

Measuring avoided material – a proposal for a multilevel indicator system*

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The European Union's (EU) waste policy relies on the waste hierarchy which sets waste prevention as the top priority for causing the least environmental burden in waste management. Practice shows that waste prevention has not got priority in the implementation of waste policies, nor has its monitoring. Because of its completely distinctive characteristics from other forms of waste management – in motivation, key players, due authorities, the legal environment, and in supporting activities – it is difficult to set up defined policy goals and the conceptual framework for monitoring. The systematic review of the waste prevention monitoring literature is presented. The paper attempts to give a panorama of the EU legislation and the waste prevention programmes of EU member states as a top–down approach, including the settlement level aspects and interests in the context to approximate local and EU-level measurement needs. It presents regression analysis of the available official statistics of Eurostat and municipal waste generation. The outcome of the research is a comprehensive proposal for EU-level waste prevention indicators which could also track progress at the local level.

Keywords:

waste prevention monitoring,
circular economy,
measurement,
indicators,
European Union

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* This article is based on the author's doctoral research (Graczka 2025).

Introduction

The physical manifestation of global economic activity is the international flow of materials, and the residual is the waste showing how effective humans are in using natural resources. The waste of material is becoming increasingly threatening, especially when it comes to critical raw materials, and the often unsustainable management of waste even in the most developed countries. The European Union (EU) as one of the major waste generators has made steps to increase its efficiency in material use and has put waste prevention on top of its priority list. Waste regulation in the EU relies on the so-called Lansink Ladder representing the basic concept of the waste hierarchy (Figure 1), which ranks the various waste management tools by the environmental burden they cause and is a basic paradigm in waste management.

Figure 1



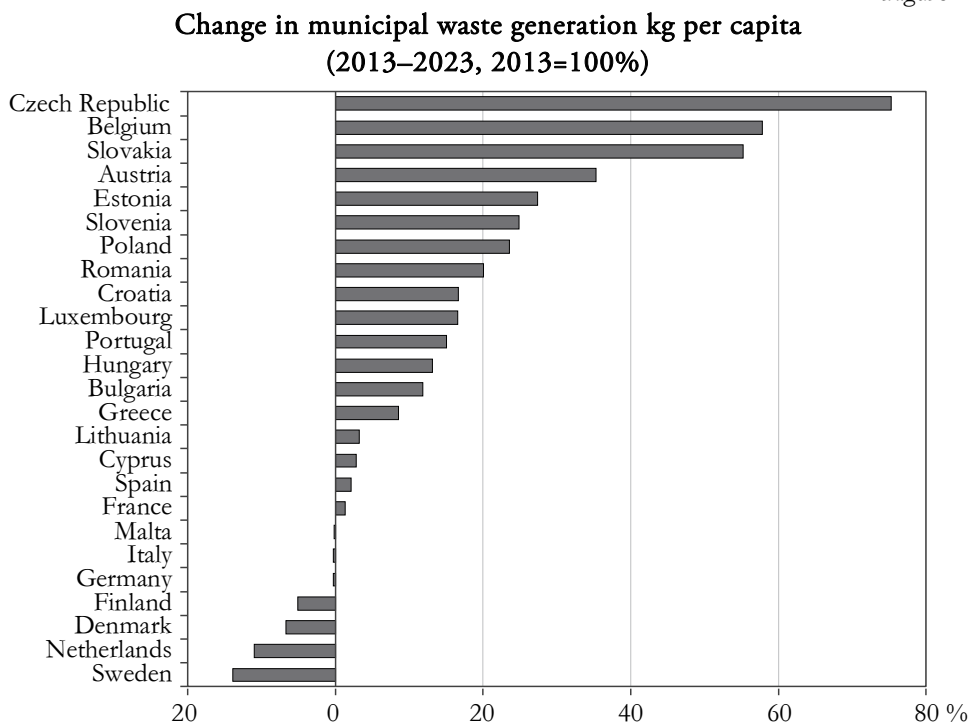
Source: EC (2025).

