Journal of Cleaner Production 348 (2022) 131266

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A selection bias approach in the circular economy context: The case of organic municipal solid waste in Italy

Massimiliano Mazzanti [a,b], Matteo Mazzarano [b,c,*], Emy Zecca [a,b,d]

[a] University of Ferrara, Department of Economics and Management, Via Voltapaletto, 11, 44121 Ferrara, Italy
[b] Sustainability Environmental Economics and Dynamics Studies (SEEDS), Via Voltapaletto, 11, 44121 Ferrara, Italy
[c] University of Siena, Department of Political and International Sciences, Via P.A. Mattioli, 10, 53100, Siena, Italy
[d] University of Ferrara, Department of Chemical, Pharmaceutical and Agricultural Sciences, Via Luigi Borsari, 46, 44121, Ferrara, Italy

ARTICLE INFO

Handling Editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Municipal solid waste
Organic waste
Italian provinces
Environmental Kuznets curve
Waste prevention
Heckman model

ABSTRACT

Organic waste is often indicative of the amount of food waste, and it primarily reflects the consumption habits of households. As underlined by the applicable principles of the Circular Economy (CE), prevention is always the first choice when dealing with waste but evaluating the prevention framework without considering the application of waste separation policies appears to be a complex task. Considering Italian municipal waste management, the implementation of separation policies has been delayed in several provinces. It is difficult to assess the effectiveness of prevention policies established by international and national authorities in this context. The lack of organic waste separation is registered as a missing value in datasets: such instances are often non-random. The research objective of this work is to assess whether economic activity affects organic waste generation and, once the selection bias has been investigated, try to assess the overall implications. Initial findings corroborate the Environmental Kuznets Curve Hypothesis under biased and unbiased estimations. The tipping point is relatively lower when the inverse Mills Ratio is considered, which is positive. Hence, an increase of the expected economic activity requirement could result in a cost that municipalities incur when delaying the enforcement of separation policies. The missing information undermines the potential feedback from practitioners and other stakeholders capable of steering expectations: the unobserved flows have to reach a certain level before being collected.

1. Introduction

The EEA (2020) states that “recently revised waste legislation within the EU’s circular economy strategy has introduced several targets and provisions that will drive both the prevention and the sustainable management of bio-waste. With a share of 34%, bio-waste is the largest single component of municipal waste in the E.U. Recycling of bio-waste is key for meeting the E.U. target to recycle 65% of municipal waste by 2035". More specifically, “About 60% of bio-waste is food waste. Reducing the demand for food by preventing food waste can decrease the environmental impacts of producing, processing, and transporting food. The benefits from reducing such upstream impacts are much higher than any environmental benefits from recycling food waste”. The report shows that “approximately 88 million tons (173 kg per person) of food is wasted every year in the EU-27+UK along the entire food value chain. This corresponds to about 20% of all food produced. To enable bio-waste to be used as a source of high-quality fertilizer and soil improver, it must be collected separately at the source while keeping impurity levels low. Contamination with plastics is a growing concern, and plastics need to be prevented from entering bio-waste. Although the share of municipal waste composted and digested was 17% in 2018, up from 11% in 2004, a high proportion of bio-waste still ends up in the mixed waste that is landfilled or incinerated, even in many countries with well-established separate collection systems”. The issue of bio-waste is multifaceted. Managi and Kumar (2018) indicate that sustainable growth models tend to be more inclusive. Within the historical evolution of E.U. policies, witnessing as key milestones the 1989 German Toepfer Law, the 1994 E.U. Packaging Directive, the Landfill Directive in 1999, the Waste Framework Directive in 2008 constituted the 2015 Circular Economy strategy with the 2020 update. The challenge of preventing waste from being produced by adopting a circular way of thinking is still a challenge for the 2020–2030 policy agenda.

Abbreviations: Closing the Loop Communication, CL; Environmental Kuznets Curve, EKC; European Union, E.U..

* Corresponding author. University of Siena, Department of Political and International Sciences, Via P.A. Mattioli, 10, 53100, Siena, Italy
E-mail address: matteo.mazzarano@unisi.it (M. Mazzarano).

https://doi.org/10.1016/j.jclepro.2022.131266
Received 31 July 2021; Received in revised form 14 February 2022; Accepted 7 March 2022
Available online 9 March 2022

The consolidated interest to reduce organic waste flows is evident in the E.U. Agenda (Commission of the European Communities, 2008; European Parliament and Council, 2008; Wilts et al., 2018; Zoboli et al., 2014). Datasets available at the national and Union level allow for complex analysis. However, it is worth noting that information regarding waste accounting depends on the level of separation enforced within a nation, region, or other forms of sub governments. Without such information, it is difficult to state the level of decoupling, i.e., the disentanglement of economic growth from producing waste. For the Italian case, a long dataset of 20 years is available at NUTS3 level, i.e., 103 provinces for 2060 observations. The years of inquiry cover 1999 to 2019.

Regarding the thematic focus of the paper and moving from the macro to the regional scale, the most refined source of data in Italy is provided by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale). However, omitted observation indicates heterogeneous reporting at the local level. This paper aims to assess the relationship between socioeconomic drivers and organic waste generation at the provincial level by controlling for sample selection bias due to omitted observations. Beigl et al. (2008) state studies evaluating the determinants of Municipal solid waste generation are informative for policy frameworks aimed at waste reduction. Moreover, this branch of literature happens at both country, regional and municipal levels (Mazzanti et al., 2008, 2009; Cole et al., 1997). There are different reasons why it is suitable for a single country (regional, provincial and municipal) level. As Ercolano et al., 2018 argued: on the one hand, it makes it possible to consider the consistent within-country heterogeneity in MSW generation; on the other hand, this reflects the local management system of MSW. This constitutes a reasonable motivation to conduct Italian analysis at the provincial level, which complements the analyses already carried out at the regional level (Cucchiella et al., 2012, 2014). The second motivation is the lack of studies aimed at evaluating socioeconomic drivers for the specific case of organic waste. The third one is based on the possibility of investigating the missing information characterizing this kind of data: trying to assess possible implications in terms of policy but also in terms of managerial advice represents an element of novelty. Moreover, the possibility of exploiting one of the broadest datasets in its context allows us to address the influence of the delaying of separation policies against the objective of waste reduction. To this aim, a sample selection exercise is organized in a context consistent with the spatial panel data. Organic municipal waste represents the primary target variable of the paper. Such flow is one of the leading indicators of food waste, and its changes are related to the separation policies affecting the entire sector of solid waste.

