks of the staff, must be framed according to a well-defined organisational scheme that assigns clear roles to all individuals operating within the organisation. In general, the organisational component of the system encompasses the individual and the asset components, including the material and immaterial means available to individuals to achieve the organisation's goals. In this sense, the importance of both the nominal and real components of the PA becomes evident, along with its capacity to organise these components to achieve public utility objectives. On the

[2] The quality of institutions is articulated in relation to territorial competitiveness from various perspectives, generally linked to the degree of corruption, accountability, and regulatory quality. These aspects highlight the positive relationship between the regulatory framework and economic development, assuming that the former influences the latter, particularly through a set of incentives aimed at guiding economic agents' behaviour in a virtuous manner. According to this hypothesis, a corrupt institutional system impedes the development of a conducive entrepreneurial climate for business activities. Simultaneously, institutional accountability towards stakeholders signals the public administration's commitment to avoiding discriminatory behaviours by applying the same rules to all actors. Regulatory quality plays a crucial role as well, benefiting the private sector with clear, simple regulations that minimise administrative burdens and promote competition among businesses. The ease of doing business and the efficiency of the judicial system are also considered good proxies for institutional quality.

other hand, the principle of effectiveness pertains to the actual results achieved by the PA. The PA is considered efficient if it manages to achieve the results it set out to attain. In this section, we aim to provide a measure of organisational efficiency, or the good organisation of inputs by the PA. We intend to capture the PA's decision-making and organisational capacity. Thus, we refer to the upstream or efficiency phase (organisational and managerial phase) of PA action, which precedes the downstream phase encapsulated by the principle of effectiveness.[3]

3.1. The good administration index

The GAI[4] will be constructed via ISTAT data covering the period from 2008 to 2020 for 103 provinces in Italy. These data provide information on both the nominal (financial accounting) and the real domain (public administration staff) of public administration operations.

The ISTAT indicators, developed within the framework of statistics on public administrations, including those in the ARCONET indicator plan, examine the following themes.

1. The impact of rigid expenses on the institution's budget
2. The collection capacity of the institution
3. Payment capacity
4. The degree of financial autonomy
5. The phenomenon of off-balance-sheet debt

Referring to the financial accounting indicators from ISTAT, we identify four components or categories that measure the financial health of public administration: expenditure, financial autonomy, surplus, and residue. These four components constitute the financial accounting domain. Additionally, unlike the Ministry of the Interior and the ARCONET Commission, ISTAT provides indicators for financial accounting and for public administration staff. These indicators help identify the domain of PA staff, encompassing measures of absenteeism, dynamism and modernisation, and digitalisation of PA. The GAI is derived from aggregating these two domains (financial domain of the PA and domain of the PA staff). These two domains comprise seven components in total—four specific to the financial domain and three specific to the PA staff. Fig. 1 illustrates the hierarchical structure of the GAI. Each domain consists of a series of variables introduced in Table 1, detailing their polarity in the construction of the GAI.

3.2. Method and results of the GAI

In this section, we present the method used for calculating the GAI. We refer in particular to the formulation by Ciommi et al. [20], who proposed a general formula from which, depending on the values of the parameters, six indicators with different properties can be derived. The general formula is as follows:

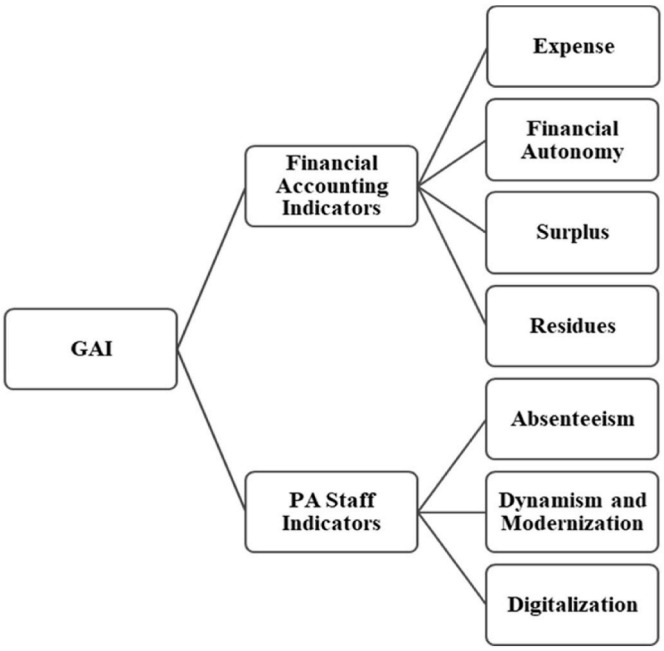

Fig. 1. Hierarchical structure of the GAI.

$$C_{ij} = \frac{1}{\sum_{j=1}^{n_h} \left(G_{jh}\right)^{\alpha}} \cdot \sum_{j=1}^{n_h} r_{ijh} \cdot \left(G_{jh}\right)^{\alpha} \pm \beta \cdot (S_{ih} \cdot cv_{ih}) \quad (1)$$

where $\alpha \in \{-1, 0, 1\}$ and $\beta \in \{0; 1\}$.

Calculating a composite indicator generally involves two phases: normalisation of the elementary indicators and aggregation of the elementary indicators. We proceed by presenting a normalisation method and various aggregation methods, summarised in Table 2, with the aim of producing different GAI versions with distinct characteristics depending on the type of weight used.

Formula (1) is preceded by a phase of normalisation of the elementary indicators to make them comparable despite their different units of measurement. For this phase, we follow the procedure introduced by Mazziotta and Pareto (2017). Scholars perform a transformation of the elementary indicators as follows:

$$\underline{x}_{jh} = Rif_{jh} - \Delta_{jh} \quad (2)$$

$$\overline{x}_{jh} = Rif_{jh} + \Delta_{jh} \quad (3)$$

Specifically, following Ciommi et al. [20], we define a matrix X_h for each domain of the GAI with $h = 1, \ldots, H$, whose element x_{ijh} represents the values of the *j-th* elementary indicator of domain h for the *i-th* statistical unit, which in our case is the Italian province, with $j = 1, \ldots, n_h$ and $i = 1, \ldots N$.[5] Rif_{jh} represents the reference value obtained by the average value of each elementary indicator. $\Delta_{jh} = \frac{\left(Max_{jh} - Min_{jh}\right)}{2}$, where Max_{jh} and Min_{jh} are the maximum and minimum of the *j-th* indicator of the *h-th* domain of all provinces (.). From (2) and (3), we observe that Δ_{jh} allows us to obtain a new minimum and a new maximum of each elementary indicator.

