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Waste generation, waste disposal and policy effectiveness Evidence on decoupling from the European Union

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ABSTRACT

Waste generation and waste disposal are issues that are becoming increasingly prominent in the environmental arena both from a policy perspective and in the context of delinking analysis. Waste generation is still increasing proportionally with income, and economic and environmental costs associated to landfilling are also increasing. Thus, the need of accelerating the eventual delinking process by the introduction of policies at all stages of waste production and disposal.

This paper provides a comprehensive analysis of waste generation, incineration, recycling and landfill dynamics based on panel data for the EU25, to assess the effects of different drivers (economic, structural, policies) and the eventual heterogeneity on such evidence between western and eastern EU countries.

We show that for waste generation there is still no absolute delinking trend, although elasticity to income drivers appears lower than in the past. Landfill and other policy effects do not seem to provide backward incentives for waste prevention. Regarding landfill and incineration, the two trends, as expected, are respectively decreasing and increasing, with policy effects providing a strong driver. It demonstrates the effectiveness of policy even in this early stage of policy implementation. This is essential for an ex post evaluation of existing landfill and incineration directives. Nevertheless, it signals the risk of widening gaps between early adopters and countries which postpone ratification and implementation.

It is also worth noting that EU15 and EU10 groups of countries show some different waste trends and driving forces of waste generation and landfill diversion hen analysed separately. We may conclude that although complete delinking is far from being achieved – especially for waste generation, there are some positive signals, and signs of a quite significant role of the EU waste policies implemented in the late 1990s and early 2000s.

1. Introduction

Indicators of 'decoupling' are becoming increasingly popular for detecting and measuring improvements in environmental/resource efficiency with respect to economic activity. The Organisation for Economic Cooperation and Development (OECD, 2002) has conducted extensive research into use of decoupling indicators for reporting and policy-evaluation purposes and the European Environment Agency's state-of-the-environment reports (EEA, 2003a,b,c) use a number of decoupling or resource-efficiency indicators. The EU policy 'thematic strategies' on resources and waste include reference to 'absolute' and 'relative' delinking indicators (Jacobsen et al., 2004).

The European Union (EU) policy 'thematic strategies' on both resources and waste, entail reference to 'absolute' and 'relative' delinking indicators (European Commission, 2003; Jacobsen et al., 2004). The former being a negative relationship between economic growth and environmental impacts associated to an inverted U shape according to the well known environmental Kuznets curves framework, the latter a positive but decreasing, in size, association. A positive lower than unity elasticity in economic terms. No delinking is observed when we are on the ascending part of the EKC with, in addition, a unitary or higher than unity elasticity. The EKC framework which is here not specifically taken in consideration, if not as a general reference. The Kuznets idea is actually embedded within the more general issue of 'delinking' analysis, with an attention on the multiple drivers of delinking.

The achievement of increasing delinking experiences is of primary necessity in the waste realm (Fig. 1). As recognised by the EEA "It is increasingly important to provide answers to these questions because waste volumes in the EU are growing, driven by changing

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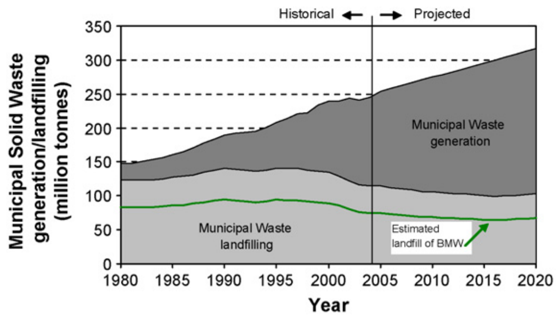

Fig. 1. Projected generation and landfilling of municipal waste in the EU-25. *Source*: ETC/RWM (2007), figures from 1980 to 2004 are data from Eurostat. Figures from 2005 to 2020 are projections.

production and consumption patterns. It is also important because there is a growing interest in sharing best practice and exchanging national-level experience across Europe, with the common goal of achieving more cost-effective solutions to the various problems being faced" (EEA, 2007, p. 4).

The EEA shows that countries can be categorised under three waste management 'groupings', according to the strategies for diversion of municipal waste away from landfill and the relative shares of landfilling, material recovery (mainly recycling and composting) and incineration. The first grouping comprises countries which maintain high levels of both material recovery and incineration, and which have relatively low landfill levels. The second grouping brings together countries with high material recovery rates and medium incineration levels and where there is a medium dependence on landfill. The third grouping contains those countries whose material recovery and incineration levels are both low and whose dependence on landfill is relatively high (EEA, 2007, p. 3).

Regarding the EU, we note that landfilling is still the predominant treatment option for the EU's municipal waste, and Italy is a country under pressure and constant monitoring and evaluation of performances. In 2004, about 45 percent of the total municipal waste was landfilled while 18% was incinerated. However, there are significant differences in how dependent countries are on landfilling (EEA, 2007, p.8). Fig. 2 clearly shows that several countries – the Netherlands, Denmark, Sweden and Belgium – have already arrived at very low landfilling rates. Those countries not only have a substantial level of incineration; they also have a high level of material recovery. In general, there seems to be two strategies for diverting municipal waste from landfill: to aim for high material recovery combined with incineration, or to aim for material recovery which includes recycling, composting and mechanical biological treatment (EEA, 2007).

The environmental/sanitary impacts, disamenity costs and economic costs of landfilling are massive (Pearce, 2004; El-Fadel et al., 1997; Garrod and Willis, 1998; DEFRA, 2005). It is worth noting that waste generation reduction at source, achievable by imposing policy targets in terms of waste generated per capita, is probably the most effective and efficient way of handling the problem in the long run. Given its potential high cost in the short run, the first phase of policy implementing at EU level has focused on landfill diversion and recycling/recovery increasing shares, thus including incineration. There is a need to empirically analyse in a multivariate framework whether such policies have been effective so far in changing the endogenous relationship between economic growth and waste trends. In other words, given that waste policies are motivated by the various negative externalities arising at different stages of the filieres (at source, at disposal level), as CBA should inform ex ante which option to pursue and what tax level to impose, ex post effectiveness analysis has the aim of assessing short run and long run effects of policies on the main target: driving down the eventual bell shape curve. In absence of such policies, we may expect a somewhat linear positive relationship between waste generation and growth, and landfill diversion would be affected only by market prices and opportunity cost (of land). A qualitative assessment of landfill and incineration policy tools at EU and country level is provided by EEA (2007).

This paper provides empirical evidence on delinking trends for municipal solid waste (MSW) at the EU25 level, with additional insights on the differences between EU15 and EU10.[1] The background and motivation is primarily the total lack of robust and updated empirical evidence, for a vast regional area like EU, regarding economic and policy drivers for waste dynamics. Main EU waste policies have not been empirically scrutinised, if not by qualitative methods.

Empirical evidence for waste is still scarce. Research on delinking for materials and waste is far less developed than research into air pollution and greenhouse gas emissions. Although some recent work, particularly by the Wuppertal Institute (Bringezu et al., 2003), has produced extensive evidence on material intensity indicators, the still limited research results for the waste sector could be a serious problem from a policy perspective. Secondly, analyses that exploit country-specific, highly disaggregated panel data on waste for cross-country studies are even scarcer. There are also very few single-country case studies using data at regional, provincial or municipal level in the literature. National and regional datasets for groups of homogenous countries may provide a better and more reliable basis for analysis and sound policy evaluation.

The empirical model we propose in this paper aims primarily to be consistent with the main objectives of the landfill directive,[2] that is, waste diversion from landfills, for both general and specific waste flows; and waste prevention. We provide a framework for the empirical analysis which we hope will become the basis of a general and widely used approach for such investigations. Our main objective is to provide new empirical evidence on relative and absolute delinking and policy effectiveness for a policy relevant region, such as the EU. A secondary objective is to identify differences between the EU15 group of countries and new entrants to the EU with respect to waste drivers, delinking trends and policy effects.

Section 2 presents recent evidence on relative and absolute delinking regarding waste trends, in order to highlight the urgent need to intensify research in this area to enable policy evaluation. Section 4 defines the conceptual framework and the empirical model; Section 5 discusses the original dataset used in this study and comments on the empirical results regarding waste generation, incineration, landfill and recycling options. Section 6 concludes.

2. Waste indicators and delinking analysis: recent empirical evidence

We refer to Cole et al. (1997), Dinda (2005), Stern (2004), Andreoni and Levinson (2001), Copeland and Taylor (2004), Brock and Taylor (2003), Brock and Taylor (2004), for major critical sur-

[1] We hereafter refer to EU15 for the group of western EU member countries, EU25 for the total group of EU countries after recent incoming members got in 2006, mainly eastern EU countries, which we define EU10 (e.g. Poland).