Eleven categories of waste define a continuous space of observation for most Italian municipalities. Some of them are directly collected via dedicated bins or door-to-door policy. Others are collected according to local or specific arrangements. These are Waste from Electrical and Electronic Equipment, Selective and Textile. The national mean of flows shows an overall reduction of MSW production. Among these, some categories have dramatically decreased and others slightly increased. The primary driver determinant of total reduction is represented by Unsorted waste. It Accounted for more than 75% of the generation in 2001. After 2008, a drastic reduction moved its weight at less than 50%. All other categories registered a slight increase. This probably describes two relevant aspects. One relates to the substitution: unsorted waste was directed to all others with sorting policies. Secondly, an absolute reduction of waste driven by unsorted waste indicates a decrease in waste patterns that were not classifiable. Therefore, some products are no longer part of the consumer basket. We find glass, organic waste, paper, plastic, and wood among the greatest repositories of increased sorting. We find organics, plastic, paper, glass, and WEEE in percentage change. In terms of kilograms' addition from 1999 to 2019, the average resident produced 48.25 Kg of more Paper (110% variation from 2001), 144.64 Kg of Organic waste (344%), 32 Kg (526%) of plastics, 14 Kg of wood (150%) and 31.76 Kg of glass (133%). Waste from Electrical Equipment and Electronics (WEEE) represents one of the highest growth changes (329%). Still, it adds 5 Kg inflow (we should expect more, considering estimated data). Among the lowest addition and low growth, we acknowledge "Other" sources of waste (street cleaning and other particular cases) with 3.84 Kg and 113% growth, metal with a mere addition of 0.57 Kg and 0.07%, textile with 2.09 Kg (104%), finally selective with 0.65 Kg of addition (108%). This last category collects a heterogeneous ex-commodity group: expired medicines, exhausted batteries, etc. In total, the estimated reduction from available Data is about 77 Kg per resident. Organic waste presents relatively to the other flows with remarkable growth. A synthetic plot is provided in Fig. 1 below.

Thus, it is relevant to analyze the micro socioeconomic facts that can support good food waste management and prevention performances at decentralized levels. This information could aid the (network of) municipalities, utilities, local communities, NGOs adopt new actions to implement the E.U. circular economy strategy. EEA (2020) shows that Italy presents a mature quality management system to produce composting from biowaste embedded in national legislation. Italy is among four countries, including Czech, Poland, France, offering regulations, especially fiscal measures to decrease income taxes and VAT (e.g. redistribution of food surpluses for charity and donations). For all the reasons present above, we believe that Italian provinces constitute a suitable *substratum* to be investigated.

The paper is organized as follows. Section two presents conceptual insights and a broad theoretical framework for analyzing the drivers and barriers of innovative behaviors under a socioeconomic perspective. Section 3 the dataset information and general insights over the socioeconomic drivers. Section 4 presents the methodologies involved in estimating the benchmark model and the correction. Section 5 synthetically regards the results, while the following discusses the implications for literature and policymaking. Finally, section 7 highlights the study's main outcomes and addresses potential.

2. Conceptual framework

As visible from the previous section, organic waste often indicates food waste and inefficiencies, representing a missed opportunity to feed the growing world population. It means an essential cost for the society and the environment, generating a twofold problem: on the one hand, it entails a sub-optimal use of natural resources, fostering economic inefficiency and resource depletion; on the other hand, it generates costs related to waste disposal (Morone et al., 2016). Changing the entire system represents one of the most impactful actions to create green cities, re-establish biodiversity, and address climate mitigation (Ellen MacArthur Foundation, 2021). In this context, as visible in the previous section, organic waste is a considerable portion of municipal solid waste (MSW) and causes critical environmental problems such as greenhouse gas emissions due to anaerobic digestion and leachate production at the landfill site. The literature highlights that managing organic waste follows the general pattern of waste management (Melikoglu et al., 2013), using the waste hierarchy to differentiate governance systems according to their environmental desirability listed from the most desired one to the least. According to the Environmental Protection Agency (2014), preventing *over-production* and *over-supply* represents the first ring of this hierarchy. Particularly relevant is the role of policy; the presence of separate policies can cause a delay in their determination which compromises the possibility of them having a determining effect-oriented towards prevention. This appears to be clear in the case of Italy, in which the separation policies at the municipal level are characterized by a strong fragmentation in the waste management system.

The extensive consensus in reducing organic waste highlights the need to prevent the volume of waste by reducing its demand. Diaz Ruiz et al. (2019) have shown different waste prevention strategies such as increasing diet valuation and building consumer awareness trying to change consumers' habits about food. According to Setti et al. (2016),

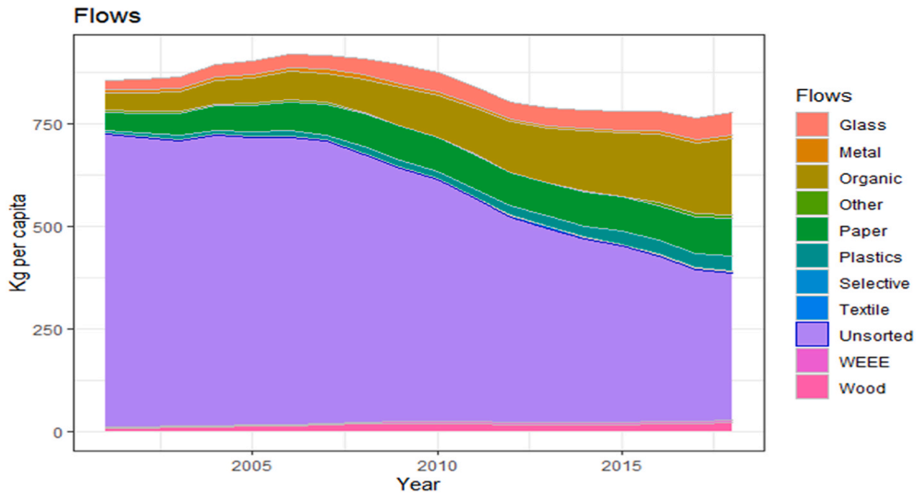

Fig. 1. Waste Categories in Italy (average per capita), Authors' Calculation from ISPRA dataset.