At this point, (2) and (3) are used to normalise the values of the elementary indicators:

[3] The effectiveness dimension is captured by numerous indicators of institutional quality offered by empirical literature on Italian data (see, among works on elementary indicators of institutional quality: [36–39]; for works on composite indicators of institutional quality: Barone and Mocetti, 2011; D'Amuri and Giorgiantonio, 2015; [16,40–47]). However, these latter indicators often end up incorporating both the upstream and downstream phases of public administration activities due to their construction.

[4] In our analysis, we choose not to use the Institutional Quality Index (IQI) as a proxy for the managerial and organisational effectiveness of Public Administration. Although the IQI is the only indicator of institutional quality at the level of Italian provinces that covers a long time span and remains up-to-date, it ends up encompassing variables that include both measures of the results achieved by provincial administrations (e.g., waste separation rates) and variables that provide more of a measure of the organisational and managerial capacity of the provinces (e.g., local government employees, regional health care deficits, etc.).

[5] The following reasoning is built on the individual domains of the synthetic indicator (financial accounting and staff of the PA) but is the same as applied for the calculation of the GAI.

Table 1
List of elementary indicators for each domain.

DOMAIN	POLARITY	COMPONENTS	VARIABLES	SOURCE
Financial Accounting	Negative	*EXPENSE*	Spending rigidity	ISTAT
Financial Accounting	Negative	*EXPENSE*	Loan repayment expenses to current income	ISTAT
Financial Accounting	Positive	*EXPENSE*	Spending power	ISTAT
Financial Accounting	Negative	*FINANCIAL AUTONOMY*	Incidence of current transfers on current expenditure	ISTAT
Financial Accounting	Negative	*FINANCIAL AUTONOMY*	Incidence of capital transfers on capital expenditure	ISTAT
Financial Accounting	Positive	*FINANCIAL AUTONOMY*	Degree of tax autonomy	ISTAT
Financial Accounting	Positive	*FINANCIAL AUTONOMY*	Collection capacity	ISTAT
Financial Accounting	Negative	*SURPLUS*	Administration surplus (deficit) to current revenues	ISTAT
Financial Accounting	Negative	*RESIDUES*	Accumulation index of passive residues	ISTAT
Financial Accounting	Positive	*RESIDUES*	Index of disposal of passive residues	ISTAT
PA Staff	Negative	ABSENTEEISM	Unpaid absences relative to total absences	ISTAT
PA Staff	Positive	DYNAMISM AND MODERNISATION	Human resources turnover index 1	ISTAT
PA Staff	Positive	DYNAMISM AND MODERNISATION	Human Resources Turnover Index 2	ISTAT
PA Staff	Positive	DYNAMISM AND MODERNISATION	Management staff rate	ISTAT
PA Staff	Positive	DYNAMISM AND MODERNISATION	Staff feminisation rate	ISTAT
PA Staff	Positive	DYNAMISM AND MODERNISATION	Managerial staff feminisation rate	ISTAT
PA Staff	Positive	DIGITALISATION	Proportion of staff with a degree or higher qualification	ISTAT
PA Staff	Positive	DIGITALISATION	Proportion of staff with a diploma or higher qualification	ISTAT
PA Staff	Positive	DIGITALISATION	Proportion of staff with seniority of service not exceeding 20 years	ISTAT
PA Staff	Positive	DIGITALISATION	Proportion of staff under 35 years of age	ISTAT

$$I_{ijh} = \begin{cases} \dfrac{x_{ijh} - \underline{x}_{.jh}}{\overline{x}_{.jh} - \underline{x}_{.jh}} & \textit{Positive Polarity} \quad (4) \\ \dfrac{\overline{x}_{.jh} - x_{ijh}}{\overline{x}_{.jh} - \underline{x}_{.jh}} & \textit{Negative Polarity} \quad (5) \end{cases}$$

Equations (4) and (5) allow for the normalisation of the elementary indicators according to their polarity, which is defined in relation to their connection with the phenomenon we aim to measure (for more details, see Ref. [20]). Finally, following Mazziotta and Pareto [21], we rescale the indicators so they range within the interval [70; 130] and the mean value is 100. This approach makes identifying values that are above or below the average easier. Ultimately, the value of the normalised indicator is calculated as follows (for more details, see Ref. [21]):

$$r_{ijh} = I_{ijh} \cdot 60 + 70 \quad (6)$$

After the data are normalised, we proceed to calculate the GAI.

Table 2 shows how varying the parameters α and β results in indicators with specific characteristics and limitations. The aggregation methods presented in Table 2 have been used to calculate the GAI. Note that the obtained indicators range from [70; 130] with a mean value of 100, allowing us to identify provinces with levels of public administration functioning either above or below the average.

Fig. 2 shows the distributions of the GAI calculated via different aggregation methods. These distributions are computed on the basis of the entire sample of data. Fig. 2 shows that while the aggregation methods have a minimal effect on the position of the distribution, they significantly affect its degree of variability. This result is notably influenced by the penalty function applied to some aggregation methods.

The result of the Spearman rank correlation coefficient shows a high correlation between some of the GAIs calculated using different aggregation methods (close to unity), whereas for others, the correlation is low and less than 0.70; in all the cases, the correlation is positive (Table 3). In the former case, we can speak of result stability and, hence, a reduced difference in results obtained with the various statistical aggregation methods. Specifically, the correlation between EW and AMPI is 0.98, and between GW and GAMPI and between RGW and RGAMPI, which are very high at 0.97 and 0.99, respectively. This result highlights that the penalty function introduced by Mazziotta and Pareto [22] has a limited effect, as the elementary indicators are balanced (see Ref. [20]).

Furthermore, it is interesting to note the low correlation between GW and RGW and between GAMPI and RGAMPI. As noted by Ciommi et al. [20], this low correlation is due to the different weighting criteria.

Additionally, we present quintile maps of the GAI to highlight territorial differences in public administration quality (Fig. 3). The quintile maps, calculated as the average of the GAI over the considered years, show that the provinces in Northeast Italy are characterised by better public administration, whereas the regions of Calabria and Sicily (southern Italy) are at the bottom of the rankings.

4. Empirical investigation

In this section, we present the methodology (4.1) and data (4.2) and analyse the effects of the GAI on the two stages of waste management: the upstream phase of waste sorting and the downstream phase of landfill disposal.