[2] In particular, with the aim to fulfil the targets provided by Directive 1999/31/EC on landfill of waste, Member States are obliged to set up national strategies for reducing the amount of biodegradable municipal waste going to landfill.

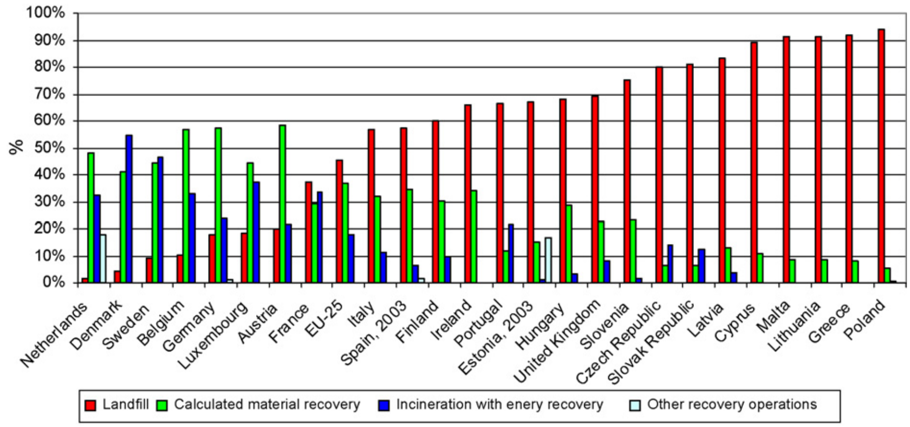

Fig. 2. Use of landfilling, incineration and material recovery as treatment options in 2004. *Source*: EEA (2007), Eurostat Structural Indicators on municipal waste generated, incinerated and landfilled, supplemented with national statistics.

veys and discussion on the theoretical underpinnings of delinking, which has so far analysed air and water emissions, mainly CO_2, with a limited focus on waste streams. A full critical survey of this very vast literature is outside the scope of this study.

We here briefly review the still scarce evidence on waste delinking and waste management and evaluation of policy tools. The main aim is to positioning our paper in the literature and suggest future, as yet unexplored, research directions. We group these works by geographical area of analysis and focus. We refer the reader to Mazzanti et al. (2008a) for a series of tables summarising main works on those issues In spite of the significant environmental, policy and economic relevance of waste issues, there is very little empirical evidence on delinking even for major waste streams, such as municipal and packaging and other waste. Analyses of policy effectiveness are also scarce. Studies of waste management optimization or evaluation of externalities largely prevail (Pearce, 2004).

Some macro-level evidence based on cross country regression analysis of data from the 1980s was presented in the international report (World Bank, 1992). More recent reports (DEFRA, 2003) highlight the positive elasticities of waste generation to income as a primary policy concern.

One of the earliest studies was by Cole et al. (1997), who found no evidence of an inverted U-shape in relation to municipal waste. They used data on municipal waste for the period 1975–1990, for 13 OECD countries; their findings revealed no TP, and environmental indicators (municipal waste generation) monotonically increasing with income over the observed range. Similarly, Seppala et al. (2001), in a study of five industrialised countries including Japan, the US and Germany and over almost the same period (1970–1994), also found no evidence of delinking regarding direct material flows. This would suggest that the evidence varies for waste generation and waste disposal. However, Fischer Kowalski and Amann (2001) analysed the richer OECD countries and found that the intensity of material input with respect to GDP shows relative, but not absolute delinking, with material growth over 1975–1995 for all countries. They note that absolute delinking holds for landfilled waste, but not for waste generated.

There is some emerging evidence in favour of delinking. Leigh (2004) presents evidence concerning a waste/consumption indicator derived from the environmental sustainability indexes (ESI). Berrens et al. (1998) and Wang et al. (1998) also find evidence in favour of a negative elasticity, focusing on US stocks of hazardous waste as an environmental impact indicator, and exploiting a county-based cross sectional dataset.

A recent study by Johnstone and Labonne (2004) is of interest; they use a panel database of solid waste in the OECD countries to provide evidence on the economic and demographic determinants of rates of household solid waste generation, regressed over consumption expenditure, urbanisation and population density. They find positive elasticities, but lower than 1, in the range 0.15–0.69. Few studies include waste policy analyses. The study by Karousakis (2006), which deals with policy evaluation, and presents evidence on the determinants of waste generation and the driving forces behind the proportions of paper/glass recycled, and the proportion of waste that goes to land-fill. The panel database is for 30 OECD countries (for 4 years between 1980 and 2000, 120 observations). MSW increases monotonically with income. Urbanisation exerts an even stronger effect on waste generation, while the time-invariant policy index is not significant.

For a group of European countries, Mazzanti and Zoboli (2005) found neither absolute nor relative delinking. Using European panel datasets they found no absolute delinking evidence for municipal waste or packaging waste respectively for 1995–2000 and 1997–2000. Estimated elasticities of waste generation with respect to household consumption were close to unity. Andersen et al. (2007) recently estimated waste trends for EU15 and EU10 new entrants, and, though departing from a different methodological standpoint, found that waste generation is linked to economic activities by non-constant trend ratios, which is in line with WKC reasoning around U and N shapes of income-environment relationship. This rather descriptive analysis of delinking in EU countries provides *forecasts* in favour of relative delinking as far as waste generation (collection) is concerned. It does not confirm full WKC evidence, at best relative delinking occurs and will occur given current technology, policy and firm's and consumer's behaviour towards waste production, management and collection. Projections for 2005–2020 for the UK, France and Italy, show a growth in MSW of around 15–20%, which, at least at first sight, may be compatible with relative delinking with respect to GDP and consumption growth.

This work has specific complementarities to our analysis since we offer econometric evidence of the 1995–2005 scenarios, finding, we anticipate, no current absolute delinking. On the EU average, only a minority of states may experience a stabilisation of waste production related to consumption growth. This diversity in behaviour and performances, driven by structural and policy levers, is an expected result, and emerges confirmed both in Andersen et al. (2007) and in our analysis. Nevertheless, at the level of EU policy, though some performance heterogeneity is intrinsic and policy heterogeneity (decentralisation) probably efficient (Pearce, 2004), the whole average figure is the main reference of effectiveness in the long run. The average figure signals some improvements in the elasticity of waste generation with respect to income compared to earlier studies, that nevertheless do not lead to an annual reduction of the main inputs of the waste filiere: waste generation. Our evidence, as we will discuss below, robustly confirms in a multivariate setting, that include various potential drivers of waste trends, what found in Andersen et al. (2007). Their focus on additional variables impacting positively on the amount for waste, such as the number of households, as potential drivers of future trends, is also coherent with our study of the possible many determinants of waste generation. As we will see, urbanisation and population density emerge positively related to waste production per capita.

Finally, a rare country level analysis worth mentioning, that uses within country regional data, is Mazzanti et al. (2008a), who find some absolute delinking evidence and signals of waste management instruments' effectiveness in driving waste generation reductions in Italy, where economic, policy and structural geographical differences are of primary interests in explaining trends. A complementary study analysing landfill diversion by exploiting the same Italian provincial and regional datasets is Mazzanti et al. (2008b), who highlight that landfill diversion is driven mainly by the environmental and opportunity costs linked to population density, by the share of provincial separated collection and by the use of economic-oriented instruments, like waste tariffs aimed at linking costs with household behaviour and at covering the full cost of the local waste services.

Focusing the lens to the main pillar of landfilling, with both environmental-related effects and policy emphasis, we note that economic analyses have predominantly focused on cost–benefit assessment of relative externalities. Works oriented towards waste management optimization or evaluation of externalities largely prevail, regarding mainly landfill and also other waste disposal strategies. The focus on cost benefit analyses and landfill siting decision has prevailed so far, partly due to the lack of reliable data at country level and within country level (Pearce, 2004).[3] Some studies have appeared in relation to the evaluation of Eu landfill Directive and the widely known experience of the UK landfill tax implementation dated back to 1996 (informed, rare case, by a specific evaluation of externalities). Such studies, given lack of data, present interesting but only qualitative assessments. During the first phase of the UK landfill tax implementation, Morris et al. (1998) offered insights on its potential and expected contribution to sustainable waste management, analysing its general structure, comparative landfill costs and the waste hierarchy. Morris and Read (2001) and Burnley (2001) consequently update the analysis highlighting some operational weaknesses and debating some preliminary reviews at that period. The latter author links the EU directive with national UK implementation. Another interesting assessment, quite pessimistic in its conclusion, is offered by Martin and Scott (2003), who stressed that tax has failed to significantly change the behavior of domestic waste producers. The landfill tax is intended to contribute to a transition away from landfilling of waste, towards recovery, recycling, re-use and waste minimization. They affirm that available evidence finds that there is reasonable data to monitor progress towards recycling, but not for re-use or waste minimization.