there are complex links among consumers' income conditions, food choices, and household food waste behaviors. These factors include different economic and social conditions and the number of individual decisions related to the characteristics of the specific food typologies. These findings are in line with the literature that emphasizes how different links among food waste can be and how other determinants could impact food waste generation (T. E. Quested et al., 2013; T. Quested and Parry, 2011; Secondi et al., 2015). It appears that developing countries will perceive a more significant impact on food waste as their populations and economies are growing, and their diet is moving from one based on cereal to one based on fat, sugar, and animals (Porter et al., 2016). As Fox and Fimeche (2013) stated, per capita meat consumption in developing countries is expected to rise by 40% by 2050. This point opens the way to the idea that knowing the determinants of the production volume of organic waste could be the right way to prevent food losses by redirecting corrective efforts toward more virtuous behaviors, including policies capable of preventing waste production. Starting with this assumption, being organic waste is a considerable part of MSW, we suppose that this fraction of waste depends on the specific economic countries/regions' characteristics. This could mean investigating the existence of an Environmental Kuznets Curve (EKC). Dinda (2004) has argued that the logic behind the EKC is clear. In the first phase of industrialization and economic growth, individuals are not interested in what happens to the environment: they are only interested in the consequences in terms of wealth and employment that it can provide. Later, once resources have been exploited and income has grown considerably, the environment becomes a priority for citizens and authorities. Recently this relationship has also been demonstrated at the spatial level. Mosconi et al. (2020) showed that a differentiated spatial activity could lead to better results in reducing environmental degradation, emphasizing the relevance of the spatial variable. Furthermore, a large branch of literature has demonstrated a link between economic wealth and waste production as modeled by the Waste Kuznets Curve (WKC), which predicts an inverted U-shaped dependence of waste production on economic development (Stern, 2004). The empirical evidence concerning the WKC hypothesis is controversial in the case of MSW, depending on the geographical level of the analysis (Ichinose et al., 2015; Mazzanti and Nicolli, 2011).

To the best of our knowledge, this link was not investigated in organic waste, in a specific *scenario* characterized by a separated policy as in the Italian case, despite its relevant implications. Economic activities have a central role, and this allows us to postulate the first hypothesis of our work:

H1. organic waste production is strictly connected to the economic setting.

It is commonly known that many factors influence consumers' behavior; among these, urban and social characteristics played a significant role. Agovino et al. (2018a,b) have investigated temporal and spatial correlation in consumption practices underlying food waste. Their analysis moved from cultural characteristics that influence pro-environmental behaviors (Crociata et al., 2016). In other words, it is possible to translate them into common values shared thanks to geographical proximity. The spatial approach to organic (food) waste allows us to understand potential links in food consuming/collecting behaviors among closely related regions. The reasons behind this are the presence of standard features such as government instruments (taxes, subsidies, different systems of waste collection, education programs, etc.) capable of influencing the consumers' awareness. The topic appears extremely interesting if we consider the geographical application of different policies across regions. Local divergences could be an essential driver of food waste production, resulting in a delay in applying correct separation policies. This puts light on a possible spatial correlation, leaving space to our second hypothesis:

H2. Considering a more spatial approach changes a tipping point in EKC estimation.

Analyzing the spatial aspect of the phenomenon could reduce the lack of information. The spatial variation represents an important information source that could lead to a different EKC estimation, helping us reach significant results capable of giving relevant policy indications. The test for such a hypothesis involves a regression of socioeconomic drivers against the target variables. The following section will provide the relevant information regarding the data distribution and relations.

3. Data

This work considers the organic fraction of MSW to account for waste originated by households and food services. As visible from the Fig. 2 below, they represent the most significant proportion of the organic fraction in Italy (67,7%); this is the reason why organic waste represents a good indicator for tasting households organic waste as Parizeau et al. (2015) and Ng et al. (2019). Furthermore, the availability allows for an assessment of the flows at the local level. To this aim, the dataset used covers a long time span from 1999 to 2019 on Italian data at level NUTS 3. The Data on organic waste were retrieved from ISPRA; specifically, the Data from 2001 to 2019 are downloadable, while the previous data (1999 and 2000) were retrieved by hand from the ISPRA Annual Reports

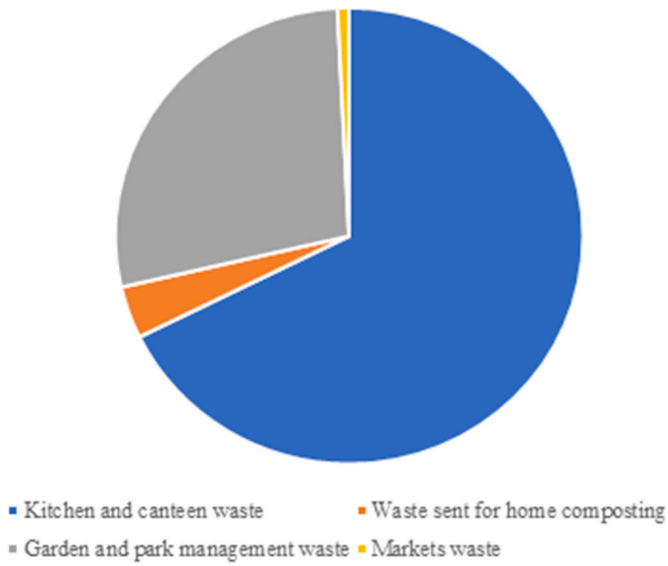

Fig. 2. Percentage shares of the organic waste fraction (Italy, 2019, ISPRA waste report).

about waste of 2001[1] and 2002.[2] This has allowed us to cover about 20 years, making the analysis robust. While socioeconomic drivers have been assembled from the EUROSTAT database.