4.1. Method

To evaluate the role played by institutions upstream and downstream of the waste management process, we resort to panel data regression. In this analysis, we consider the following equation (Stock and Watson, 2020):

$$y_{it} = \alpha + \sum \beta_k x_{itk} + u_{it}$$

where y_{it} is the dependent variable (i.e., SWC per capita or landfill disposal per capita), the subscript i refers to the statistic unity (the province) and t refers to the time (from 2008 to 2019). β_k is the coefficient of the $k-th$ covariate, whereas α represents the intercept. u_{it} is the stochastic error term. In the panel analysis, we distinguish between fixed effects (FEs) and random effects (REs). In particular, in a panel analysis, the error can be decomposed into $u_{it} = u_i + \lambda_t + v_{it}$, where u_i represents a specific individual effect, λ_t is a specific temporal effect and v_{it} is the stochastic error term. In REs, these three variables are independent and identically distributed random noise, which is assumed to be uncorrelated with the covariates in the model. In contrast, in the panel with FEs, u_i is not a random variable but a parameter to be estimated, and it is specific to the province; it captures a structural aspect of the province that differentiates it from others. Additionally, λ_t is a parameter that captures annual changes common to all provinces. To choose between FEs and REs, we resort to the Hausman test, which allows comparisons of the results obtained with the two estimators. According to the test, under the null (alternative) hypothesis, REs (FEs) are the preferred model. That is, under the null hypothesis, the statistical proprieties of the generalised least squares (GLS) estimator of REs allow it to be classified as BLUE. Under the alternative hypothesis, this property is lost. The same does not occur with FEs, which is consistent under both

Table 2
Different aggregation methods used for the construction of the GAI.

Aggregation Method	α	β	Formula	Characteristics and Properties
Equally Weighted average (EW)	0	0	$EW_{ih} = \sum_{j=1}^{n_h}\left(r_{ijh}\cdot\frac{1}{n_h}\right)$	Each elementary indicator is given the same weight and, consequently, each has the same importance in measuring the GAI. This aggregation method has several limitations. First, it allows perfect substitutability between indicators: a deficit in an elementary indicator can be compensated by the surplus of another elementary indicator (see Ref. [20]). Furthermore, the arithmetic mean suffers from the problem of outliers.
Adjusted Mazziotta-Pareto Index (AMPI)	0	1	$AMPI_{Ih} = EW_{ih} \pm S_{ih}\cdot cv_{ih}$*	This method allows overcoming the problems present in the EW aggregation method. The AMPI through a penalty function solves the problem of compensability among indicators [21,22]. The double sign (±) depends on the polarity of the composite indicator with respect to the GAI. In our case we use the negative sign because an increase in the indicator will correspond to a positive variation of the phenomenon (for example, an improvement in the functioning of the PA) [23]. This approach is among the aggregation methods that allow horizontal variability. In particular, the AMPI penalises statistical units that present a more unbalanced distribution among indicators that belong to the same GAI domain (see Ref. [20]).
Gini based weighted average (GW)	1	0	$GW_{ih} = \frac{1}{G_h}\sum_{j=1}^{n_h}\left(r_{ijh}\cdot G_{.ih}\right)$**	In this case, differently from the AMPI, a higher weight will be associated with an elementary indicator characterised by greater inequality (greater concentration) [20].
Reciprocal Gini based weighted average (RGW)	−1	0	$RGW_{ih} = G_h\sum_{j=1}^{n_h}\left(r_{ijh}\cdot\frac{1}{G_{.jh}}\right)$	This indicator gives greater weight to elementary indicators characterised by a more homogeneous distribution (low Gini index values).
Gini based adjusted Mazziotta-Pareto Index (GAMPI)	1	1	$GAMPI_{ih} = GW_{ih} \pm S_{ih}\cdot cv_{ih}$	Ciommi et al. [20] proposed a mixed approach where they combine horizontal and vertical variability by algebraically adding to GW and RGW the penalty function introduced by Mazziotta and Pareto [22] in the AMPI indicator. This approach ends up penalising more the PA that presents both low values in the indicators with a more unequal distribution (greater concentration) among the PAs and with greater variability among the indicators within the same domain.
Reciprocal Gini based adjusted Mazziotta-Pareto Index (RGAMPI)	−1	1	$RGAMPI_{ih} = RGW_{ih} \pm S_{ih}\cdot cv_{ih}$	In this case, unlike the GAMPI index, administrative units with low values in the most equally distributed indicators (low Gini index values) and high variability among the elementary indicators within each GAI domain are doubly penalised [20].

Note.

* EW_{ih} *is the arithmetic mean of the normalised indicators, whereas* $S_{ih} = \sqrt{\frac{\sum_{j=1}^{n_h}\left(r_{ijh} - EW_{ih}\right)^2}{n_h}}$ *and* $cv_{ih} = \frac{S_{ih}}{EW_{ih}}$ are, respectively, the standard deviation and the coefficient of variation of the normalised indicators r_{ijh}; their product is the penalty effect.

** Where $G_{.ih}$ is the Gini index of the j-th indicator associated with the h-th domain and $G_h = \sum_{j=1}^{n_h} G_{.jh}$.

hypotheses. As a result, under the null hypothesis, the FE and RE estimates are statistically similar, whereas under the alternative hypothesis, the FE is the model to estimate because it is efficient (Crociata el al., 2015).

4.2. Data

The empirical investigation was carried out using official data drawn from the National Italian Institute of Statistics (ISTAT) and the Institute for Environmental Protection and Research (ISPRA). The units of analysis are the 103 Italian provinces (NUTS-3 level of EUROSTAT territorial classification), for which we collected annual data from 2008 to 2019.

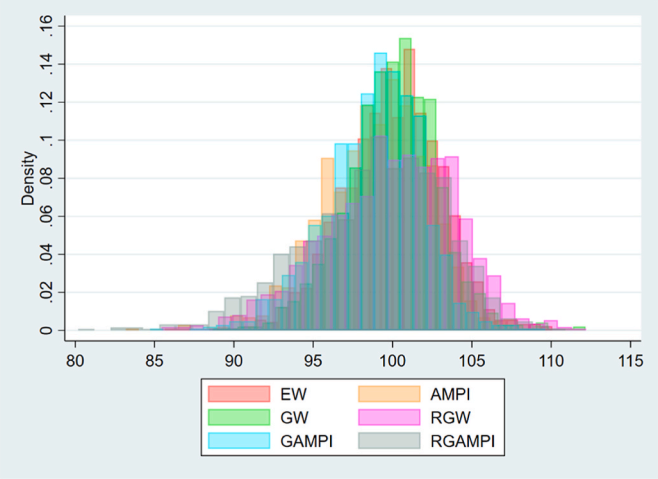

Fig. 2. GAI distributions calculated with the six aggregation methods, 2008–2020.