Among other more recent works, we refer the reader to Davies and Doble (2004), who survey the UK landfill tax from its introduction, offering insights on future evolutions, criticalities, and externality evaluation. Such works were by definition of qualitative nature given the lack of data and the aims of specific analyses.

Very recently, a UK specific regional assessment on waste strategies is offered by Phillips et al. (2007). Regional based analyses are nevertheless a rarity, if any.

Outside UK, analyses are rare. Taseli (2007) recently presented an assessment of EU landfill directive on Turkey, a potential incoming country that may be compared to some eastern Eu newcomers. The study highlights the great difficulties of such countries in achieving the targets even in the long run, and shows a clear analysis of the EU framework. Though the analysis extensively uses data in support of arguments, statistical investigation is not the aim and a possibility. What lacks so far is a comprehensive analysis at EU level at 7 years from the landfill Directive first appearance. A main recent report study is by IVM (2005) on landfill tax effectiveness.

The literature on waste determinants and WKC for waste, referred to above, underlines that waste indicators generally tend to increase with income or other economic drivers, such as population, and, in general, an inverted U-shape curve is not in line with the data. A decreasing trend (negative elasticity) may be found in industrialised countries where waste management and policies are more developed. Nevertheless, the risk is that bell shapes (absolute delinking) are associated with a few rich countries or areas and can divide countries in terms of waste performance indicators. There could be multiple underpinnings of such evidence. Some authors have suggested that for stock pollution externalities, for example, waste to a great extent, the pollution income relationship difficulty turns into a bell shaped curve, with pollution stocks monotonically rising with income (Lieb, 2004). Another structural motivation concerning the lack of evidence on waste may be that the change in sign for the income elasticity of the environment/income function should occur at relatively lower income levels for pollutants whose production and consumption can be easily spatially separated, for example, by exporting associated pollution or by relocating activities. This will likely be more difficult for waste flows, especially biodegradable waste.

The survey of the literature shows a lack of in-depth investigation of driving forces and policy effects, taking as case study a single country or a homogenous policy relevant over a sufficiently long period of time. We aim at bringing together different pieces of the puzzle: delinking analyses with policy effectiveness studies and an extensive evaluation of waste drivers.

3. The empirical framework: from waste generation to waste disposal

The empirical models we use for studying waste generation, incineration, landfilling and recycling trends and their drivers are coherent with most multivariate analysis of delinking drivers. All variables are specified in logarithmic form using per capita values, to provide elasticity values and to smooth the data. Except where it is not feasible, logarithmic transformations are used for all covariates. We below present and discuss the models and the main hypotheses regarding potential drivers for each of the four level of investigation in the waste filiere, from waste generation to landfilling.

[3] We quote among the others Powell and Brisson (1995), Miranda et al. (2000), Eshet et al. (2004), Brisson and Pearce (1995) and Dijkgraaf and Vollebergh (2004). Recently, Caplan et al. (2007) offered an example of how economic evaluation techniques may inform landfill siting process. Instead, Jenkins et al. (2004) present a sound and very interesting econometric analyses on the socio economic factors that explain the level of monetary compensation paid to landfill host communities.

3.1. Waste generation

This level of analysis provides direct evidence regarding the usual delinking hypothesis in terms of the waste generation–income relationship. Waste generation reduction (that is, 'waste prevention') is the ultimate objective of any social policy targeted towards waste flows, though explicit policy actions do not exist (targets in terms of waste generated per capita), besides some rare countries. Though waste prevention is at the top of the EU waste hierarchy, no action oriented towards waste prevention has been included in formal Directives so far. Waste management (separated collection) and landfill diversion policies have prevailed if not dominated the field, probably given the presumed relative lower implementation and compliance costs.

Let analyse the various research hypotheses we may formulate at this level of reasoning. Regarding economic drivers, a proper Kuznets-like/delinking oriented structure of the model allows the estimation of an eventual turning points (TP) of the bell shape for waste generation. This is generally not observed if not, as noted, in some recent studies and for some richer areas within a specific country. The TP provides a hint about the GDP/consumption level beyond which the relationship, in this case between waste production and income, turns negative. Econometric and descriptive empirical evidence have always shown that at best relative delinking, if any, is observed. We aim at providing updated new evidence through official data for the EU.

Secondly, we here test various hypotheses on possible effects exerted by socio-economic and structural variables. Waste generation/collection is eventually affected by a diverse set of factors. We always refer the reader to Table 3.

First, population density (or urban population)[4] is likely to positively impact on waste generation. Only economies of scale spurred by urbanisation could invert the trend and reduce collection where density is higher.

Household related features may matter at such a level. In fact, we expect that the larger the size of households, the less is waste generated per capita. Nevertheless, even a positive link could be plausible in case collection schemes and waste management at home level (composting) is poorly developed on average. Accordingly, more single households should drive waste generation up.

We also use as control variable an age index. From a socio-economic point of view, we believe any outcome could be possible. Opposite forces may play a role: on the one hand older people may produce less waste than younger ones, but it is also true that older people may be less accustomed and committed to collection and recycling of waste. Nevertheless, we may add that the opportunities cost of time is lower for older people, and waste collection actions require time. The sign of the relationship is then highly unpredictable. The interaction with data on education levels would be interesting, but this is matter for micro-based studies. The aforementioned factors are also probably more robustly tested at that level of analyses. We here use them given their availability, as controls and tools for mitigating problems of omission of relevant variables. Some of these socio economic variables capture more than one of the structural/institutional elements characterising a country.

Third, we include in our analysis two types of 'policy proxies'. The first is related to the European Landfill and Incinerations Directives and their effective implementation in the member states. These proxies are built as dummy variables that take the value 1 in a given year between 1995 and 2005 if the country has transposed these directives into national law. We expect that implementation correlates positively with delinking performances.

The second group of policy indices is more country specific.

We first exploit a 'decentralised waste management index' that reflects the degree of waste policy decentralisation across countries.[5] Decentralisation may be beneficial to waste performances though higher flexibility and specificity in policy implementation, that may account for local idiosyncratic costs and benefits elements related to waste policies (Pearce, 2004).[6] Though decentralisation may thus improve the efficiency of policy implementation in the EU, it may also lead to drawbacks in case factors related to local rents exploitation by public and private agents emerge. Rents are neither good nor bad in principle in environmental realms. It depends on their effects on both static and dynamic elements like value creation and innovation. Waste 'markets' like landfilling and even recycling may be associated to rents that could lock in a local system in less than optimal equilibrium (Mazzanti and Zoboli, 2006). This open hypothesis calls for further research in the future.

Finally, an environmental policy index is considered. This last is a proxy for national policies over the time period examined. It captures all possible information regarding national implementation of waste related policies (MSW, biodegradable solid waste, packaging waste, end of life vehicles, other), even independently of the Landfill Directive. We used the country studies available on EIONET[7] as our information source. This index is both extremely comprehensive with regard to landfill directive related variables,[8] and also may capture some of the waste prevention features of national policies.[9] It is noteworthy that, besides the decentralised policy index, all other proxies vary across countries and over time.

The importance of introducing policy proxies is crucial in the waste arena, and a main contribution of our work. Their role is very relevant because many European policies were enacted quite recently, and their inclusion in a WKC framework could be a sort of ex-post effectiveness evaluation. Both structural indicators and policy variables may be important drivers of WKC shapes; their omission could overestimate the 'pure' economic effect.

[4] Those two variables are used alternatively, given their high correlation.

[5] This discrete index variable captures the extent to which a country is decentralised in (waste) policies, and more in general, is structured as a federal state. Actually, 4 countries are associated to value one: Italy, Germany, Austria, Spain (main federal states), two have value 0.5 (UK and Belgium), all others are associated to 0, see also Table 1.

[6] Fredriksson (2000) studies the pros and cons of decentralisation vs. centralised management options regarding the siting of waste facilities. Decentralised systems are in first place theoretically preferable, though drawback may emerge.

[7] EIONET is a partnership agency of the EEA and its member countries; it is fundamental to the collection and organisation of data for the EEA. Prominent examples of overall environmental policy performance indexes setup for many countries based on a synthesis of diverse policy performances can be found in Eliste and Fredrikkson (1998) and Dasgupta et al. (1995). Cagatay and Mihci (2006, 2003) provide an index of environmental sensitivity performance for 1990–1995, for acidification, climate change, water and even waste management.