The investigation involves mainly seven variables. A summary of the variable values is portrayed in Table 1. Organic fraction is the target variable; it represents the per capita amount of waste from household food waste and other organic residuals, usually collected in bins. The mean annual flow consists of 63.270 Kilograms per capita. We recorded as 0 the minimal amount: this quantity signals that the province in question still does not separate organic waste from other flows. The distribution is skewed on the right, indicating a fat tail over high waste production. Among the socioeconomic drivers, it is possible to find Economic activity represented by GDP per capita, Tourism intensity, and Population Density. Economic activity is one of the main drivers of municipal solid waste flow and represents a proxy for the resources necessary to municipal solid waste management. Its mean during the period in question was 24,333. Considering that Economic growth was almost stagnant after 2008 at the national level, it is a proper representation of the distribution center. However, this variable is distributed in a right-skewed distribution as the dependent variable; highly developed provinces comprise a minority in the Italian landscape. Tourism intensity is a proxy for touristic pressure and is calculated as the number of visitors estimated annually in one region. Due to the cultural heritage, certain provinces attract more tourists concerning the others. The distribution indicates that highly attractive provinces are a small number, even in this case. Urban population is an indicator taking three values: 1 (City), 2 (small cities), 3 (low-density areas). It is possible that Italian provinces are below the transitional value of 2, which indicates the low urbanized areas. Population density represents the number of people living within a specific zone. It is a proxy for differentiating between provinces with cities and low-density areas. It has been noted that social capital might be a relevant driver to waste generation (Mazzanti and Montini, 2013). Several indicators could be used to measure it (Andini and Andini, 2019; Calcagnini and Perugini, 2018). In this case, an indicator of trust suggested by Nannicini et al. (2013) was implemented. The indicator is self-reported by samples of individuals according to each province, and it indicates the percentage of individuals who think that most people can be trusted. It originated from the World Value Survey, which unfortunately does not provide a comprehensive data range. Unfortunately, this measure could not be collected repetitively (it jumps from 1999 to 2008). Thus, it was considered fixed after a change. It has a maximum ideal level of 100% and a minimum of 0. In this sample, its standard deviation was 15.7%, and the average was 30.9%, indicating a low level of trust on average. However, the highest value indicates 84.6%, which is remarkably higher than the 75th percentile of 38%. Finally, employment refers to the quota of the population currently occupied in any socioeconomic activity. The mean occupation level in Italy between 1999 and 2019 was 39.6, with a standard deviation of 9.4%. The distribution is well centered between the 25th and the 75th percentiles.

Cited literature warns about a potential correlation between socioeconomic drivers. Economic activity is the primary input of our model. We, therefore, calculated the correlation between all variables implemented in the econometric exercise. The resulting correlation matrix is presented in Table 2. GDP per capita presents a low correlation level with Touristic pressure (25.8%) and density (24.7%), while high with occupation (54%). The first two variables are loosely correlated. Social capital variables are naturally correlated with economic activity (Boulila et al., 2008; Knack and Keefer, 1997; Muringani et al., 2021), with a level of 33%.

Local income divergence is a well-documented phenomenon. The implication for food waste is not straightforward. Considering the selection bias of collection efficiency, a significant number of provinces experienced an increase in waste despite the underperforming economy. The introduction of effective separation policies had to be considered. Certain provinces in the north appreciated a slight reduction in waste. Organic waste collection and then removal vary strongly among provinces after the failure of Lehman Brothers in 2008 and the debt crises afterward. The implication for our study is that economic activity is an unclear instrument for controlling the selection bias, which represents a non-avoidable exercise to assess the prevention.

Two policy breaks are added to the dataset to account for structural changes in the relationship between waste collections. Such variables are defined as dummies, reporting a value of 1 posterior to the implementation date of the policy; it is 0 otherwise, and it is cross-sectionally constant. One policy break was deemed relevant in implementing waste prevention policies: the waste framework directive of 2008 (WFD). The second break is the European Commission's communication "Closing the Loop'' in 2015 (CL). Such variables take part in the three estimation exercises. The methodological model has been explained afterward. The objective of the analysis is to use the variables reported above to assess the level of selection bias and incorporate it within the estimation exercise.

4. Methodology

Described data presents three underlying limits for a clear analysis. One is the influence of intertemporal bias or the influence of previous observation to the subsequent. The second relates the non-randomness of the relationship between the missing data and the observable one. Finally, local performances called local cross-sectional dependence do not allow estimating of the effect of variables correctly. When studying waste prevention and its relation to management, the operational hypothesis is that economic growth can reduce waste flow. Environmental Kuznets's hypothesis implies a linear and positive relationship between economic activity and waste production until a tipping point. If the hypothesis is valid, the relation between waste and economic activity appears to be negative. The phases are called relative decoupling and the second absolute decoupling. However, Stern's examination proved that spurious regressions might emerge in the statistical mismanagement of the models. In this context, the problems in literature consisted of several categories: different time trends (also called non-cointegration),

[1] https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-2001.

[2] https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-2002.

Table 1
Summary table.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Organic fraction	2060	63.270	53.087	0	14.0	104.2	246
GDP Capite	2060	24,332.980	6629.567	11,142.640	18,568.000	28,791.260	57,277.680
Turism intensity	2060	2.697	4.190	0.019	0.781	2.723	33.140
Social Capital	2060	0.309	0.157	0.000	0.216	0.380	0.846
Urban Population	2060	1.913	0.670	1	1	2	3
Employment	2060	0.396	0.094	0.014	0.330	0.461	0.818
Density	2060	252.171	333.473	36.800	107.850	276.250	2687.400

Table 2
Correlation table.

	Organic fraction	GDP Capite	Turism intensity	Social Capital	Urban Population	Employment
Organic fraction						
GDP Capite	0.54***					
Turism intensity	0.09***	0.26***				
Social Capital	0.17***	0.33***	0.08**			
Urban Population	0.03	0.06**	0.08***	−0.02		
Employment	0.24***	0.54***	0.23***	0.18***	0.02	
Density	0.06**	0.25***	0.00	0.13***	−0.23***	0.05*

interactions between individuals or groups, and sample selection. In this section, a brief analysis of the problems is made using time trends to control the former problem. A brief talk about sample selection is at this moment made.

Flows of separated flows are endogenous to the policy of recovering. Therefore, it is challenging to measure waste prevention performance without considering the effectiveness of recovery management. This was not a problem that emerged in the literature. Previous studies had focused on total flows in a period when systemic losses were under control. In other words, the total flow of municipal solid waste encompassed the totality of the externality. Regarding separated flows such as plastics, paper, and our case food, the measure has to rely on the separation policies enforced locally. Therefore, a selection bias emerges. The problem of interaction is serious and relevant in any economic analysis. It is challenging to commensurate how waste-income relation is explained by the observed individual and its endogeneity.