Table 3
Spearman's rank correlation coefficient for the six GAI calculation methods.

	EW	AMPI	GW	RGW	GAMPI	RGAMPI
EW	1					
AMPI	0.9872	1				
GW	0.8906	0.8947	1			
RGW	0.9489	0.9302	0.7292	1		
GAMPI	0.862	0.8973	0.9699	0.6995	1	
RGAMPI	0.9464	0.9407	0.7336	0.9936	0.7215	1

Per the aim of this research, we estimate several models using, alternatively, two dependent variables: 1) separate waste collection (SWC) per capita and 2) landfill disposal (L) per capita. The *SWC* per capita is defined as the ratio between the SWC (in tons) and residents. It is measured by LD 152/2006 as the share of urban waste separately collected. Similarly, the *landfill disposal* variable represents the ratio between tons of waste landfilled and the residents. For both variables, only urban waste generated by households is considered, excluding industrial waste, debris from demolitions, etc. (Agovino et al., 2023).

To explain SWC (L) per capita, we use a set of covariates selected following the related theoretical and empirical literature. In particular, we control for population density, value added per capita, the elderly dependency ratio, the immigrant population, the GAI, and the interaction between the GAI and macro-area dummies. Since the SWC and L represent two reversed faces of the same coin, we expect that the relationships between covariates and SWC are the opposite of those between covariates and L. For this reason, we present only the expected SWC-based relationships. *The population density* is the ratio between the total population and total square kilometres of the province. The expected relationship with SWC is ambiguous because this variable controls for different land values and the presence of agglomeration and scale effects. That is, the greater the population density, the higher the price of establishing collection sites (Simões et al., 2012). Limitations linked to congestion may also arise (Hage and Söderholm, 2008). However, good opportunities related to economies of scale and transport costs may emerge because of the shorter distances between agents and sorting infrastructure [6]. *The value added* per capita measures provincial economic well-being ([24]; D'Amato et al., 2015; Agovino et al., 2019). This is particularly important in terms of collection methods used since the significant economic resources required to implement an effective waste segregation and collection model (e.g., door-to-door). The empirical relationship between value added and SWC has been proven in several studies referring to various internal contexts (Torras, 2005; Andersen et al., 2007; Musella et al., 2018). The *elderly dependency ratio* is the ratio between the number of people aged older than 64 years and those aged 16–64 years. The literature highlights the ambiguous effect of this variable on SWC. On the one hand, older individuals have greater attitudes and responsibilities towards environmental issues (Sargisson et al., 2020; Escario et al., 2020; Lazaric et al., 2020; Peluso et al., 2021). On the other hand, with increasing age, the probability of health problems or disabilities increases, with a clear negative impact on the commitment to environmental issues (Jones and Dunlap, 1992). The *immigrant population* variable represents the share of immigrant residents in the total population. The presence of immigrants could affect waste-related activities in various ways, ranging from a negative impact [25–27] to a positive effect (Muradian, 2006; Neumayer, 2006; Røpke, 2006; Squalli, 2021) or even a nonsignificant relationship (Lovelock et al., 2013). This relationship is conditioned by immigrants' country of origin and degree of cultural integration [28,29]. The characteristics of the GAI are explained extensively in Section 3. Finally, we created interaction variables between the GAI and macro-areas, namely, North, Central, and South Italy (macro-areas correspond to the NUTS-1 level of the EUROSTAT territorial classification). We first define the dummy variables that allow us to establish which macro-areas belong to a province and then determine the interaction variables to capture the geographical differences in the role played by institutions in promoting the circular economy. Table 4 shows the main features of the dataset.

5. Results

This section presents the results of the empirical analysis. Specifically, we examine the impact of the GAI on the two phases of the waste management process: the upstream phase of waste sorting (SWC per capita) and the downstream phase of landfill disposal (landfill per capita). For both estimates, we consider the results of each GAI calculation to capture the effects of the different aggregation methods used in the GAI construction. Additionally, the analysis was replicated to account for the interaction between the GAI and the three Italian macro-areas (North, Centre, and South Italy) to evaluate how regional differences in administrative capacity affect the achievement of circular economy objectives.

Table 5 presents the results for the GAI calculated via the equal weight (EW) and additive methods with penalisation index (AMPI) aggregation methods. In both cases, the GAI's effect on SWC per capita shows the expected positive sign, and the parameter is statistically significant. Conversely, the relationship is negative when the dependent variable is landfill per capita, with the parameter also being statistically significant.

When the effect of the GAI by macro-area is considered, the parameter associated with the GAI for SWC per capita remains significant and positively signed in both estimates (EW and AMPI), with a more substantial impact observed via the EW aggregation method. Additional differences emerge when examining the interaction between the GAI and the macro-area variable (with North Italy as the reference macro-area). Specifically, for the EW method, the GAI parameter for southern Italy, while statistically significant, has a negative sign. This finding indicates that the functioning of PAs in southern Italy results in a lower SWC per capita than that in northern Italy. This reflects a significant organisational disparity in public administration that disadvantages the southern provinces. This result is not observed with the AMPI method, where the GAI parameter for southern Italy is negative but not statistically significant, suggesting that no substantial difference in SWC per capita between North and South Italy can be attributed to varying PA performance.

The situation reverses when the analysis focuses on landfill per capita. Here, the organisational disparity of PAs, disadvantaging southern provinces, is evident when the aggregation uses the AMPI method. Given the aggregation methods' characteristics, the results from the AMPI method are preferable because it addresses outliers and reward provinces with balanced indicators. In other words, effective PA