[8] Thus, in any given year each country is associated with an index value, assigning 1 to the maximum potential value (all considered policies present). We have differentiated between the presence of only a "strategy" (low value) and that of an effective regulatory policy (high value). The latter has been assigned a stronger weight (0 for no policy, 1 only strategy, 2 policy).

[9] Though specific waste prevention targets actions do not exist (landfill related) policy variables can be included even at this level of analysis. We may hypothesise that the backward effects of landfill policies and waste management actions on the MSW generated are not significant. Nevertheless, since out synthetic policy index also captures the variety of measures a country has implemented on waste, not only landfill diversion actions, some effects may emerge.

Table 1
Descriptive statistics and a summary of research hypotheses

	MIN	MAX	Mean	Acronym	
Dependent variables					
MSW collected/generated (kg per capita)	239.00	753.00	484.70	MSW-GEN	Descriptive stats are calculated for EU 25 over 1995–2005
MSW landfilled (kg per capita)	9.00	659.40	283.95	MSW-LAND	
MSW incinerated (kg per capita)	0.00	396.60	73.47	MSW-INC	
MSW recycled (kg per capita)	8	412	182.89	MSW-REC	
	MIN	**MAX**	**Mean**	**Acronym**	**Hypothesised correlation[a]**
Independent variables					
1. Economic drivers					
Final consumption expenditure of households (Euro per inhabitant - at 1995 prices and exchange rates)	900.00	21000.00	8103.27	C	+G, eventual inverted U, +I, −L
Gross domestic expenditure on R&D (% of GDP)	0.19	4.25	1.37	RD	+I, −L
2. Structural and socio-economic variables					
Population density	16.70	1276.00	174.80	DENS	+G,
Urban population (% of total)	50.60	97.20	71.36	URBPOP	−L,
Household size	1.9	3.4	2.62	SIZE	?+G
Single households (%)	10.12	38.30	25.04	SINGLE	+G
Age index or 'elderly ratio' (population 60 and over to population 20–59 years)	0.3	0.5	0.358	OLDNESS	?G
Value added at factor cost, share of manufacturing	9.10	36.30	18.54	VAMAN	−G
Household expenditure for food and non-alcoholic beverages, clothing and footwear, furnishing, household equipment and routine maintenance at current prices (% of total household consumption expenditure)	18.10	48.90	28.76	COMPC	+G, −R
3. Policy variables					
Decentralised waste management policy drivers (dummy)	0	1	0.24	DECPOLIND	?G, L, I
Incineration Directive (dummy: years/country in which directive is ratified)	0	1	0.24	INCDIR	−G, +I, −L
Landfill Directive (dummy: years/country in which directive is ratified)	0	1	0.27	LANDIR	−G, +I,
Waste strategy policy index (range 0–1)	0.00	0.95	0.34	POLIND	−L
Landfill strategy policy index	0.00	0.25	0.09	LANDPOLIND	

All values in non-log format.

[a] The sign on the hypothesised correlation is shown, as well as the level at which this is most relevant (G for generation, L for landfilling, R for recycling, I for incineration). The element (?) means that the hypothesis is ambiguous either because opposing forces may be influencing the link or because economic theory and other scientific fields do not provide clear insights.

The specification we test in this level (waste generation) is then:

$$\log(\text{MSW generation per capita}) = \beta_{0i} + \alpha_t + \beta_1 \log(\text{C})_{it} + \beta_2 \log(\text{C})^2_{it} + \beta_3(\text{Xi})_{it} + \beta_4(\text{Zi})_{it} + e_{it} \quad (1)$$

where X contains the above discussed socio-economic/structural factors (DENS or URBPOP, SIZE, SINGLE, OLDNESS, VAMAN) and Z the policy levers (DECPOLIND, INCDIR, LANDIR, POLIND).

3.2. Waste management: incineration and recycling

It should be noted that the two management routes are linked by some post-treatment flows (e.g. waste from incineration, waste from the recycling industry, etc.), but in general can be assumed to be alternative separate routes following separated collection and pre-treatment. They avoid a direct landfilling of waste. It is not our aim to address the optimal allocation among incineration, landfilling and recycling. The literature is too wide and evolving in all waste-related disciplines and environmental economics and management. We refer to main contributions as Pearce (2004), and Dijkgraaf and Vollebergh (2004). The main economic point to stress is that market and non-market costs are sooner or later increasing for all options. Even if economies of scale may matter in terms of efficient allocation in a first stage of the investment (all options present not negligible fixed costs), corner solutions are never optimal. This means that a portfolio of options, different across states and regions depending on structural conditions, economic factors, and policy choices, is the solution to the waste issue.

3.2.1. Incineration

The delinking relationship assumes here a different flavour. In fact, we may surely expect that incineration, at least in EU15 (the analysis is carried out only for EU15 given lack of data – most EU countries show incineration level close to zero nevertheless), is positively related to economic growth over the recent years. This is evident from descriptive analysis and is obviously linked to the landfill diversion trend. Nevertheless, the non-linearity of the relationship could assume either an exponential dynamics or a bell shape dynamics. The latter case that we deem more plausible given that incineration is associated to some extent to diminishing marginal returns and increasing external costs. The interpretation is then different with respect to the usual EKC shape for waste generation and landfilling. It is related to the fact that we face other possible 'residual' options, like recycling and composting. An increasing role of such strategies, common in most countries, should lead to and make compatible scenarios of landfill diversion and increasing, but not exponentially incineration. As quantified by many applied studies, in the waste arena corner solutions are seldom (never) optimal strategies, given the increasing marginal costs – financial and social – of both landfilling, incineration and recycling.

Linked to the above comment on the role of density, we here state that a clear hypothesis cannot be formulated. The resulting sign is unambiguous, depending on the chosen alternative to landfill disposal, if any. If we assume that densely populated areas move away from landfilling, the opportunity costs and environmental costs of incineration can represent a relatively better scenario. If instead the country moves away from landfilling primarily using recycling options, incineration and population density/urbanisation degree may be linked negatively.

A crucial factor we here test is R&D intensity, exploited as a country specific effect. Though some outliers may exist, that is countries showing high R&D/GDP shares and low incineration, eventually because they pursue recycling strategies more heavily, on average we expect to find a dynamic strong correlation between the technological intensity of a country and its incineration performance. The example of Germany may represent a paradigmatic case in Europe. We test whether this anecdotic fact may represent a general statistical regularity. Given the potential correlation with the economic driver, R&D is tested both in alternative to consumption. Eventual non-linearity is tested to account for diminishing marginal effects of R&D on incineration technological strategies.

The reasoning around policy levers is similar, with an opposite expected sign, to what commented on for landfill diversion. At this stage we maybe expect a robust specific link between the implementation of the incineration directive and incinerated waste dynamics. The inclusion of both an endogenous driver such as R&D and a policy lever allows a compelling assessment on the relative strengths of endogenous and exogenous drivers.

The specification for incinerated waste is then:

$$\begin{aligned}&\log(\text{MSW incinerated per capita})\\&\quad=\beta_{0i}+\alpha_t+\beta_1\log(C)_{\text{it}}+\beta_2\log(C)^2_{it}+\beta_3(\text{Xi})_{it}+\beta_4(\text{Zi})_{it}+e_{it}\end{aligned}\qquad(2)$$

or

$$\begin{aligned}&\log(\text{incinerated waste per capita})\\&\quad=\beta_{0i}+\alpha_t+\beta_1\log\left(\frac{\text{R\&D}}{\text{GDP}}\right)_{it}+\beta_2\log\left(\frac{\text{R\&D}}{\text{GDP}}\right)^2_{it}\\&\qquad+\beta_3(\text{Xi})_{it}+\beta_4(\text{Zi})_{it}+e_{it}\end{aligned}\qquad(3)$$

X (DENS or URBPOP) and Z (DECPOLIND, INCDIR, LANDIR, POLIND) usually refer to the socio-economic and policy variables.

3.2.2. Recycling

Having discussed main hypothesis for waste generation and incineration, and being recycling statistically determined as the residual term (waste generation – incineration – landfilled waste), the discussion can be easier in terms of hypothesis testing.

Regarding the income driver, we expect a positive trend as for incineration. In terms of elasticity, we have not specific expectations or benchmarks given past evidence, if any, is rare. We expect a linear, not bell shape relationship, that may well emerge in the future where for the EU average high critical thresholds in the recycling shares were surpassed.

As far as socio-economic drivers are concerned, we think it is plausible to test the effect of variables like URBPOP, SIZE, SINGLE, OLDNESS, and also here the share of household expenditure for food and non-alcoholic beverages, clothing and footwear, furnishing, household equipment and routine maintenance at current prices (COMPC). This latter element captures the share of less recyclable materials. And should be negatively related with recycling. Expectations over the other factors are less clear cut. Opposite latent forces may lead to a net negative or positive relationship. For instance, taking URBPOP, we may expect a positive link with recycling if urban waste management systems are able to exploit economies of scale of high population density for increasing the effectiveness of separated collection and recycling, as main option in those cases, where the opportunity costs of landfilling and incineration are stronger and more perceived.