4.1. Econometrics of sample selection in waste policies

Omitted observations have been treated mainly with three methodologies: data imputation, propensity score matching and sample selection. The former approach consists in the replacement of missing observations. In the case of separation policies, no waste collected could be registered as zero Kg per capita. It is a viable alternative when the missing of observations is not endogenous to any of the independent variables. Propensity score matching is similar to the latter procedure: it attempts to mitigate the bias of omitting observation from simply comparing outcomes among units that received the treatment versus those that did not. It is however more prone to biases due to instabilities when the dataset conforms as a panel. When the ratio between individuals (Provinces) and time is so small. In our case, time averages at province level could be used as proxies for Fixed effects and use a sample selection to avoid the limitations of propensity score matching and the bias of data imputation. Heckman (1974, 1978, 1979) represents the best alternative among the three. The first step is to build a probit model with the dummy variable indicating the missing observations as “s" as reported in equation (1).

$$s^*_{i,t} = z'_{i,t}\gamma + \varepsilon_{i,t}\ s^*_{i,t} = \{1,\ if\ y \neq NA\ 0,\ if\ y = NA\} \tag{1}$$

This exercise allows for the estimation of the inverse Mill’s ratio in the second phase, which would have been the spatial analysis in the context of a spatial regression model. This enables comprehension of the local cross-sectional dependence while incorporating the selection bias. The standard model of estimation would have been according to equation (2).

$$y^*_{i,t} = \lambda W y^*_{i,t} + x'_{i,t}\beta + \varepsilon_{i,t} \tag{2}$$

In this case, the expectations surrounding the socioeconomic drivers of waste incorporate the limits of collecting policies. The statistical expectations will therefore be structured as explained in Equation (3). The value δ indicates the marginal effect of missing information and represents the inverse Mills’ ratio. The spatial model in equation two is characterized by the impacts β of socioeconomic drivers collected in matrix X. The idiosyncratic process is here defined as $\varepsilon_{i,t}$ distributed along a i.i.d. The spatial lag is presented by $\lambda W y^*_{i,t}$, where the term λ incorporates spatial dependence. The value of its estimates varies from −1 to 1, which are the extreme cases of spatial dependency.

$$E\left(y^*_{i,t}\middle| x'_{i,t}, s^*_{i,t} = 1\right) = x'_{i,t}\widehat{\beta} + \widehat{\rho}\widehat{\sigma}_\varepsilon\widehat{\delta}\left(z'_{i,t}\gamma\right) \tag{3}$$

To assess the impact of the selection bias, three models will be estimated: two regarding the sample selection and the spatial autoregressive model in equation two without the correction. The method of estimation will not differ substantially. Both processes consist of a maximum likelihood method. However, the selection model implements a two-step estimator called limited information maximum likelihood. The spatial panel estimation uses a non-restricted version. Therefore, the inappropriate use of Heckman’s correction would yield inconsistent estimates.

Environmental and economic indicators are affected by skewness. In other words, they do not behave normally by nature. This could potentially yield inconsistent estimates. One of the main ways to mitigate this problem was to use logarithmic transformation (Ichinose et al., 2015; Mazzanti et al., 2008). Such an approach relies on the assumption that the estimates will be interpreted similarly. It has been noted that it can be interpreted as non-linear elasticity (Mazzarano et al., 2021). In this case, a revised estimator of the Heckman model is used, which is especially calibrated for skewed data (Ogundimu and Hutton, 2016). The software R provides a package for the estimation.[3]

5. Results

The regression exercise involved three estimations. The first model (1) represents a spatial panel model with the Heckman correction. The

[3] https://github.com/fsbmat-ufv/ssmodels/.

purpose of this estimation is to have a benchmark to compare the impact of selection bias. According to the report in Table 3, spatial interaction is captured from the spatial lag. Furthermore, Economic activity is statistically significant, and the signs present a typical inverted U form. The marginal effect of GDP per Capita (in thousands of euros) is equal to 11.543. According to this value, Organic waste is expected to grow of around 11 Kg each thousand of euros increment. However, it should be noted that for the same increment, there is a reduction of −0.146. The tipping point would therefore occur theoretically around 39,530 euros and it is statistically significant. This value is significantly above the 75th percentile of economic activity in Italian provinces. Touristic pressure is significant and decreases waste production with a marginal effect of −0.665. Density is, on the other hand, statistically insignificant along with Urbanization, Employment and Social Capital. WFD and CL introduction breaks are both positive as well as significant. The estimated Mills ratio effect is statistically significant around 14.691. The R squared amounted to 80.2%. The model presents an overall statistically significant according to the F test.

The second model represents the first step of the Heckman model. Economic activity designates the main driver. The probability to account organic waste is driven by all indicators collected. Among the major drivers, it is possible to find employment and economic activity. Furthermore, the assumption of homoscedasticity and no error autocorrelation are violated according to the Breusch-Pagan and Breusch-Godfrey tests. Clustered robust standard errors are therefore applied.

The spatial panel model (3) was estimated to control the role of the effect of surrounding provinces in an unbiased way. The Heckman model might be biased in dealing with spatial autocorrelation. However, the estimates of the third model support the evidence of spatial autocorrelation presented by the sample bias model. The values do not vary drastically from the first estimation. However, it appears that the uncorrected marginal effect of economic activity is lower in one unit, equal to 10.653 kg for each 1000 euros. Furthermore, the model presents similar characteristics in terms of statistical significance: density, urbanization, employment, and social capital are statistically insignificant. Tourism intensity yielded a slightly lower marginal effect of −0.570. The downward “drift” was estimated to be −0.131, to be very similar to the Heckman model. The tipping point would emerge around 40,700. It is higher than the one expected by the Heckman model within a standard deviation of economic activity; still it is biased. The OLS panel data was estimated to give a benchmark level over the other two corrections. Accounting for the sample selection bias increases significantly the R squared. In both cases then, most provinces would be far away from the absolute decoupling of organic waste.

Table 3
Estimation table.