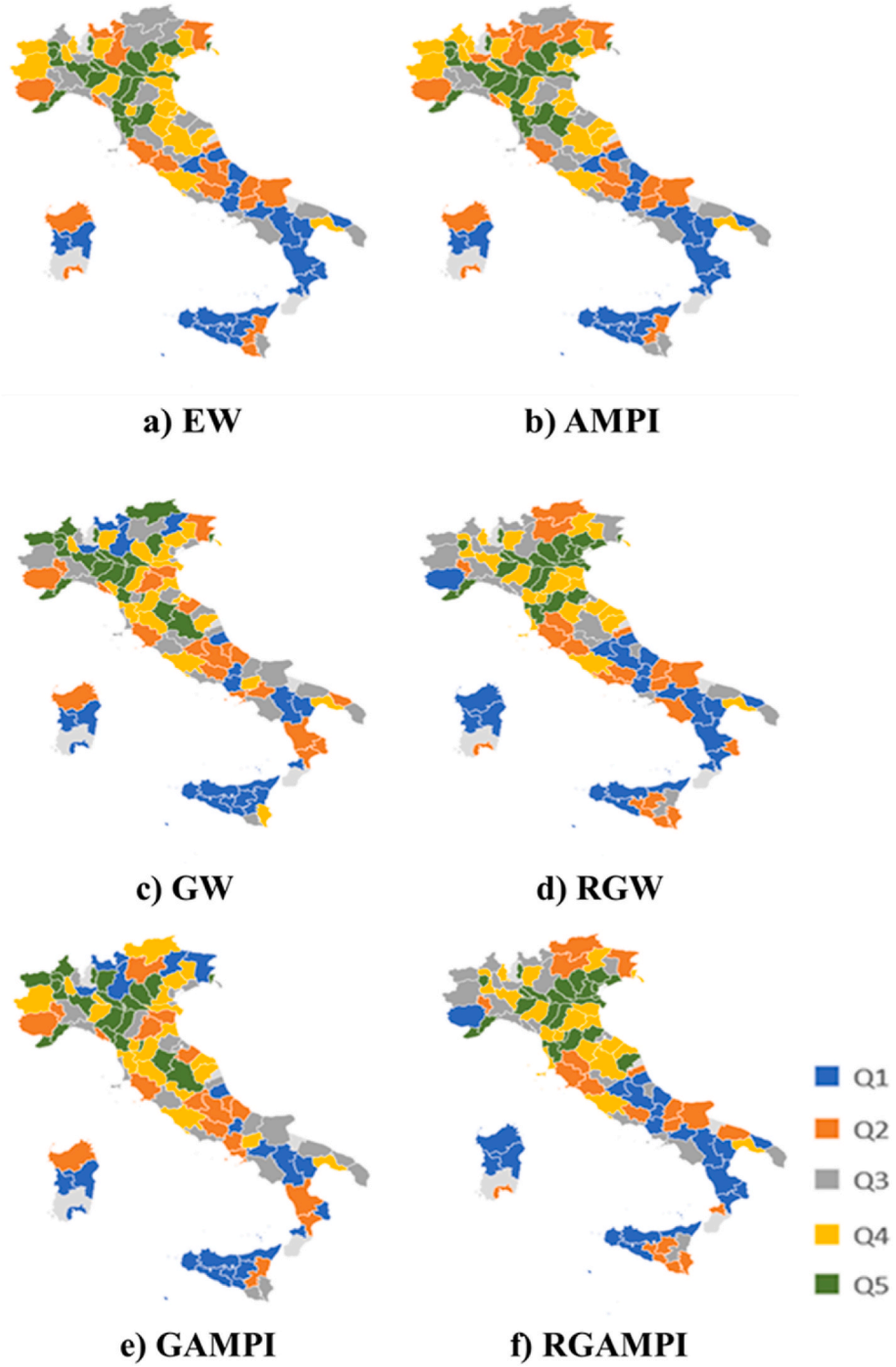

Fig. 3. GAI quintile maps for each calculation method.

requires that all functions governing public offices perform adequately, and excellence in one function cannot compensate for poor performance in others. Thus, preferring the GAI derived from AMPI implies that southern Italy's PA must undertake balanced actions to promote waste disposal methods aligned with circular economy principles (e.g., energy recovery, composting).

This finding aligns with data from ISPRA, which reports the lower cost of landfill use in southern provinces than in central and northern Italy. This cost difference has created a market for landfills, with southern Italy attracting a significant amount of undifferentiated waste from other parts of the country. The low disposal cost, coupled with the lack of previous regulations defining maximum thresholds for landfill disposal, has resulted in neglecting investment in alternative waste management methods. These factors, along with infrastructural, institutional, and economic deficiencies, have contributed to the persistent North–South disparity in environmental performance observed in Italy over the years [24,30].

Table 6 presents the results for the GAI calculated via the GW and RGW aggregation methods. This analysis reveals some notable findings. Specifically, only with the GW aggregation method does the GAI have a statistically significant effect on both SWC and landfill per capita. In contrast, when the GAI is aggregated via the RGW method, the parameter associated with the GAI is statistically significant only for the upstream phase of waste management (SWC per capita).

These results persist even when the impact of the GAI by macro-area is examined. Specifically, for SWC per capita, the GAI constructed via

Table 4
Descriptive statistics and data sources. Italy, 2008–2019.

		Obs.	Min.	Max	Mean	St. Dev.	Source
Dependent variable	SWC	1236	32.07	86.63	51.03	9.67	ISPRA
	Landfill	1236	0.67	62.45	22.99	10.94	ISPRA
Covariates	Population density	1236	36.73	624.5	229.92	109.48	ISTAT
	Value added per capita	1236	12,909	50,049	22,996.78	6243.92	ISTAT
	Elderly dependency ratio	1236	20.89	49	35.01	5.19	ISTAT
	Immigrant population	1236	0.46	34.8	7.19	3.56	ISTAT
	GAI – EW	1236	88	110	100.01	3.06	Authors' elaboration on ISTAT data
	GAI – AMPI	1236	85	112	99.91	4.17	
	GAI – GW	1236	83	108	98.90	3.30	
	GAI – RGW	1236	89	112	99.99	2.93	
	GAI – GAMPI	1236	85	110	98.82	3.07	
	GAI - RGAMPI	1236	80	111	98.81	4.43	
	GAI – EW *Central Italy	1236	0	110	21.33	40.22	
	GAI – EW *South Italy	1236	0	104	34.83	46.20	
	GAI – AMPI *Central Italy	1236	0	112	21.35	40.26	
	GAI – AMPI *South Italy	1236	0	106	34.46	45.72	
	GAI – GW *Central Italy	1236	0	107	21.16	39.88	
	GAI – GW *South Italy	1236	0	105	34.41	45.63	
	GAI – RGW *Central Italy	1236	0	112	21.32	40.20	
	GAI – RGW *South Italy	1236	0	111	35.14	46.63	
	GAI – GAMPI *Central Italy	1236	0	110	21.14	39.83	
	GAI – GAMPI *South Italy	1236	0	107	34.72	46.05	
	GAI – RGAMPI *Central Italy	1236	0	111	21.19	39.95	
	GAI – RGAMPI *South Italy	1236	0	105	33.98	45.07	

Table 5
Estimates of Fixed Effects models by GAI's aggregation procedures. EW and AMPI.