Finally, the test of policy levers is here of indirect nature; the expected sign of the relationships nevertheless positive, if significant. Landfill diversion oriented policies could induce, more than waste reduction at source, which is as discussed currently unlikely, a shift towards more recycling activities. It is obvious that (EU and national or regional) policies focusing on the landfill stage and local decentralised waste management actions through waste charges and incentives to separated collection both may drive towards higher recovery/recycling performances.

The specification we analyse is:

$$\begin{aligned}&\log(\text{recycled waste per capita})\\&\quad=\beta_{0i}+\alpha_t+\beta_1\log(C)_{it}+\beta_2\log(C)^2_{it}+\beta_3(\text{Xi})_{it}+\beta_4(\text{Zi})_{it}+e_{it}\end{aligned}\qquad(4)$$

X (URBPOP, SIZE, SINGLE, OLDNESS, COMPC) and Z (DECPOLIND, LANDIR, POLIND) refer to the socio-economic and policy variables we test at this level of analysis.

3.3. Landfill diversion

The final level of the empirical model then, focuses on the disposal stage of the waste chain, landfilling.

The economic driver is here hypothesising to impact landfilled waste following a bell shape. In fact, on average, even if some countries are still increasing their landfill share and heterogeneity is striking across Europe, shares of landfilled waste and also landfilled per capita have been constantly decreasing over the last decade. We may also expect to find a negative relationship, not a bell shape. From an average EU viewpoint, the period 1995–2005 may be already at the 'right' descending side of the inverted U shape relationship concerning the landfill-economic growth relationship. In the future testing N shape tests may become relevant. As an example, a major country like Italy has witnessed, following a decade of strong landfill diversion, a slight increase in waste landfilled per capita in 2006 with regard 2005.

As far as socio-economic and structural factors are concerned, we note that population density and urbanisation should be negatively related to landfilled waste. Both opportunity costs linked to the higher value of land in densely populated and urban areas value of land, of commercial activities a crowded out by landfill sites, and other public investments, and the higher externality costs which arise where more people live, ceteris paribus, should drive down the use of landfills as disposal option and a real 'investment' opportunity linked to rents that are compared to other market rents (André and Cerda, 2004). Nevertheless, since opportunity costs and environmental costs may vary across regions (e.g. EU15 vs. EU10) this hypothesis is to be carefully scrutinised case by case. We do not see any other factors relevantly impacting landfill trends from a socio-economic point of view. The role of R&D investments of a country is expected to correlate negatively with landfill diversion. The reason is nevertheless related to the expected role of R&D as driver of incineration dynamics. Relatively speaking, the technological content and innovation dynamics associated to incineration options are stronger than in landfill site management.

The core factors we test at such a level are instead policy levers. This is a crucial test in the analysis. By exploiting both binary indices and the continuous synthetic index – it is worth noting that both vary over time across country – we verify the extent to which the policy experiences that have characterised Europe in the last decade, primarily the pivotal role of the 1999 Landfill Directive, have affected the waste–income relationship. Since the synthetic policy index also captures the general commitment of a country over the period, some early actions occurred before 1999 and the effective ratification of the Directive are taken into account in the econometric investigation.

The tested specification is then:

$$\log(\text{MSW landfilled per capita}) = \beta_{0i} + \alpha_t + \beta_1 \log(C)_{it} + \beta_2 \log(C)^2_{it} + \beta_3(\text{Xi})_{it} + \beta_4(\text{Zi})_{it} + e_{it} \quad (5)$$

X (DENS or URBPOP) and Z (DECPOLIND, INCDIR, LANDIR, POLIND) usually refer to the socio-economic and policy variables linked to this stage of the investigation, as summarised in Table 2.[10]

4. The data sources

The dataset includes information on waste collected, waste landfilled, incinerated and recycled for all European countries in 1995–2005 (Eurostat sources). We took household expenditure (consumption) per capita as the main economic driver, following the hypothesis that consumption is a better independent variable for waste collection and disposal (Rothman, 1998; Jacobsen et al., 2004). The standard specification includes other variables to control for intra-country heterogeneity. These fall into two main groups: structural variables and policy indices.

The first group controls for the socio economics factors that might differ between countries, such as population density, urban population degree, household size, share of manufacturing in the economy, income inequality (the full list is reported in Table 1). The second group controls for the presence of environmental policies in the countries analysed. The importance of introducing policy proxies is crucial in the waste arena. Their role is also more relevant in our case, because many European policies were enacted quite recently, and their inclusion in a proper delinking framework could be a sort of ex-post effectiveness evaluation. We include in our analysis two types of policy proxies. The first is related to the European Landfill and Incinerations Directives and their implementation in the member states. These proxies are built as dummy variables that take the value 1 if the country has transposed these directives into national law. The second group of policy indices is more country specific. We include a dummy for a decentralised waste management index that reflects the level of waste policy decentralisation between countries, and finally an environmental policy index dummy. This last is a proxy for national policies over the time period examined. It captures all possible information regarding national implementation of waste related policies (MSW, biodegradable solid waste, packaging waste, end of life vehicles, other), independent on the Landfill Directive. We used the country studies available on EIONET as our information source. This index is both extremely comprehensive with regard to landfill directive related variables, and also may capture some of the waste prevention features of national policies. Although unlike waste disposal and waste management, there are no specific EU waste prevention targets or policies, national authorities could act as early movers.

[10] For landfill diversion and incineration we test two stage regressions, including as covariate the predicted values of waste generation in specifications, replacing the economic driver. This is to account for the unchained and consequential nature of waste flows from generation to disposal. Results do not change; predicted values significance reflects the significance of consumption, with elasticities around unity or even higher.

5. Empirical results

All the analyses are conducted in three consequential steps: (i) a traditional baseline specification, including only the main economic driver; (ii) the specification with the structural drivers introduced as control variables; (iii) testing the significance of the different policy indices. All regressions are estimated by both fixed and random effects, and the best specification is selected following the Hausman test. Specifications are tested in the EU25 setting and in the two sub-samples, the EU15, and new incoming countries (EU10), where it is statistically meaningful and/or data availability allows it.

5.1. MSW generation

5.1.1. EU25

The analyses for EU25 (Table 2a) do not show overall WKC evidence for MSW generation. The linear term shows a significant and positive coefficient for consumption, with an elasticity ranging from 0.114 to 0.23 across specifications.[11] The EU15 and EU25 analyses are similar, but with a higher elasticity (around 0.70–0.80) in the case of the former. These elasticities are slightly lower compared to previous analyses of Europe using waste data for the 90s (Mazzanti, 2008), and seem also to imply a more active delinking process in the EU10 countries.[12] In general, we thus observe evidence of a 'relative delinking' in the relation. This result is interesting and partially confirms expectations of only a relative delinking, but with some positive signals in terms of currently lower elasticities.

The introduction of socio-economic controls does not alter previous results. The analysis shows an evidence of relative delinking, and elasticity equal to 0.72 in the sub-sample EU15. The most significant and robust control variables are population density, or alternatively the share of urban population, and the share of manufacturing[13] in the total economic activities. The share of manufacturing shows a negative sign coherent with our expectations: richer and services oriented economies produce more waste. This opens a question on the relatively better environmental performances we may at first sight attribute to services, if we think mainly at pollution-related issues: composition effects could show, for a theme like waste (e.g. MSW include some commercial & business derived waste), counterintuitive results. Population density or alternatively urban population instead impacts positively on waste generation: scale effects prevail over possible economies of scale in waste prevention and waste management/collection activities.

All other factors are never significant. Summing up, socio-economic structural factors add some useful hints and food for thought for waste management though they do not impact on the core relationship. Household related variables seem to not have a great influence. This may indicate that policy efforts are still weighting more post collection actions, such as recycling and landfilling

[11] Table 3 presents only linear specifications. Overall results do not change when running quadratic specifications that do not show EKC evidence but a linear term having a negative coefficient and the quadratic term a positive one. This is due to the nature of the data, and captures the effect of the low-income countries (e.g. Lithuania, Czech Republic, Slovakia, Poland and Slovenia), which registered a reduction in the total MSW collected in the period studied. This slight anomaly generates a downwardly sloped relationship between MSW collected and consumption in the first phase. This trend does not appear in sub samples EU10 and EU15.