This concept sets the environmental scientific background for policy priorities (Hultman–Corvellec 2012), i.e. shifting waste management from landfilling and waste incineration (and recovery) towards recycling, reuse, and most importantly waste prevention. Waste prevention activities occur during production and consumption, in other words, in the product itself or non-waste phase of the product life cycle, while all other waste management activities take place in the waste phase. The distinction of product and waste phase is important because the responsibility of prevention rests on all actors of society, while waste management is assigned to public companies who are usually more interested in the growth of waste generation. As products and waste are regulated in completely different legal environments, the policies rely on different public apparatuses. An obvious solution to the waste problem is represented by the circular economy concept. Although it is frequently used as a synonym for recycling, it has particularly important implications, the concept

also includes the goal of shrinking and slowing the loop, working towards zero waste (EMF 2023).

The municipal waste (MW) generation per capita in the EU27 member states increased until 2021, reaching an EU27 peak of 534 kg per capita. The next two years' data show a decrease arriving to 515 (2022) and 511 (2023) kg per capita based on Eurostat imputation. The mandatory introduction of national waste prevention programmes of member states in 2013 did not bring the desired reduction of waste, with Central and Eastern Europe producing stagnating or increasing output (Figure 2).

Figure 2



Note: Ireland, Latvia: data n/a.

Source: env_wasmun (Eurostat 2025c).

These data refer to the waste generated by households and legal entities with wastes similar to household waste (e.g. offices, service providers). Industrial waste is much more significant in mass units, however, household waste reduction is the most critical for its heterogeneity and the diversity and numerosity of the generators. Household waste deserves particular attention as its generators include a substantial part of the final consumers adding significant information to the main challenge of natural capital loss in economies represented by the total material consumption. There are no specific waste prevention indicators available at the EU-level, typically quantity-based proxy indicators are applied like waste generation focusing on the

decoupling of waste generation from economic growth (Wilts et al. 2015, Gentil et al. 2011). However, they do not provide any direct data on the impact of policy measures.

Waste prevention appeared in the EU legislation more than 40 years ago in the Waste Framework Directive of 1975 (WFD) (Directive 2008/98/EC). Although it has been of top priority since 1998, the thorough elaboration of the policy measures was missing for more than two decades. Lists of potential measures and best practices are available to date. According to the European Environmental Agency prevention indicators are essential to move up the waste hierarchy (EEA 2015). This research attempts to set out the monitoring framework of waste prevention in the European Union for the better planning, implementation, comparability and accountability of the environmental policy.

Background

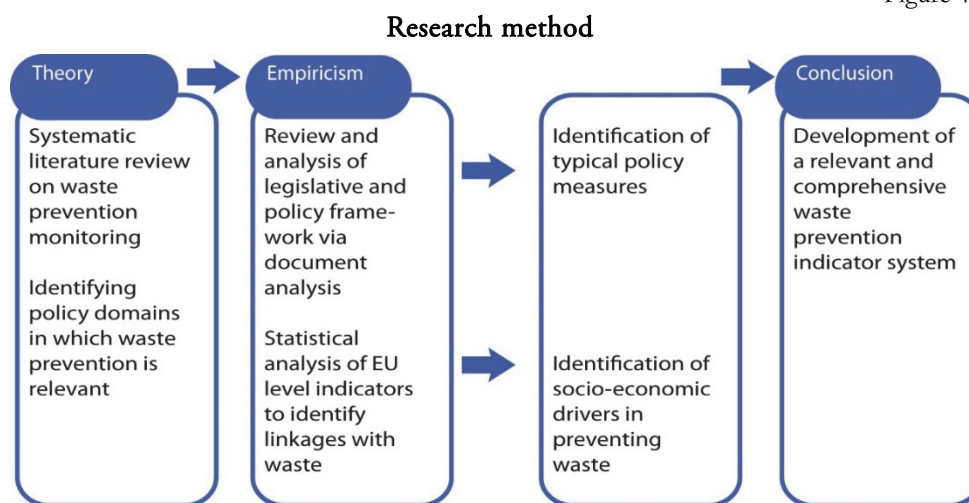
The systematic literature review on waste prevention monitoring has had only a modest outcome: 31 documents – mostly articles – proved to be relevant out of 235 hits, the remaining primarily focuses on the recycling/re-use analysis of materials or industrial sectors. Findings confirm that waste prevention is most often mentioned as an important goal in waste management though not discussed in detail. Within the modest waste prevention literature, monitoring/statistics is the least addressed topic (26%), following the context of waste prevention actions (39%) household/consumer behaviour (35%) and waste policy (29%). As an outcome of the co-occurrence analysis made in VosViewer (Figure 3) the term waste prevention was found to be closely related to the terms *zero waste*, *circular economy*, *material use (life cycle assessment [LCA], resource efficiency)* and sustainability. These domains were reviewed in order to identify published waste prevention indicators.