	EW				AMPI			
	SWC (1)	SWC Macro-Area (2)	Landfill (3)	Landfill Macro-Area (4)	SWC (5)	SWC Macro-Area (6)	Landfill (7)	Landfill Macro-Area (8)
Population density	−0.015 (0.018)	−0.016 (0.018)	−0.285*** (0.091)	−0.286** (0.091)	−0.016 (0.018)	−0.016 (0.018)	−0.280*** (0.090)	−0.269*** (0.090)
Value Added per capita	0.385*** (0.035)	0.382*** (0.035)	−0.066 (0.175)	−0.064 (0.176)	0.391*** (0. 035)	0.392*** (0.035)	−0.088 (0.175)	−0.109 (0.175)
Elderly dependency ratio	−0.551*** (0.032)	−0.556*** (0.032)	3.521*** (0.159)	3.523*** (0.159)	−0.556*** (0.032)	−0.557*** (0.032)	3.537*** (0.159)	3.584*** (0.159)
Immigrant population	−0.029*** (0.007)	−0.028*** (0.007)	0.290*** (0.036)	0.289*** (0.036)	−0.030*** (0.007)	−0.029*** (0.007)	0.291*** (0.036)	0.284*** (0.036)
GAI	0.202** (0.070)	0.378*** (0.115)	−0.778** (0.343)	−0.960* (0.566)	0.140** (0.054)	0.174* (0.089)	−0.441* (0.266)	−1.523*** (0.438)
GAI*Central Italy	–	−0.155 (0.216)	–	−0.236 (1.061)	–	0.049 (0.177)	–	0.707 (0.865)
GAI*South Italy	–	−0.316** (0.153)	–	−0.447 (0.752)	–	−0.078 (0.118)	–	1.974*** (0.576)
Constant	3.512*** (0.451)	3.404*** (0.459)	−2.011 (2.215)	−1.696 (2.255)	3.766*** (0.412)	3.684*** (0.423)	−3.441* (2.022)	−2.276 (2.063)
Hausman Test	80.15***	56.48***	102.18***	98.74***	80.65***	54.74***	99.53***	105.51***

the GW method shows no significant differences across macro-areas. However, with the GAI constructed via the RGW method, the functioning of PAs in the South has less impact on SWC per capita than in the North.

These results further confirm how the choice of aggregation method can lead to different outcomes in terms of significance and direction when controlling for the performance of public administration by macro-area. Both indicators reflect vertical variability, and if a choice must be made, it seems reasonable to prefer the GW aggregation method. This is because it favours provinces that perform better in the individual functions of public administration. This choice is justified because an important criterion when assessing public administration performance is efficiency, which is represented by the quantitative results (given inputs, the province that achieves the highest output is favoured). However, this criterion could be critiqued, as quantity is not always synonymous with quality. In our case, we can conclude that this coincidence holds true and is ensured by the elementary indicators selected for constructing the GAI.

Finally, Table 7 shows the results for the GAI obtained with the GAMPI and RGAMPI aggregation methods. In these two cases, the GAI is aggregated considering two penalties: vertical penalties (between provinces) and horizontal penalties (between elementary indicators of the same province). In the case of the GAMPI, the parameter associated with the relationship between the SWC per capita and the landfill per capita and the GAI is never statistically significant. In contrast, the RGAMPI aggregation method returns opposite results regarding significance. Specifically, in the case of the SWC per capita, the GAI positively influences separate waste collection. In terms of landfill per capita, a better organisation of public offices favours the reduction of treatment practices typical of the linear economy model, and the problem is more accentuated among the PAs of the provinces of southern Italy.

With respect to the control variables, the coefficient for per capita value added is statistically significant and positive only for the upstream phase, whereas for landfilling, the coefficient is negative but never statistically significant (see Tables 5–7). Conversely, when population density is considered, the estimated coefficients indicate that the effect

Table 6
Estimates of Fixed Effects models by GAI's aggregation procedures. GW and RGW.

	GW				RGW			
	SWC (1)	SWC Macro-Area (2)	Landfill (3)	Landfill Macro-Area (4)	SWC (5)	SWC Macro-Area (6)	Landfill (7)	Landfill Macro-Area (8)
Population density	−0.015 (0.018)	−0.015 (0.018)	−0.288*** (0.091)	−0.299*** (0.091)	−0.017 (0.018)	−0.018 (0.018)	−0.272*** (0.090)	−0.272*** (0.091)
Value Added per capita	0.380*** (0.036)	0.381*** (0.036)	−0.027 (0.177)	−0.041 (0.177)	0.388*** (0.035)	0.381*** (0.036)	−0.087 (0.176)	−0.096 (0.177)
Elderly dependency ratio	−0.548*** (0.032)	−0.549*** (0.032)	3.499*** (0.159)	3.478*** (0.160)	−0.551*** (0.032)	−0.553*** (0.032)	3.527*** (0.159)	3.526*** (0.159)
Immigrant population	−0.028*** (0.007)	−0.028*** (0.007)	0.285*** (0.036)	0.288*** (0.036)	−0.029*** (0.007)	−0.028*** (0.007)	0.290*** (0.036)	0.292*** (0.036)
GAI	0.145** (0.061)	0.194** (0.095)	−0.788** (0.298)	−0.403 (0.467)	0.105* (0.056)	0.233** (0.091)	−0.149 (0.278)	−0.017 (0.450)
GAI*Central Italy	–	0.120 (0.191)	–	−1.848** (0.933)	–	−0.185 (0.169)	–	0.054 (0.833)
GAI*South Italy	–	−0.142 (0.130)	–	−0.299 (0.637)	–	−0.217* (0.125)	–	−0.307 (0.615)
Constant	3.819*** (0.411)	3.698*** (0.420)	−2.265 (2.015)	−1.560 (2.056)	3.951*** (0.412)	3.963*** (0.414)	−4.799** (2.021)	−4.873** (2.034)
Hausman Test	79.08***	52.52***	99.58***	100.08***	80.25***	53.75***	94.23***	93.65***

Table 7
Estimates of Fixed Effects models by GAI's aggregation procedures. GAMPI and RGAMPI.