[12] This may be interpreted in terms of the (observed even in other contexts) delinking occurring in some east European countries (Hungary among others), which may be driving the general empirical picture. Even the EU25 quadratic analysis shows a U shaped curve affected by the delinking occurring in low-income eastern countries. Bluffstone and Deshazo (2003) present a case study on an eastern country process of coping with EU waste management challenges.

[13] There are no data for Greece on manufacturing share.

Table 2a
MSW generation (EU25)

Model	FEM	FEM	FEM	FEM	REM	FEM	FEM	FEM
C	0.230***	0.163***	0.117**	0.158***	0.188***	0.114*	0.118**	0.164***
Dens	0.629***	···	···	···	···	···	···	···
Urbpop	···	4.263***	1.760***	42.582***	0.290	1.760***	1.761***	1.777***
Vaman	···	···	−0.284***	···	−0.319***	−0.284***	−0.285***	−0.291***
Size	···	···	···	0.117	···	···	···	···
Oldness	···	···	···	0.120	···	···	···	···
Decpolind	···	···	···	···	−0.015	···	···	···
Polind	···	···	···	···	···	0.002	···	···
Landdir	···	···	···	···	···	···	−0.0005	···
Incdir	···	···	···	···	···	···	···	−0.022
TP	–	–	–	–	–	–	–	–
N	275	275	264	275	264	264	264	264

(···) means not included. Significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); *F* test show overall significance for all regressions at 1%, *R* squared present reasonably high value for panel settings.

Table 2b
MSW generation (EU15)

Model	FEM	FEM	FEM	FEM	REM	FEM	FEM
C	0.772***	0.816***	0.787***	0.825***	0.811***	0.776***	0.830**
C^2	°	···	···	···	···	···	···
Dens	0.254	···	···	···	···	···	···
Urbpop	···	−0.203	−0.059	−0.004	−0.234	0.009	0.002
Vaman	···	···	0.092	···	···	···	···
Size	···	···	···	0.279**	0.357***	0.292**	0.279**
Oldness	···	···	···	0.340**	0.348**	0.289*	0.345**
Decpolind	···	···	···	···	0.018	···	···
Polind	···	···	···	···	···	0.001	···
Landdir	···	···	···	···	···	···	−0.001
TP	–	–	–	–	–	–	–
N	165	165	165	165	165	165	165

(···) means not included. Significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); *F* test show overall significance for all regressions at 1% *R* squared present reasonably high value for panel settings; °significant at 10% if included, though the observed associated TP is well above the observed range (136.000€), confirming the low statistical and economic significance of the estimated quadratic form. All regressions given this evidence are estimated without the quadratic term.

Table 2c
MSW generation (EU10)

Model	FEM	FEM	FEM	REM	FEM	FEM
C	5.49***	4.76***	5.82***	5.63***	6.32***	5.68***
C^2	−0.365***	−0.315***	−0.383***	−0.361***	−0.413***	−0.362***
Urbpop°	13.25***	12.55***	13.32***	13.66	13.13***	12.98***
Vaman	···	−0.15***	···	···	···	···
Size	···	···	0.120	···	···	···
Oldness	···	···	−1.694***	−1.39***	−1.72***	−1.69***
Polind	···	···	···	−0.129*	···	···
Landdir	···	···	···	···	−0.025	···
Incdir	···	···	···	···	···	−0.087***
TP	1845	1911	1970	2435	2103	2610
N	110	110	110	110	110	110

(···) means not included. Significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); *F* test show overall significance for all regressions at 1%, *R* squared present reasonably high value for panel settings, °DENS is less significant and links to less significance of the regression.

operations. Household behaviour and characteristics, at least on average, are not correlated to the amount of waste collected, neither negatively nor positively.

We next exploit our policy proxies adding these variables to the set of explanatory factors. The effect of neither the Landfill Directive nor the environmental policy index is statistically significant. This means that the efforts made so far have not promoted a stronger delinking between waste collection and domestic consumption.[14] The results are the same for the analyses of the smaller samples. Overall, policy levers appear to have a very marginal, if any, impact on waste generation. This reflects the lack of waste prevention oriented policies and the marginal or negative effects of landfill policies on waste generation. All of these points to the need for waste policies targeting waste reductions at source by stimulating more efforts by firms, that may change product characteristics and reduce product weight (Glachant, 2004) and households, that may affect production through changing consumption and then reducing waste collection, and improving the quality of waste collection by separating materials. As trivial, behaviour may change through a shift towards more environmental preference, having in mind hat income matters since environmental quality of private and public goods is increasing more proportionally than income. In addition, policy can affect behaviour by influencing the relative prices of market and non-market goods in favour of a partial or total internalisation of environmental diseconomies (Choe and Fraser, 1999). Waste reduction at source efforts have been lacking so far; in the

[14] The underlying correlation between the dummies for landfill and incineration directives is 0.66.

Table 3
Incinerated MSW (EU15$\hat{}$)

Model	REM	REM§	FEM	FEM	REM	FEM	FEM	FEM
C	20.293***	1.676***	22.450***	24.287***	19.328**	...	...	19.34
C^2	−1.014**	...	−1.143***	−1.269***	−0.965**	...	...	−0.994
Urbpop	0.651	...	0.111	0.252	1.157	4.451***	1.192***	0.145
RD	...	...	...	...	...	1.414***	3.623***	...
Decpolind	...	...	...	...	−0.868***	...	...	...
Incdir	...	...	0.076*	...	...	...	...	...
Polind	...	...	...	0.380***	...	...	0.151*	...
Landdir	...	...	...	...	...	...	...	0.143***
TP	22168	–	18409	14319	22348	–	–	16787
N	137	126	137	137	137	137	137	137

(···) means not included; significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita), Ĝreece and Ireland are discarded since they show only 0 values over the period, the panel is unbalanced for some years where Portugal also shows 0 values; § excluded Luxem; *F* test show overall significance for all regressions at 1%, *R* squared present reasonably high value for panel settings.

early stages, policies related to waste disposal were perceived as less costly. This may be true if we do not decide which policy is better following a quantification of net present value in the medium long run, that leads to clearer efficiency assessments (Pearce, 2004).

5.1.2. *Comparing EU15 and EU10*

As far as MSW generation is concerned, we may robustly sub divide the analysis between EU15 and EU10. Some comments were anticipated above. We here comment on more specific differences, if any (Tables 2b and 2c).

We first note that the relationship regarding the core economic driver is different between the two sub samples: the average EU25 evidence is driven by the (majority of) western countries. In fact, Tables 2b and 2c highlight, as already noted, that while the EU10 is showing a bell shape dynamic, coherent with absolute delinking – given a quite low TP – EU15 countries are still generating an – unsustainable – waste growth that is not decoupled from[15] economic trends. This interesting and partly counterintuitive result deserves more future investigation, as the 'explanations' may be diversified. Eastern countries may benefit, ceteris paribus, of joining the EU having to comply with strict environmental law at a relatively low-income level, and/or some waste management practices in relatively more important rural areas may underestimate waste collection in such countries.

Also perhaps counter-intuitively, it seems that the above-observed positive relationship between population density/urbanisation and waste generation is mainly driven by EU10 countries. EU15 could have reached economic of scale and efficiency level in waste management that counterbalance the scale effect of population density relatively to waste collection trends.

Finally, moving to other explanatory forces, we may note that the insignificant effects we find for SIZE and OLDNESS derive from quite different dynamics in the groups: household size and the elderly index correlate positively with waste generation in western countries (the latter effect being somewhat counter-intuitively, but possibly explained by a stronger pro-environment commitment of young generations). EU10 instead present a more expected negative sign that may derive from the stronger correlation between elderly ratio and rural areas, where waste generation is intrinsically lower.

Finally, eastern EU countries also present negative and quite significant coefficients associated to POLIND and INCDIR. Those policy related effects may be coherent with what affirmed above: the decoupling trend is present even for waste generation.

5.2. *Recycled waste*

We now look at the recycling of waste, which, is a priority in the EU waste hierarchy and is often explicitly targeted by states or local public authorities dealing with environmental issues.[16] We would expect to find a significant positive trend for recent years. See Table 4 as reference.

First, the relationship between the amount of waste recycled and household consumption is positive and linear, with a high and significant elasticity of 2.66. Since even the quadratic term is significant, we present quadratic specification in the table. The interpretation does not change: the amount of recycling per capita is increasing in the EU along economic development, at an even stronger pace with respect to income growth. This was expected, at lead in this still initial phase, if we consider the EU on average, of waste management dynamics. Decreasing relationship may be expected in the future when economies of scale are fully exploited. The marginal cost of increasing recycling will start biting; economically speaking when marginal costs will become much higher than average costs, which will increase themselves.