Two groups are formulated from the available monitoring tools based on their approach. The first is theory based ('theory-based school'), and builds calculated, composite indicators based on how the waste prevention should ideally be measured: waste hierarchy index (Pires–Martinho 2019), annual product demand (Tasaki et al. 2006), mass prevented waste (Matsuda et al. 2018), zero waste index (Zaman–Lehmann 2013), progress in waste reduction (Fernández-Brana et al. 2019), MIPS (Hinterberger–Schmidt-Bleek 1999), food loss index (FAO 2024), and food waste index (UNEP 2024). In this case, the theoretical problem is well-addressed, but data is often unavailable. The second is the 'data-driven school'. Representatives of this group create indicator sets based (partly or entirely) on available indicators to better describe the phenomena of waste prevention (Yano–Sakai 2016, Due et al. 2023, Zaman 2014), resource efficiency scoreboard (EC 2013), Circular Economy Monitoring Framework (Eurostat 2023). These are better applied in practice; however, their weakness is that they typically do not address the measurement of key policy instruments, or the ideal level granularity needed for the principle of

acquis, while actions are expected to vary from country to country. This is the basis for following a top–down approach in the empirical part of the research (Figure 4) initiated from the EU waste legislation proceeding towards national level policy documents using Hungary as an example. The documentary analysis also targeted the national waste prevention programmes of the member states which had been fine-tuned in targets and indicators since the first versions of 2013, although because it is non-binding it weakens the performance (Karigl et al. 2022). The review of the documents results a collection of the typical waste prevention measures and applied indicators.

Parallel to that, the relationship analysis of Eurostat-based official statistics and municipal waste generation was conducted by correlation and regression to better understand the environmental, social and economic factors affecting waste prevention. The final goal was the creation of a set of indicators based on international statistical standards, appropriate for keeping track of waste prevention policy performance. The indicator set has the dual function of serving the needs – particularly comparability of member states, and the demand for aggregation – of the EU-level policy makers. It also supports local governments in developing local policy and actions in line with the principle of subsidiarity that has to be applied when measuring community and household level actions (Zaman 2017).

Figure 4



Discussion

Indicators on waste prevention

The key legislative document of the European Union is the Waste Framework Directive (Directive 2008/98/EC) defining and regulating waste prevention, and

giving guidance on what is expected to be monitored. Of the measures recommended, municipal waste is related to those addressing the consumption and use phase of products. This includes tools like payment for packaging, awareness raising campaigns, eco-labels, consumer information, the integration into public and corporate procurement, and finally, the promotion of repair and reuse centres with all types of measures (including education, logistics, etc.). The identified main guiding documents of waste prevention are listed in Figure 5.

Figure 5

Legislation and policy documents commanding waste prevention in the EU and in Hungary – chronological (not legislative hierarchical) order



Due to the length limits, the detailed analysis of EU and national legislation and policy paper measures are not presented in this paper, although three types of approaches were found regarding the focus of monitoring.

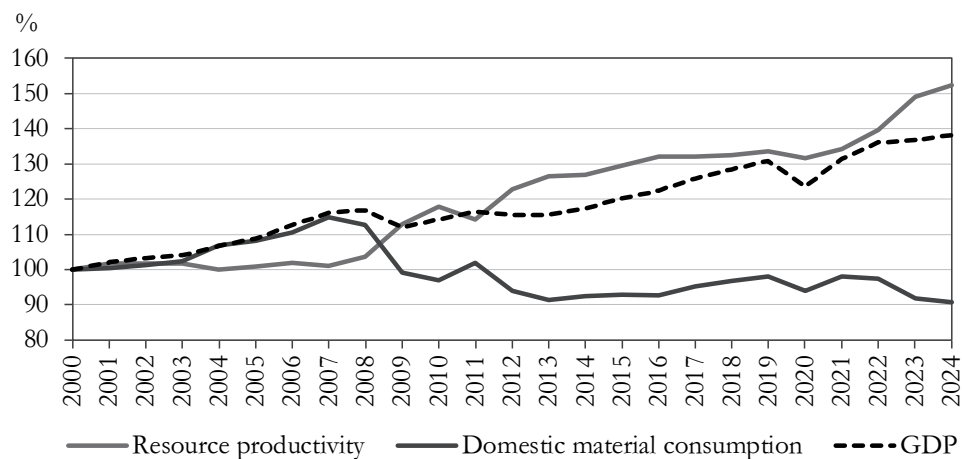
The first, most common category of indicators were found to be quantity-based waste indicators – waste generation in absolute or relative terms (per GDP or population), or waste generation of various waste streams (e.g. food waste). These mass indicators appear in every document analysed. There is a rationale in using waste generation as a general outcome indicator, but it cannot distinguish between the effect of waste prevention policies (Salhofer et al. 2008), behaviour changes, and the socio-economic drivers that have an indirect effect on waste generation through consumption and production. An economic recession may lead to a decrease in municipal waste generation, but this is not necessarily a consistent behavioural change.