	Dependent variable: Separated Organic Waste			
	Heckman	*probit*	*coefficient*	*panel*
	selection		*test*	*linear*
	(1)	(2)	(3)	(4)
Spatial Lag	0.284***		0.177***	
	(0.033)		(0.024)	
I(GDP_CAP/1000)	11.543***	0.089***	10.653***	11.253***
	(0.834)	(0.020)	(0.689)	(0.702)
I((GDP_CAP/1000)2)	−0.146***		−0.131***	−0.140***
	(0.015)		(0.012)	(0.013)
I(Turism/population)	−0.665***	0.108*	−0.570***	−0.459**
	(0.211)	(0.056)	(0.203)	(0.207)
Density	0.0002	0.001*	−0.001	−0.001
	(0.003)	(0.0003)	(0.003)	(0.003)
Urbanization	0.208	−0.189**	−0.176	0.170
	(1.368)	(0.084)	(1.257)	(1.281)
employment	−13.766	4.522***	−16.981	−20.400*
	(11.277)	(1.155)	(10.773)	(10.979)
Trust	2.654	−0.896*	−6.751	4.711
	(6.751)	(0.455)	(4.624)	(6.394)
WFD	23.302***	1.548***	27.009***	34.876***
	(2.555)	(0.274)	(1.838)	(1.873)
SDG_Adoption	17.437***	−0.420	20.197***	25.091***
	(2.736)	(0.376)	(2.500)	(2.547)
Constant	−151.057***	−4.268***	−131.961***	−133.544***
	(12.281)	(0.444)	(9.049)	(9.222)
Observations	2060	2060	2060	2060
R^2	0.802	0.470ⱡ	0.441	0.507
Adjusted R^2	0.800			0.505
Log Likelihood		−292.366		
rho	0.390			
Inverse Mills Ratio	14.691**			
	(6.503)			
F Statistic	555.7***			263.782***
chi^2		520.294***		
Tipping Point	39530***		40700***	40300***
	(532.390)		(527.566)	(499.964)

Note: *p < 0.1; **p < 0.05; ***p < 0.01; ⱡ McKelvey & Zavoina's Pseudo R Squared.

6. Discussion

The model estimated follows previous exercises in the cited literature. The main socioeconomic drivers accounted for being economic activity, touristic pressure, density, and policy breaks. According to the standard errors, socioeconomic drivers were highly significant in regressing the waste flow, however not significant in organic separation. There is a significant difference in predicting power between the Heckman model and the spatial panel estimation in terms of estimation. Furthermore, estimated values often diverge. The inverse mill's ratio was statistically significant, indicating that the selection bias was statistically relevant for the estimation.

The results corroborate the Environmental Kuznets Curve Hypothesis for organic waste. The estimates' signs were different and drew an inverted “U" to describe the relationship between economic activity and organic waste. According to our estimates, a selection bias exists if not accounting for provinces that lag in separation policies. The difference in estimates changes the expected tipping point: estimated tipping point distances 1170 euros of distance. The correct tipping point lies within the observed distribution.

The sign of a positive effect from the Inverse Mills ratio indicates that there exists an implicit food waste flow that is not actively collected before a certain amount of Kg per person. Provinces start separating waste flow only after reaching a threshold point, due to cost efficiency. In terms of impact, tourism intensity could be a drive to postpone separation policies in lower development areas. The Probit model corroborates this assertion by presenting a weak statistical significance of the effect of tourism on the probability to enforce organic separation policies. This is potentially due to the costs impending to operations in such areas where economies of scale are difficult to achieve. Therefore, organic waste is relatively more difficult and costly to separate, even for its scarcity. In high developed provinces, tourism accounts for improved funding and relatively better economies of scale to deal with organic waste. Thus, the negative signs accounts for a reduction of separated waste in rich and tourism intensive areas. These variables have effects of different magnitudes. It is possible to compare the effects according to the standard deviation of variables in such a manner $\beta(SD) = \beta\frac{SD(X)}{SD(Y)}$. The estimated magnitudes tell the percentage of dependent variable explained by the independent variable effect. A standard deviation in economic activity explains the 246% of organic waste standard deviation. The effects of the Inverse Mills Ratio and Tourism intensity were respectively 5.2% and −5.5%. The former exerts its effect only on low economic development areas. The magnitudes of effect of the two are marginal compared to the economic one. Given the comparability of the effects, the coincidence of low development and high tourism might coincide with a low propensity to collect organic waste. This could potentially mean that tourism in such areas might be a driver of policy inefficiency even when it provides funds for municipalities, as it is still not enough to compensate separation costs.

Delaying implementation of waste policies has been estimated to increase divergence across regions, increasing future implementation costs (Mazzanti et al., 2008; Mazzanti and Zoboli, 2009).

The inverse mills' ratio represents the minimal expected amount of waste collected if separation policies are enforced. Waste policies tended to reduce the unseparated waste flows; thus, it is coherent that they positively affect organic waste generation. Population density is a proxy to differentiate highly populated areas against sparsely populated. According to the estimates, there is evidence to distance the second from the first in food waste. Touristic pressure does not drive the amount of collected food waste. This result partially contradicts previous studies that linked municipal solid waste with tourism (Arbulú et al., 2015; Lebersorger and Beigl, 2011; Oribe-Garcia et al., 2015). This result indicates that organic waste at provincial level cannot be linked to touristic activities. In other words, it is not imported via visitors. However, low development areas might be locked in a condition where current waste separation cannot be increased. In turn, postponing waste separation will increase future costs to decouple organic waste from economic activity.

The results around the tipping point indicate that there is an evident divergence in potential performances of waste separation and waste reduction according to economic activity. This limit indicates that current policies are insufficient to prevent the issue. This potentially has repercussions to the objective of organic and especially food waste prevention.

7. Conclusion

The reduction of organic waste can trickle down several positive effects for both society and the geosphere. The improvement of behavioral drivers could foster new markets and reduce costs for municipalities and citizens themselves. Policies defined by the European Union and carried out at the local level were intended to reduce total waste and increase separation. When accounting for organic waste reduction objectives, it is necessary to incorporate the enforcement of waste separation in the policy analysis.