	GAMPI				RGAMPI			
	SWC (1)	SWC Macro-Area (2)	Landfill (3)	Landfill Macro-Area (4)	SWC (5)	SWC Macro-Area (6)	Landfill (7)	Landfill Macro-Area (8)
Population density	−0.018 (0.018)	−0.018 (0.018)	−0.276*** (0.090)	−0.280*** (0.091)	−0.016 (0.018)	−0.016 (0.018)	−0.272*** (0.091)	−0.262*** (0.090)
Value Added per capita	0.389*** (0.036)	0.386*** (0.036)	−0.070 (0.176)	−0.092 (0.177)	0.386*** (0.035)	0.388*** (0.035)	−0.088 (0.176)	−0.100 (0.175)
Elderly dependency ratio	−0.552*** (0.032)	−0.553*** (0.032)	3.521*** (0.159)	3.512*** (0.159)	−0.553*** (0.032)	−0.553*** (0.032)	3.530*** (0.159)	3.560*** (0.159)
Immigrant population	−0.029*** (0.007)	−0.029*** (0.007)	0.289*** (0.036)	0.291*** (0.036)	−0.029*** (0.007)	−0.028*** (0.007)	0.290*** (0.036)	0.281*** (0.036)
GAI	0.053 (0.054)	0.104 (0.081)	−0.338 (0.266)	0.061 (0.399)	0.125** (0.05)	0.194** (0.083)	−0.097 (0.248)	−1.102*** (0.409)
GAI*Central Italy	–	−0.133 (0.167)	–	−1.202 (0.820)	–	0.150 (0.166)	–	0.495 (0.813)
Gai*South Italy	–	−0.078 (0.117)	–	−0.564 (0.575)	–	−0.172 (0.109)	–	1.861*** (0.536)
Constant	4.187*** (0.399)	4.238*** (0.405)	−4.049** (1.955)	−3.586*** (1.983)	3.873*** (0.394)	3.673*** (0.403)	−5.033*** (1.933)	−3.871* (1.973)
Hausman Test	79.11***	50.72***	93.00***	94.96***	80.04***	56.46***	97.83***	93.48***

on per capita landfilling is negative and statistically significant in each model, meaning that as population density increases, the amount of landfilling per capita decreases. In contrast, the coefficient for the upstream phase (SWC per capita) is negative but not statistically significant. This suggests that in more densely populated areas, the downstream phase of waste management is affected by increased waste transportation costs, which increase for both public and private agents, thereby promoting a reduction in landfill use (see Ref. [6]). Furthermore, higher population density also increases the costs of creating collection and disposal sites (Simões et al., 2012).

With respect to the elderly dependency ratio, the estimated coefficient is negative and statistically significant for the upstream phase, whereas it is positive and statistically significant when the dependent variable is the landfill per capita. In other words, as the older population increases, the SWC per capita decreases, and the amount of waste sent to landfills increases. The ability of older adults individuals to engage in environmental activities is often limited because health problems and disabilities increase with age. Disability is indeed correlated with age, and individuals with disabilities who are already engaged in caregiving activities tend to neglect pro-environmental activities (such as separating their waste; see Ref. [31]).

Similarly, the effect of the immigrant population variable is negative and statistically significant for SWC per capita and positive and statistically significant for landfill per capita. These results are related to the degree of cultural integration of these individuals and the communication and informational difficulties related to waste service organization (see Ref. [25–29]). The PA should structure SWC schedules in multiple languages to better accommodate various language needs and improve service effectiveness.

In summary, the empirical analysis results highlight that the good organisational management of the financial and real resources of PAs is crucial to achieve circular economy objectives. Specifically, good PA administration promotes proper waste separation and reduces waste disposal methods that are not aligned with circular economy principles (e.g., landfilling). Thus, Hypotheses H1 and H2 are confirmed.

6. Discussions

The results show that, although the AMPI method is useful for addressing outliers and rewarding provinces with balanced indicators, the RGAMPI method should be preferred. The latter method, indeed, highlights provinces that excel in terms of individual public administration functions and avoids compensatory methods among functions. Instead, it aims for harmonious functioning across different PA functions, ensuring that all functions perform adequately without compensating for the deficiencies of others.

Furthermore, the significance of the results varies with the aggregation method, particularly when comparing PA performance across geographic areas (i.e., North vs. South). For example, when the GAI calculated with the AMPI aggregation method is used, the effect of the GAI is significant for landfilling per capita but not for the upstream phase (per capita SWC). Conversely, the EW method better captures the differences between northern and southern Italy in the upstream phase, whereas AMPI highlights the differences in the downstream phase. Therefore, the aggregation method captures different management aspects that influence the upstream (SWC) or downstream (landfilling) phase of waste management differently when geographical areas of the country are compared.

In general, the interaction term between the GAI and macro-areas highlighted the lower effectiveness in the organisation of PAs in the southern area than in the northern PA for the upstream phase (SWC per capita) and for the downstream phase (landfilling).

The results obtained by comparing the Italian macro-areas in the levels of good administration reveal important evidence and are linked to preexisting and ongoing problems. The first is linked to the incompleteness of the administrative governance provided for by Italian legislation (see LD 22/1997 and LD 152/2006). The incompleteness of the *governance models* inevitably leads to a slowdown in the good functioning of the institutional supply chain or is the result of it in many cases. This incompleteness results in incomplete and unfinished waste management processes by the local PA, which leads to worse results for the upstream phase than for northern Italy and has repercussions for the correct management of the downstream phase. The reduced performance of the institutional supply chain is also contributed to by a strong temporal discontinuity in the management of the waste services present, especially in the South. Procurement procedures, particularly in southern areas, for the assignment of waste management services have a duration of 5 years or less. This translates into a sudden change in management in the territories that, in the absence of strong local governance and long-term planning of all the functions and resources to be used in the waste management process, can affect the possible levels of improvement in management and, certainly, the possibility of implementing significant investment plans in structures to facilitate SWC or alternative disposal methods to landfill (see Ref. [32]). In this regard, southern Italy has a significant plant deficit, so it is subject to the transport of waste to plants outside the region, which heavily affects the cost of the waste management service compared with the average costs observed in other areas of the country. The availability of an adequate plant system for waste recycling and for energy recovery of nonrecyclable waste is fundamental to reducing landfill disposal. In short, the poor functioning of local institutions leads to waste and inefficiencies that would otherwise be avoidable with negative repercussions on the various phases of waste management. Waste leads to excessively high costs of the service, and these costs are passed on to citizens, who are required to pay too high a price for the service offered. On average, citizens residing in the South are subject to a greater financial waste system (a waste tax Tari labelled, see Agovino et al., 2021) than other geographical areas.[6] To not generate distortions in citizens' behaviour, the waste fee/tax should be as close as possible to the value of the service provided. Only in this case could it act as a Pigouvian tax and lead citizens to respect the pyramid defined by the European directive. When a price system is set too high, there is a risk that citizens will not feel effectively incentivised to reduce waste production and will not pay the tax (Agovino et al., 2021). This can further strain local government budgets and, consequently, to further difficulties linked to the lack of monetary resources for the correct functioning of PA offices and in necessary and alternative plants and infrastructures to the landfill.