An alternative approach to measuring waste prevention policy is linked to the concept of dematerialisation or decoupling meaning the absolute or relative reduction in the quantity of materials used by an economy and/or the quantity of waste generated in the production of a unit of economic output (Cleveland–Ruth 1999). Decoupling takes place in absolute terms, if the domestic material consumption (DMC) decreases, or in relative terms, if the growth of economy (in GDP) overcomes the growth rate of material consumption (Domenech–Bahn–Walkowiak 2019). Von Weizsäcker et al. (1997) claimed that although there are limits, the efficiency may

be increased through productivity. Resource productivity is considered a decoupling indicator (Fischer-Kowalski–Swilling 2011, Bringezu et al. 2017) which demonstrates the extent to which the economic growth is independent from the use of resources. The objective is to increase added value in production instead of extensive growth requiring ever more natural resources. The key indicator used in the EU Resource Efficiency Scoreboard for waste prevention was resource productivity (GDP/DMC) as a decoupling indicator, and a proxy to measure the effective use of material within an economy (Figure 6) showing a strong decoupling since the financial crisis of 2008 at first sight.

Figure 6

Resource productivity in the EU (2000 = 100%)



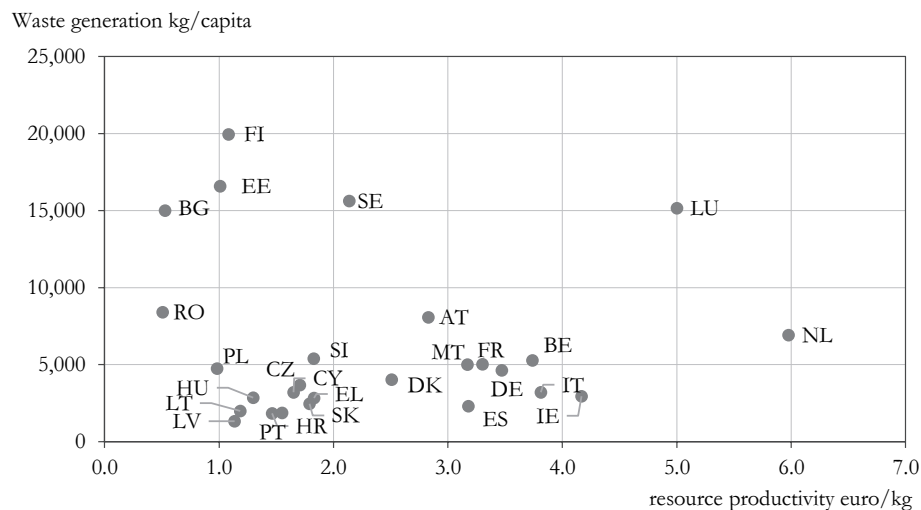
Note: GDP in chain-linked volumes, reference year 2010

Source: own compilation based on Eurostat, nama_10_gdp, env_ac_mfa, env_ac_rp (Eurostat 2026a, 2026b, 2026c).

Increase in resource efficiency equals waste prevention only if the following underlying reasons are valid: less use of material occurs by optimisation of and/or cut in production and consumption processes, i.e. the resource efficiency leads to resource saving. If the use of resources is rationalised by substitution, waste prevention may not occur in total (Cleary 2010). The outsourcing of production to the developing countries should also be mentioned as a distorting factor on the DMC when the material consumption of production is also considered beyond imported goods. Once resource efficiency increases because the growth of GDP is more intense than the growth of DMC, the reduction of waste generation in absolute terms may not be valid. It was proven in the research (Figure 7) that there is no correlation pattern between the two variables in the European Union.