The paper presented an analysis regarding the decoupling state of economic activity from organic waste reduction. A familiar framework to the literature of EKC has been established to assess the relationship between socioeconomic drivers. The target variable can be considered as a proxy for food waste as well. Dataset involved Italian provinces from 1999 to 2019 from ISPRA. To the best of our knowledge, it is one of the broadest available. The methodology involved two econometric exercises. One is the spatial autoregressive model, while the other adjusted the Heckman model with a spatial lag. The results corroborate the existence of the decoupling process along with spatial dependence of spatial. There is evidence that organic waste has no relation with touristic activity, despite the outlined studies by literature for total waste. According to the results, there is evidence of selection bias when missing observations are not accounted for. In the context of waste decoupling, the effect influences the tipping point: it is more distant when complete information is considered. We commented on this outcome as a hidden cost of delaying separation policies in the context of waste management.

While this evidence opens a new perspective over the completeness of waste management and waste prevention, it gives additional importance to missing values in environmental accounting. In this case, it was evidence of heterogeneity in environmental performance. Furthermore, our study involved the topic of simply organic waste. A similar key issue comprehends plastic pollution and its prevention. The effective separation policy is emerging globally, and in Europe, great advancements have been made (European Commission, 2015; European Parliament and Council, 2008; Hahladakis et al., 2018). Therefore, future studies could also extend this approach to other waste flows. This study corroborates previous work's evidence of spatial interaction among local waste flows (Ichinose et al., 2015; Mazzanti et al., 2012; Mazzarano et al., 2021). While our extension proved to have a solid predictive capability, the selection model was ineffective. Other drivers probably trigger separation policies: this represents a potential gap in the literature with possible repercussions to the waste management research field.

CRediT authorship contribution statement

Massimiliano Mazzanti: Conceptualization, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Matteo Mazzarano:** Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Emy Zecca:** Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

Declaration of competing interest

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

Acknowledgments

The work could not have been possible without the effort of ISPRA and its databases. We are thankful for the disclosure of data regarding food waste in Italy and its composition.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.131266.

References

Agovino, M., Cerciello, M., Gatto, A., 2018a. Policy efficiency in the field of food sustainability. The adjusted food agriculture and nutrition index. J. Environ. Manag. 218, 220–233. https://doi.org/10.1016/j.jenvman.2018.04.058.
Agovino, M., D'Uva, M., Garofalo, A., Marchesano, K., 2018b. Waste management performance in Italian provinces: efficiency and spatial effects of local governments and citizen action. Ecol. Indicat. 89 (June 2017), 680–695. https://doi.org/10.1016/j.ecolind.2018.02.045.
Andini, C., Andini, M., 2019. Social capital and growth: causal evidence from Italian municipalities. J. Econ. Geogr. 19 (3), 619–623. https://doi.org/10.1093/jeg/lby024.
Arbulú, I., Lozano, J., Rey-Maquieira, J., 2015. Tourism and solid waste generation in Europe: a panel data assessment of the Environmental Kuznets Curve. Waste Manag. 46, 628–636. https://doi.org/10.1016/j.wasman.2015.04.014.
Beigl, P., Lebersorger, S., Salhofer, S., 2008. Modeling municipal waste generation: areview. Waste Manag. 28 (1), 200–214.
Boulila, G., Bousrih, L., Trabelsi, M., 2008. Social capital and economic growth: empirical investigations on the transmission channels. Int. Econ. J. 22 (3), 399–417. https://doi.org/10.1080/10168730802287994.
Calcagnini, G., Perugini, F., 2018. Social capital and well-being in the Italian provinces. Soc. Econ. Plann. Sci. 1–10. https://doi.org/10.1016/j.seps.2018.11.005. *November*.
Cole, M.A., Rayner, A.J., Bates, J.M., 1997. The EnvironmentalKuznets Curve : an empirical analysis. Environ. Dev. Econ. 2, 401–416.
Commission of the European Communities, 2008. The Raw Materials Initiative : Meeting Our Critical Needs for Growth and Jobs in Europe. No. 699.
Crociata, A., Agovino, M., Sacco, P.L., 2016. Neighborhood effects and pro-environmental behavior: the case of Italian separate waste collection. J. Clean. Prod. 135, 80–89. https://doi.org/10.1016/j.jclepro.2016.06.083.
Cucchiella, F., D'Adamo, I., Gastaldi, M., 2012. Municipal waste management and energy recovery in an Italian region. Waste Manag. Res. 30 (12), 1290–1298.
Cucchiella, F., D'Adamo, I., Gastaldi, M., 2014. Strategic municipal solid waste management: a quantitative model for Italian regions. Energy Convers. Manag. 77, 709–720.
Diaz-Ruiz, R., Costa-Font, M., López-i-Gelats, F., Gil, J.M., 2019. Food waste prevention along the food supply chain: a multi-actor approach to identify effective solutions.