Focusing on other potential main driver, we note that the share of urban population appears to exert a significant negative effect: it seems that for the EU15 (specific differences across states could be present) the higher urbanisation the lower the recycling performances. Waste management costs of collection, separation and recycling may be strong constraints in highly urbanised areas.[17] Incineration may also be used in such highly urbanised contexts as more efficient option for recovery. This evidence is important and worth being further investigated given the increasing urbanisation degree of main EU areas. The shift towards urban centres is to be carefully managed in terms of waste issues and transport issues, the two key environmental problems related to high urban population density.

Interestingly, the variable COMPC representing the share of food products on total consumption is negatively and significantly correlated with recycling, and also works to lower the

[15] We underline that dealing with socio economic driver no clear hypothesis is definable. The hypothesis listed in Table 1 derives from a survey of economic, sociological, and waste related disciplines studies, and represent the current consensus on the possible links between waste trends and the set of explanatory factor, we here capture with great richness. Counterintuitive not highly expected results may sometime emerge from the presence of idiosyncratic features in specific country or regional situations. We remind that econometric analysis provides evidence in terms of statistical regularities associated to a defined set of units, in our case countries.

[16] See Pearce (2004) on the potential differences between the EU waste hierarchy and specific hierarchies emerging from contingent cost–benefit analyses.

[17] Nevertheless, when including the square term of urbanisation, the sign on this second factor is positive. This means that potential positive effects on recycling performances are expected and possible along the urbanisation development. The exploitation of economies of scale is the key factor to avoid or mitigate the waste-effects driven by urbanisation.

Table 4
Recycled MSW (EU15)

Dependent variable	Log waste recycled/POP	Log waste recycled/POP	Log waste recycled/POP	Log waste recycled/POP
Model	FEM	FEM	FEM	FEM
C	−51.77***	−39.42***	−34.29***	−33.37***
C^2	2.93***	2.30***	2.00***	1.92***
LURB	...	−7.31***	−8.42***	8.17***
COMPC	...	...	−2.42**	−2.30**
Landdir	...	...	...	0.170**
N	165	165	165	165

(···) means not included; significance at 90%, 95% and 99% is denoted by *, ** and ***; *F* test show overall significance for all regressions at 1%, *R* squared present reasonably high value for panel settings.

consumption elasticity. This may mean that the composition of consumption, though slowly changing, has an impact on determining the amount of (potential) waste that is recycled. One explanation may be that recycling is better developed for commercial (and packaging) waste. We just note that, if tested, it is not significant instead as a driver of waste generation. Other potential discussed factors like the share of single households, the size of households, the elderly ratio factor, are not statistically significant when included.

Finally, the inclusion of policy indices does not change the core results. The landfill directive, the decentralisation policy index and the synthetic policy indices are positively correlated with the amount of recycled waste. Nevertheless, only the former (the landfill Directive time variant dummy) is linked to a significant coefficient. This is in line with and confirms the findings for the incineration and landfill analyses, and shows that in Europe the tendency is towards a diversion of waste from landfill, to stimulate incineration and recycling.

5.3. Landfilled waste

5.3.1. EU25

The analysis relative to Landfilled waste reported in Table 4 below shows evidence in support of a WKC, which given the scenario in recent years is to be expected. The process of diverting waste from landfill in fact started, on average in the EU, around or even before 1995. Thus, our data register mainly the downward-sloped part of the relationship. This evidence connects to the aforementioned relatively better performance for the EU10 in waste generation. Further investigations are needed in the future to confirm this possible difference.[18]

The introduction of socio economic/structural variables does not alter the previous results, and again shows a trend towards absolute delinking in relation to waste disposal in Europe. Other factors that are significant are density and degree of urbanisation (EU25/EU15, respectively positive and negative signs).[19] The latter shows a stronger statistical significance associated to a negative sign. It is in our eyes a structural factor that recalls economic rationales: the significance of density and urban population, above positively correlated to waste generation, is well expected, and shows that where opportunity costs are higher (in urban areas, densely populated areas) and disamenities/external effects influence more people, landfill diversion is stronger. As an example, landfill studies have flourished in situations where the value of land is especially high and population density reaches world peaks as in Asia (Lang, 2005; Ozawa, 2005).[20] The size of the coefficient is high, as well its statistical significance. Such factors could explain the degree of delinking and landfill diversion in the endogenous scenario without policy interventions.

Finally, the analysis shows that the policy levers here tested, that is the policy indices, and the landfill directive and the incineration directive are highly significant and negatively correlated to landfill diversion. These results, are confirmed for both sub-samples. This is an important result because it underlines the high level of effectiveness achieved by European policy, as additional lever to the ones above commented on, in terms of diverting waste from landfill. Policies help 'tunnelling through' the endogenous delinking path driven by mere economic drivers. As expected given the high correlation between LANDDIR and INCDIR, if we include the latter as alternative to the former, the sign we note is negative with a very significant coefficient. The joint set of policies related to the 1999 landfill Directive brings about relevant effects on landfill diversion.

In terms of the other environmental policy proxies analysed, the Decentralised Waste Management (DWM) index (taking three values, low/medium/high), is significant at 1% and has a positive coefficient. This seems to suggest that the more that waste management is decentralised within countries the more difficult is diversion from landfill. The interpretations remain open, but the evidence is not strikingly counterintuitive: in DWM systems (Italy being one example) there are often incentives for the local waste management actors (municipalities) to increase waste disposal in terms of landfill or recycling, depending which option produces the higher rent in the local "market". Since landfill rents are often very high, DWM could favour "distort" dynamics.[21] We are not suggesting negative effects from DWM overall. We would underline that this variable is time invariant capturing only cross country heterogeneity and may be lower compared to other policy proxies.

We would underline that from a statistical viewpoint policy dummies appear not to be affected by endogeneity issues, being positively but not highly correlated with income variables (below 0.10), but the policy index is. Early movers are likely to be wealth-

[18] The evidence may be driven by an effective good performance of those countries that are experiencing a period of economic growth which began in the late 1990s associated with the implementation of environmental policies (a requirement for joining the EU) proposed by the richer EU countries. We could claim that, from a development point of view, the EU10 countries have more opportunities to be more efficient, at the same level of income, since their growth is embedded in a scenario characterised by a rich set of environmental policies that cannot be avoided as they (among other aspects) are prerequisites for entry in the EU by these incoming countries.

[19] Those become both positive in EU10. This may imply for urbanisation degree a different influence or level of opportunity costs linked to the urbanisation. Urbanisation is in EU10 countries still in its infancy and strong opportunity costs in terms of land use and land prices do not emerge, prevailing scale effects with negative impacts on the environment through landfilling.

[20] We also refer to the 2008 march issue of the *Journal of Environment and Development*.

[21] The fact that analyses show that the more a country is decentralised the more they use landfill as option may be driven by countries such as Italy, Spain, Belgium, UK, that present medium-low landfill diversion performances in comparison to other EU15 countries. As always, econometrics catches regularities, with exceptions being possible (Germany) within the average evidence.

Table 5a
Landfilled MSW (EU25)

Model	FEM	FEM	REM	REM	REM
C	3.382**	3.658***	4.156***	3.390***	3.666***
C^2	−0.242***	−0.248***	−0.260***	−0.236***	−0.224***
Urbpop°	−3.694**	−1.554**	−1.714**	−1.340**	−2.679***
Decpolind	...	0.576**	...	...	...
Landdir	...	...	−0.324***	...	...
Polindˆ	...	...	...	−0.632***	...
Incdir	...	...	...	...	−0.312***
TP	1083	1595	3610	3951	3532
N	275	275	275	275	275

(...) means not included; °DENS is less significant; ˆif a specific index only related to landfill policy is included results do not change. The correlation between the two is 0.81. Significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); *F* test show overall significance for all regressions T 1%, *R* squared present reasonably high value for panel settings.

Table 5b
Landfilled MSW (EU15)

Model	FEM	FEM	REM	FEM	FEM
C	65.09**	42.13***	48.96***	61.52***	55.94***
C^2	−3.53***	−2.33***	−2.69***	−3.27***	−2.96***
Urbpop	−21.01**	...	−6.65**	−20.72***	−20.75**
Dens	...	−2.39**	...	...	...
Decpolind	...	...	0.689*	...	...
Landdir°	...	...	...	−0.375***	...
Polindˆ	...	...	...	...	−0.160***
TP	10092	8440	8958	12169	12699
N	165	165	165	165	165

(...) means not included; ˆif a specific index only related to landfill policy is included results do not change; inserting Incdir does not change the evidence. The correlation between the two is 0.81. Significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); *F* test show overall significance for all regressions T 1%, *R* squared present reasonably high value for panel settings.

ier countries, Germany as an example.[22] We note that here and above, as far as index POLIND is concerned, two stage instrumental variable regression using consumption as driver of the index in the first stage and then including the predicted values of POLIND in the specification analysing waste indicators confirm results. In this case, POLIND is highly and negatively related to Landfilled MSW per capita. This potential endogeneity, that characterises only this more comprehensive index capturing the overall waste policy commitment and action of a country, is not undermining our evidence and is dealt with.