Figure 7

Correlation of resource productivity and waste generation in the EU



Note: AT: Austria; BE: Belgium; BG: Bulgaria; CY: Cyprus; CZ: Czech Republic; DE: Germany; DK: Denmark; EE: Estonia; EL: Greece; ES: Spain; FI: Finland; FR: France; HR: Croatia; HU: Hungary; IE: Ireland; IT: Italy; LT: Lithuania; LU: Luxembourg; LV: Latvia; MT: Malta; NL: Netherlands; PL: Poland; PT: Portugal; RO: Romania; SE: Sweden; SI: Slovenia; SK: Slovakia.

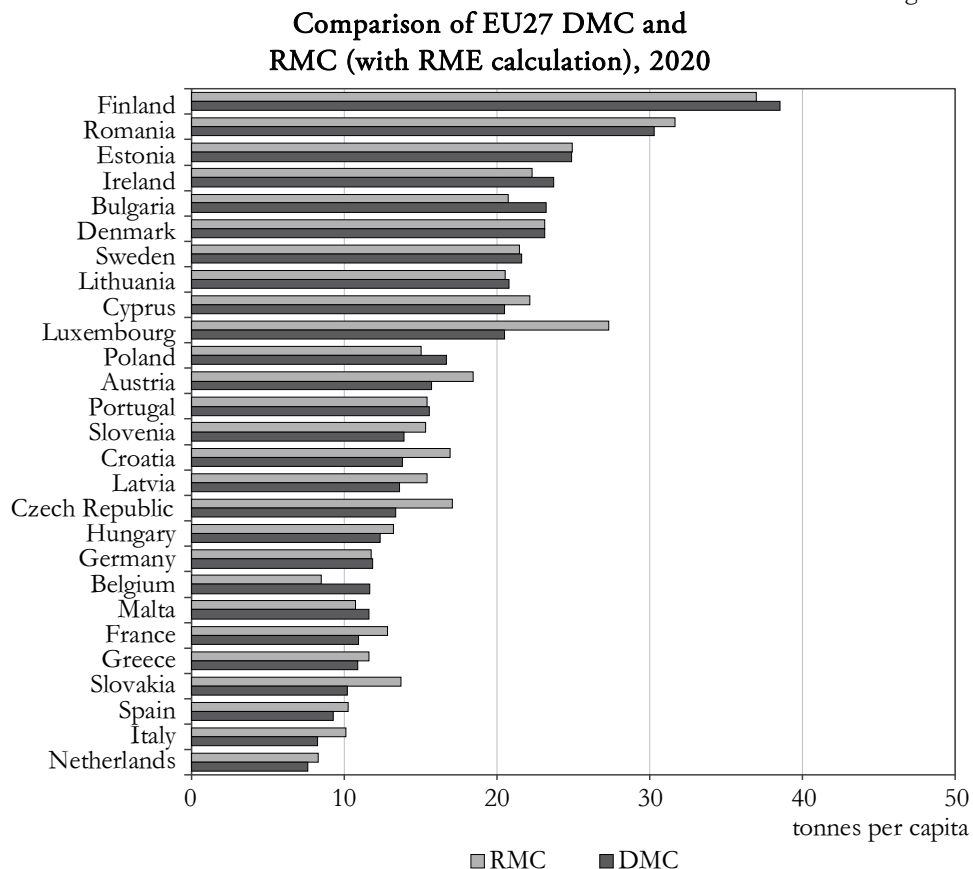
Source: own compilation based on Eurostat, env_wasgen, env_ac_rp, 2022 (Eurostat 2025a, 2025b).

Resource productivity usually refers to the level of countries' income (Fischer-Kowalski–Swilling 2011). The best correlation of municipal waste generation was with personal expenditure (0.969), indicating that waste grows expressively, if spending increases (Coggins 2001). In addition, based on the data, the income elasticity of non-hazardous (i.e. municipal and packaging) waste in the EU might go below one in the medium term, but it is not negative (Mazzanti 2008), suggesting that decoupling cannot become reality. Growing consumption is expected, and even if recycling rates rise, the environmental pressure will further increase for the growing waste generation.