Resour. Conserv. Recycl. 149, 249–260. https://doi.org/10.1016/j.resconrec.2019.05.031.
Dinda, S., 2004. Environmental Kuznets curve hypothesis: a survey. Ecol. Econ. 49, 431–455.
Ellen MacArthur Foundation, 2021. Universal Circular Economy Policy Goals.
Ercolano, S., Lucio Gaeta, G.L., Ghinoi, S., Silvestri, F., 2018. Kuznets curve in municipal solid waste production: an empirical analysis based on municipal-level panel data from the Lombardy region (Italy). Ecol. Indicat. 93, 397–403. https://doi.org/10.1016/j.ecolind.2018.05.021.
European Commission, 2015. Closing the Loop - an EU Action Plan for the Circular Economy - (ANNEX 1). Communication from the Commission to the European Parliament, the Council, the Europena Economic and Social Committee and the Committee of the Regions.
European Parliament and Council, 2008. Waste Framework Directive. Official Journal of the European Union.
Fox, T., Fimeche, C., 2013. Global Food: Waste Not, Want Not. institution of mechanical engineers.
Hahladakis, J.N., Purnell, P., Iacovidou, E., Velis, C.A., Atseyinku, M., 2018. Post-consumer plastic packaging waste in England: assessing the yield of multiple collection-recycling schemes. Waste Manag. 75, 149–159. https://doi.org/10.1016/j.wasman.2018.02.009.
Heckman, J., 1974. Shadow prices, market wages, and labor supply. Econometrica 42 (4), 679. https://doi.org/10.2307/1913937.
Heckman, J., 1978. Dummy endogenous variables in a simultaneous equation system. Econometrica 46 (4), 931. https://doi.org/10.2307/1909757.
Heckman, J., 1979. Sample selection bias as a specification error. Econometrica 47 (1), 153. https://doi.org/10.2307/1912352.
Ichinose, D., Yamamoto, M., Yoshida, Y., 2015. The decoupling of affluence and waste discharge under spatial correlation: do richer communities discharge more waste? Environ. Dev. Econ. 20 (2), 161–184. https://doi.org/10.1017/S1355770X14000370.
Knack, S., Keefer, P., 1997. Does social capital have an economic payoff? A cross-country investigation. Q. J. Econ. 112 (4), 1251–1288. http://www.jstor.org/stable/2951271.
Lebersorger, S., Beigl, P., 2011. Municipal solid waste generation in municipalities: quantifying impacts of household structure, commercial waste and domestic fuel. Waste Manag. 31 (9), 1907–1915. https://doi.org/10.1016/j.wasman.2011.05.016.
Managi, S., Kumar, P., 2018. Inclusive Wealth Report 2018, first ed. Routledge. https://doi.org/10.4324/9781351002080.
Mazzanti, M., Montini, A., 2013. Waste management beyond the Italian north-south divide: spatial analyses of geographical, economic and institutional dimensions. In: *Handbook On Waste Management* (Issue 47 Final, pp. 256–284. https://doi.org/10.4337/9780857936868.00017.
Mazzanti, M., Montini, A., Nicolli, F., 2012. Waste dynamics in economic and policy transitions: decoupling, convergence and spatial effects. J. Environ. Plann. Manag. 55 (5), 563–581. https://doi.org/10.1080/09640568.2011.616582.
Mazzanti, M., Montini, A., Zoboli, R., 2008. Municipal waste generation and socioeconomic drivers. J. Environ. Dev. 17 (1), 51–69. https://doi.org/10.1177/1070496507312575.
Mazzanti, M., Montini, A., Zoboli, R., 2009. Municipal waste generation and the EKC hypothesis new evidence exploiting province-based panel data. Appl. Econ. Lett. 16 (7), 719–725. https://doi.org/10.1080/13504850701221824.
Mazzanti, M., Nicolli, F., 2011. Waste dynamics, decoupling and ex post policy effectiveness: evidence from the EU15. Int. J. Global Environ. Issues 11 (1), 61–78. https://doi.org/10.1504/IJGENVI.2011.040252.
Mazzanti, M., Zoboli, R., 2009. Municipal waste Kuznets curves: evidence on socioeconomic drivers and policy effectiveness from the EU. Environ. Resour. Econ. 44 (2), 203–230. https://doi.org/10.1007/s10640-009-9280-x.
Mazzarano, M., De Jaeger, S., Rousseau, S., 2021. Non-constant income elasticities of waste generation. J. Clean. Prod. 126611. https://doi.org/10.1016/j.jclepro.2021.126611.
Melikoglu, M., Lin, C., Webb, C., 2013. Analysing global food waste problem: pinpointing the facts and estimating the energy content. Open Eng. 3 (2) https://doi.org/10.2478/s13531-012-0058-5.
Morone, P., Morone, A., Morone, M., Falcone, P.M., Imbert, E., 2016. New consumers behaviours in the sharing economy: an experimental analysis on food waste reduction. https://doi.org/10.13140/RG.2.2.14666.57281.
Mosconi, E.M., Colantoni, A., Gambella, F., Cudlinová, E., Salvati, L., Rodrigo-Comino, J., 2020. Revisiting the environmental Kuznets curve: the spatial interaction between economy and territory. Economies 8, 74.
Muringani, J., Fitjar, R.D., Rodríguez-Pose, A., 2021. Social capital and economic growth in the regions of Europe. Environ. Plann.: Econ. Space 53 (6), 1412–1434. https://doi.org/10.1177/0308518X211000059.
Nannicini, T., Stella, A., Tabellini, G., Troiano, U., 2013. Social capital and political accountability. Am. Econ. J. Econ. Pol. 5 (2), 222–250. https://doi.org/10.1257/pol.5.2.222.
Ogundimu, E.O., Hutton, J.L., 2016. A sample selection model with skew-normal distribution. Scand. J. Stat. 43 (1), 172–190. https://doi.org/10.1111/sjos.12171.
Oribe-Garcia, I., Kamara-Esteban, O., Martin, C., Macarulla-Arenaza, A.M., Alonso-Vicario, A., 2015. Identification of influencing municipal characteristics regarding household waste generation and their forecasting ability in Biscay. Waste Manag. 39, 26–34. https://doi.org/10.1016/j.wasman.2015.02.017.
Parizeau, K., von Massow, M., Martin, R., 2015. Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph, Ontario. Waste Manag. 35, 207e217.
Porter, S.D., Reay, D.S., Higgins, P., Bomberg, E., 2016. A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. Sci. Total Environ. 571, 721–729. https://doi.org/10.1016/j.scitotenv.2016.07.041.
Quested, T.E., Marsh, E., Stunell, D., Parry, A.D., 2013. Spaghetti soup: the complex world of food waste behaviours. Resour. Conserv. Recycl. 79, 43–51. https://doi.org/10.1016/j.resconrec.2013.04.011.
Quested, T., Parry, A., 2011. New Estimates for Household Food and Drink Waste in the UK. Waste & Resources Action Programme (WRAP), Oxon.
Secondi, L., Principato, L., Laureti, T., 2015. Household food waste behaviour in EU-27 countries: a multilevel analysis. Food Pol. 56, 25–40. https://doi.org/10.1016/j.foodpol.2015.07.007.
Setti, M., Falasconi, L., Segrè, A., Cusano, I., Vittuari, M., 2016. Italian consumers' income and food waste behavior. Br. Food J. 118 (7), 1731–1746. https://doi.org/10.1108/BFJ-11-2015-0427.
Stern, D.I., 2004. The rise and fall of the environmental Kuznets curve. World Dev. 32 (8), 1419–1439. https://doi.org/10.1016/j.worlddev.2004.03.004.
Wilts, H., Bahn-Walkowiak, B., Hoogeveen, Y., 2018. Waste prevention in Europe — policies, status and trends in reuse in 2017. https://doi.org/10.2800/15583.
Zoboli, R., Paleari, S., Marin, G., Mazzanti, M., Nicolli, F., Montini, A., Miceli, V., Speck, S., 2014. Resource-efficient green economy and EU policies. https://doi.org/10.2800/18514.