5.3.2. *Comparing EU15 and EU10*

As for waste generation, data availability on landfilling allows an investigation of EU15 and EU10 taken separately. The evidence showing landfill diversion – a bell shape curve – is associated to both EU 15 and EU10, with plausibly different TP, higher in the former case. The most striking difference is related to the URBPOP factor that also presented opposite signs when we commented on waste generation in par 4.1.2.

Here, we find that the negative effect of URBPOP and DENS on landfilled waste, then arising as a crucial factor of landfill diversion,[23] turns into a positive effect as far as the EU10 group is concerned. There, urbanisation seems to undermine landfill diversion. The very plausible motivation may be that in a first stage of development, though experiencing as we find here good performances in terms of waste collection and landfilling, those countries may suffer from (rapid) urbanisation dynamics, often concentrated in few big cities.

The economic reason may relate to the lower opportunity costs (lower land values) in the EU10 compared to EU15. If this is true, the expected reduced divergences in land values may endogenously help in the future the landfill diversion performances of eastern countries.

Finally, the significant and robust evidence showing that all tested policy levers are crucial explanatory factor of landfill diversion is confirmed without great differences in both EU15 and EU10 countries (Tables 5a, 5b and 5c).

Table 5c
Landfilled MSW (EU10)

Model	FEM	FEM	REM	REM
C	6.49***	4.49**	7.89***	5.80***
C^2	−0.449***	−0.313**	−0.522***	−0.386***
Urbpop	12.40***	...	10.84***	12.86**
Dens	...	1.39***	...	...
Landdir	...	...	−0.215***°	...
Polindˆ	...	...	...	−0.240***
TP	1376	1303	1914	1831
N	110	110	110	110

(...) means not included; ˆif a specific index only related to landfill policy is included results do not change; inserting Incdir does not change the evidence. The correlation between the two is 0.81. Significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); *F* test show overall significance for all regressions T 1%, *R* squared present reasonably high value for panel settings.

6. Conclusions

This paper sets out to establish a sound framework to analyse delinking for diverse waste related trends, within a conceptual environment that encompasses the policy evaluation stage. This study has provided new evidence on waste generation and disposal delinking by exploiting a rich EU based dataset, that allows various analyses on the relative roles in driving the waste process played by: economic drivers, structural, socio-economic and policy factors. The core delinking hypothesis was tested and its robustness confirmed by the inclusion of explanatory variables; it was exploited for ex post policy evaluation. We would stress that the general value added of delinking analysis is not (only) to show whether economic drivers produce decoupling effects, but more especially, to assess whether and to what extent, there are additional factors that influence the core relationship, which increase the explanatory power of the model proposed.

The results show that regarding waste generation no absolute delinking trend is present, though elasticity to income drivers appears lower than in the past, pointing to the presence of a current relative delinking. For the EU10, there are strong delinking signals, although for a more robust validation this aspect should be further investigated. No landfill or other policy effects seem to provide backward incentives to waste prevention, a result that calls for the introduction of waste policies targeted at the level of the sources of the waste generated.

We have shown that landfill and incineration are, as expected, decreasing and increasing respectively, with policy effects significantly driving these trends: both policy dummies and the policy

[22] Recent studies have focused on analysing the drivers of environmental regulation, defining endogenous factors (Cole et al., 2006; Alpay et al., 2006). Efforts aimed at setting up environmental policy indexes for climate change, waste and other areas show that developed countries' environmental regulations are more stringent. Consistent with EKC reasoning, policies may result endogenous especially if correlated with income factors at both supply and demand levels (Cagatay and Mihci, 2006). Regarding (paper) waste, evidence is supporting higher demand for waste management and environmental policies in more developed richer countries (Berglund and Soderholm, 2003).

[23] Similar very robust evidence is found in the recent work on Italy. Being Italy in any case quite representative of the EU15 situation, the result provides further insights on this possible difference between low income and high-income countries within the EU.

index we defined were negatively correlated to landfill waste across specifications. Finally, recycling is exhibiting a linear but positive trend with elasticity higher than unity. Some additional factors, such as land use, urbanisation, consumption type, and policy levers appear to be playing a role.

We found that there are socio-economic factors that are impacting on waste trends. It should also be noted that the effects of policy may in part be endogenous in terms of economic indicators, which is particularly relevant in the waste arena. To sum up, although complete delinking is far from being achieved, especially for waste generation, some positive signals are emerging, with a quite significant role played by EU waste policies implemented in the late 1990s and early 2000s in diverting waste away from landfill and towards incineration and recycling. Nevertheless, the role played by other socio economic and technological factors (R&D) should not be overlooked. Policies interact with other socio-economic and economic factors within a scenario of endogenous development in which vicious or virtuous circles drive regions' and countries' performance in relation to waste.

Though some positive signals emerge for landfill diversion trends and lower waste production elasticities, the overall evidence of no absolute delinking present – even a mere stabilisation does not emerge as possible current and future scenario, given the depicted situation of socio-economic and policy drivers – in the EU poses serious food for thought for current and future EU policies on waste generation and disposal. On the average, waste generation is not decupled with respect to income, then structural changes in consumption and production and specific policies should be targeted at that level. The average figure may then hide a heterogeneous situation, with some countries performing better and other worse than average. This makes necessary, though policy decentralisation has probably more benefits than costs given idiosyncratic features in terms of economic development, technologies and disposal costs, an higher attention on single country implementation of waste policies and performances.

This claim is even more important if we match our ex post evidence on past and current performances with the recent Andersen et al. (2007) evidence on future projections, which is in line with EEA analysis and expectations. Waste generation is a real hot problem even in industrialised countries, not less important then other topics like climate change. The EU arena faces the challenge of reducing waste generation in order to provide a crucial positive input to disposal actions and recovery options, whose performances has to be improved on average and reducing gaps between both 'north and south' and 'east and west' areas of the EU, currently characterised by some great divergences. Without a reduction of waste produced at source, such divergences may not be reduced, even in presence of effective landfill-oriented and incineration oriented policy measures.

Regarding landfilling, the observed decoupling average trend could be not sufficient and sustainable if waste generation does not decrease or at least stabilise. Landfill diversion oriented dynamics driven by policies and economic factors, added to increases of recycling and incineration as complementary options, could be undermined in their final effectiveness, with the risk of generating some regional/national critical hot spots in terms of socio-economic and environmental critical conditions as the scarcity of land increases year by year and the stock of annually produced waste continues to grow. Where population density is high we may find stronger endogenous incentives and policy commitment towards landfill diversion. Nevertheless, if this does not happen areas associated with high population density may transform in really critical hot spots where the accumulation of waste to be disposed is then difficult to be reversed (as an example the current situation in Naples area in Italy). The balance between waste generational and disposal/recovery is hard to be reversed when the equilibrium collapses.

We may note that urbanisation dynamics do not help, but further bear, on such potential critical conditions concerning waste management and disposal. The expected intensification of urbanisation adds problems. Linked to the latter point, we also point out as food for though for the policy debate that the existing and possibly increasing diversity in recovery and disposal trends across regions and nations are in addition only marginally 'solved' by potential 'waste trade', which may be efficient at local level, but not at regional or national level, given the high cost of trading and transporting waste flows. Waste externalities are locally determined and accumulated in stocks: infra-regional and intertemporal swaps or trade are not a possible economic solution as for some (global) pollutants.

Overall, our evidence gives support to the claim that in order to pursue a more sustainable dynamic of waste generation and disposal, the weight of policy actions should be rebalanced towards the former: although waste prevention at source is at the top of the EU waste hierarchy, policy efforts so far have been biased towards disposal and recycling. Policies have contributed to creating and sustaining markets and rents. There is a risk that EU waste policies and the dynamic of the waste system, will become stagnated in recycling/incineration, and even landfill oriented strategies, assigning a lower weight to waste prevention actions that may receive mention within policy principles, but are never effectively implemented. The higher present costs of such a strategy may work to lower the targeted achievement costs, at all stages of the waste filiere, in the future.

Further incremental research is needed to investigate the role of policies in affecting waste–income elasticity, perhaps by setting up more complex policy indicators to analyse sub regional delinking in specific areas or groups of countries in depth, and to complement quantitative analyses with country level quantitative and qualitative research studies.

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