The economy-wide material flow accounts (EW-MFA) tracking the inflow and outflow of materials in an economy should also be mentioned in a broader context, not only via its most used indicator, the DMC. The system of material flow accounts, however, faces data availability problems, especially when it comes to tracking the cross-border footprint of production and consumption. A Swedish research on the cross-border climate impact of consumption has found that the major part of the emissions (>60%) related to Swedish consumption is realised outside its borders (Palm 2018). The international life cycle of production implies the outplacement of

waste generation to developing countries. This practice may result in the underestimation of waste generation of the European Union falsifying achievements in prevention. As a complementary model, the MFA in raw material equivalent (RME) was introduced at Eurostat (Schoer 2023) in an attempt to convert the imported and exported products in mass weight in a form which includes the estimated amount of raw material used during production. One interesting derived indicator is the raw material input (RMI) including domestic extraction and the RME of imports. The other is the raw material consumption (RMC) indicator generated by deducing the RME of exports and exported materials from the RMI, presenting the overall material consumption of an economy including cross-border impacts. The difference between RMC and DMC should be the raw material that was not consumed but was used during production (e.g. spoil of extraction). Given the Swedish example (Palm et al. 2019), the question seems obvious: how is it possible that RMC and DMC are so close to each other (Figure 8)? The author suggests considering RMC with caution due to ongoing methodological improvements, and uncertainties in estimation.

Figure 8



Source: own compilation based on Eurostat env_ac_rme, env_ac_mfa (Eurostat 2026d, 2026b).

The third group of indicators, as in the case of the Circular Economy Monitoring Framework (EC 2018), relate to production and consumption with indicators on green public procurement and self-sufficiency in raw materials. The update of the circular economy monitoring (Eurostat 2023) included additional material use indicators. Other indicators in this group appear in the national waste prevention programmes discussed below.

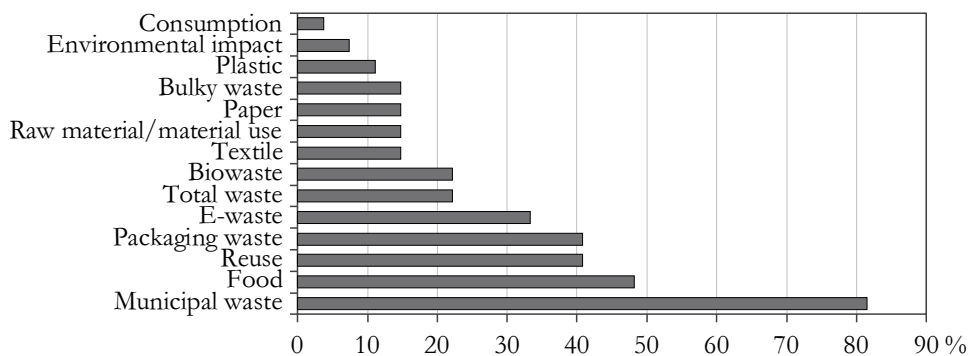
National waste prevention programmes: policy measures, targets and monitoring

Article 29 (3) of the WFD expects member states to set up appropriate monitoring of waste prevention measures. The national waste prevention programmes were finalised by the end of 2013. The 2020 revision of the national programmes (EEA 2020) has concluded that 9 out of 27 member states did not set any quantitative target, so the progress was slow, but in the 2023 revision (EEA 2023) there was substantial improvement.

The most common target was reduction of the total generation of municipal waste, but packaging waste and food waste were also addressed as priorities due to the new regulations (Directive 2019/904, EU 2019). Setting recycling targets is typical, despite the fact that recycling may immediately counteract prevention by offering an alternative to households in waste management in which the responsibility is transferred to the waste management company. The motivators for prevention and recycling are clearly different: prevention is linked to inner drivers, values and beliefs and environmental concerns, while recycling is rather normative, motivated by social pressure (Barr 2007, Bortoleto et al. 2012, Cox et al. 2010), and may have a pull effect on consumption.

Figure 9

Distribution of indicators of the national waste prevention programmes based on their subject (% of countries, EU27=100%)



Source: own compilation based on EEA (2023).

Contrary to the situation in 2020, as of the metrics of prevention, in the 2023 review total waste generation as an indicator has lost its prominent first place, today there is a much more diversified picture (Figure 9).