In this regard, it is important to remember that a high level of source separation by citizens allows increasing SWC and a reducing the undifferentiated waste that ends up in landfills, keeping constant the amount of waste produced. However, in order to encourage citizens to separate their waste, it is crucial to plan and design appropriate waste collection programmes that prevent the separation process from becoming overly time-consuming. The SWC method adopted is affected by the local economic capacity to cover costs. In some of the most economically disadvantaged areas, cost-effective methods in monetary terms – though more time-consuming for citizens – are still employed, which can negatively impact the overall outcome. For example, door-to-door waste collection, while less time-demanding for citizens, is more costly for the government, making its implementation challenging in poorer areas. Panetta [33] notes that the economic gap between the South and the Centre-North in terms of GDP per capita is now wider than it was in the 1970s. A low GDP makes it difficult to absorb the high costs of door-to-door collection and to invest in more efficient, less polluting waste management technologies. While Northern provinces tend to be more effective with door-to-door collection, the South faces additional challenges due to a significant and deep infrastructure deficit [30]. It is therefore clear that if an area is already struggling with limited economic resources, a malfunctioning institutional supply chain only exacerbates the allocation of these resources across various essential needs and services.

To promote a connection between all PA functions and correct management of real and monetary resources with positive effects on the different phases of waste management, it is necessary to invest in implementing ad hoc programs to strengthen the weakest administrative functions and create a well-functioning process in all its parts. Recent programs and projects that arise from an agreement between local authorities, such as the National Association of Italian Municipalities (ANCI) and the National Packaging Consortium (CONAI), could promote improvements in PA functions related to the waste sector. In fact, the actions planned and foreseen for the public offices participating in the projects include providing assistance and support to local authorities in drafting development projects for SWC (National Recovery and Resilience Plan (PNRR) call by the Ministry of the Environment and Energy Security); financial support for local communication, such as information campaigns on SWC; tools for territorial planning, including the possibility of developing projects and plans for urban waste management with the collaboration of specialised technicians; training programs for administrators and technicians; and a technical structure within ANCI that guarantees ongoing consultancy to those who need it.[7] Similar projects can promote the connection between the different PA functions and the correct placement of real and monetary resources. Furthermore, with explicit reference to the waste sector, similar programs help PA personnel develop plans for the various phases of waste management and provide citizens with the right knowledge by planning ad hoc programs for immigrants and older individuals. To address the challenges in waste management, particularly in relation to the immigrant population and the elderly, policies should focus on implementing educational programmes targeted at specific demographic groups. Local authorities could run informational campaigns in multiple languages, ensuring that residents from different linguistic backgrounds are well-informed about waste separation and collection procedures. Additionally, programmes aimed at educating the elderly on how to participate in recycling could improve engagement and reduce the amount of waste sent to landfills.

In summary, the results highlight the importance of strong public functions at all levels. The preference for the RGAMPI method highlights the importance of balanced performance across all functions of public administration. Policymakers should focus on creating incentives for

[6] https://www.cittadinanzattiva.it/comunicati/14565-dossier-rifiuti-2021-ecco-quanto-costano-in-italia-provincia-per-provincia.html, 3/08/2024 last accessed.

[7] https://www.anci.it/wp-content/uploads/Presentazione-XIII_Rapporto-BD_23_def.pdf, last accessed 04/08/2024.

provinces to excel in individual administrative functions without allowing deficiencies in one area (in the institutional value chain) to be compensated by others. A key policy implication is the need to invest in strengthening the public administration, particularly in Southern Italy. This could be achieved by improving governance structures and ensuring continuous, long-term planning for waste management. Local authorities should be supported in addressing institutional gaps and fostering a more cohesive and effective management system for the entire waste management cycle, from recycling to disposal. In this regard, in addition to actions that could arise from the recent agreement between ANCI and CONAI, another measure to consider for the proper functioning of public administration is the sharing of best management practices among local public administrations. This could help address existing disparities in public administration levels across different regions of the country and reduce the performance gap in waste management practices implemented in various geographical areas. One way to encourage this process of comparison is through the 'name and shame' incentive (or disincentive) system, which could be introduced by central environmental legislation. This approach is already used at a local level in the Portuguese waste sector to monitor companies operating within the primary and secondary markets of the waste management system [34,35]. The rankings aim to motivate improvement by showcasing the best-performing countries as 'benchmarks' and publicly identifying the poorest performers as 'slackers'. In this context, such a system could be applied to each level of the local institutional supply chain, fostering competition with better-performing local institutions. Consequently, this system could serve as an effective incentive to enhance the proper functioning of the public administration, encouraging each function to operate correctly.

7. Conclusions

The work had the two aims: defining an indicator of good administration of the PA, GAI labelled, at the provincial level and testing the effect of the GAI on the two main phases of waste management—the upstream phase of SWC and the downstream phase related to waste disposal in landfills.

The analysis has shown how the GAI significantly affects both management phases. The comparison of the results obtained considering different aggregation methods for constructing the GAI highlights how the AMPI and RGAMPI methods are preferable in the waste sector. The latter is the one that best allows us to grasp the full functioning of each function of the PA offices and the harmonious functioning of the different functions that guarantee good PA administration. In other words, all the functions that concern the PA must 'work', and none must compensate for the malfunctioning of another. This can guarantee the definition of complete management plans, preceded by the definition of complete governance. In the waste sector, these aspects are even more evident when moving from one management phase to another and from one disposal method to another. A good administrative waste management process with positive effects on the full transition to the circular economy means not neglecting any of the necessary PA functions. The recent investments and projects related to the PNRR and the ANCI-CONAI agreements will be able to help the provincial PA offices, especially in southern Italy, also complete and define suitable waste collection–disposal processes that are still lacking. In doing so, a significant role is played by information campaigns to address not only citizens (especially immigrants and older individuals) but also PA personnel.

Future research developments will focus on the effects of PNRR funds related to projects and programs established through ANCI-CONAI agreements in the waste sector. It will be particularly interesting to analyse how these investments impact the administrative functions that have benefited from them and to assess their effects on the waste management phases in Italian provinces.

CRediT authorship contribution statement

Massimiliano Agovino: Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Antonio Garofalo:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Katia Marchesano:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Simona Monteleone:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Gaetano Musella:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Data statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Financial interests

The authors declare they have no financial interests.

Conflicts of interest (financial or non-financial)

The authors have no relevant financial or non-financial interests to disclose.

Data availability

Data will be made available on request.

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