To show how decoupling takes effect, either absolute, or relative indicators (to GDP, gross value added [GVA], per capita) are set which are meant to be intensity indicators. Almost all waste prevention programmes focus on the mandatory targets set by the EU on recycling (and reuse) of separately collected waste: on phasing out single-use plastic products and the reduction of food waste. Reuse is emphasised, as an implementing regulation has been adopted by the Commission on mandatory reporting of reused textiles, furniture, electronic and electrical items and construction materials. Applying waste indicators related to stages of the waste hierarchy other than prevention is misleading. The latent convergence towards end-of-pipe indicators – including recycling – stems from path dependencies understood as ‘self-reinforcing feedback loops’, meaning that once a decision for a system design is made, this is favoured over all others, as well as future alternatives (Wilts 2012).

Promising specific indicators also appeared: Austria, for example, links material use consumption to waste prevention with domestic resource productivity [€/t, index], Denmark on the other hand, uses the material footprint (raw material consumption per capita). Lithuania and Denmark measure the greenhouse gas emissions of the waste sector as an impact indicator. A predictor indicator could be the sales of products, another good example is from Denmark, where they measure the marketed amount of plastic packaging. Greece, Croatia, Belgium (in separate programmes for 3 regions) and Slovakia have an extensive list of indicators covering numerous waste streams, but due to the granularity, data availability may be an issue. Indicators on information campaigns are included in lot of countries, where policymakers understandably refuse to set targets of impact indicators on household actions. They prefer to stay on the ‘safe side’ by applying output indicators of awareness raising campaigns (e.g. number of reaches, events, distributed leaflets), as this is directly controllable. In some countries a weak point is that households are not provided with access to prevention services, e.g. reuse centres, sharing services or neighbourhood composting, or the availability of refillable packaging.

Analysis of available statistics

Part of the top–down approach in the research was the analysis of the official Eurostat database in the context of waste prevention. The model is based on the literature review: the broad conceptual framework is given by the input-output model of Bartelmus (2003), setting up the relation of natural resources, material use and consumption. The widely used monitoring model chosen as a basis was the DPSIR (drivers–pressure–state–impact–response) model from Smeets–Weterings (1999) based on the PSR (pressure–state–response) model created by the OECD in 1993.

This is a causal, circular model defining stages in the interaction of human activity and the environment, mapping the environmental effects and the responses to them, relying on descriptive indicators. The phases of the model detailed in Appendix Table A1 are 1. *driving force*, as the causes of pressure, 2. the *pressure* of human activities on environment, 3. change in the *state* of environment caused by pressure, 4. *impact* as the consequence of state in change, and 5. *responses* given by policies. Then the circle is looped as the response creates a new environment for the driving forces.

Referring to the national prevention programmes, there is hardly any circular approach. Few cases for driver indicators (demographic, material use and consumption data), and response indicators (existence of policies, incentives) occur. For the state indicator, Lithuania and Denmark present the only case with the greenhouse gas (GHG) emission of the waste sector, even though landfilling has a substantial methane emission. Waste management accounts for 20% of the anthropogenic methane emission (Hogg 2024). At the same time, Cleary (2010) and Hutner et al. (2018) presented supportive LCA models for waste prevention.

The analysis continued with the identification of relevant indicators that could be placed in the causal context of DPSIR, and to cover the material flow approach. The indicator list seemed to be the most profound in the sets proposed by Zaman (2014), Yano–Sakai (2016), and Due et al. (2023). All three indicator sets have a lot in common, and these served as a compass for the next step, which was to review the database of Eurostat. To maintain comparability, the search had to be based on the Eurostat database including data from all member states. The search resulted in 109 indicators which, based on the literature might have related to municipal waste generation as the dependent variable. Based on data availability 2020, turned out to be the most comprehensive year for providing relatively recent data. Panel regression was excluded due to the substantial data gaps in time series due to the different frequencies of surveys.

Given that avoided material can be tested by the reduction of municipal waste generation this was set as dependent variable. Pearson correlation tests were made in SPSS for the selected variables, to give a first snapshot on the relations, not only for the second most comprehensive, and most recent dataset of 2020, but also for the year 2015 (lowest missing values) as a cross-check. The test gave similar outcomes for the two years. Partly, this served as a basis for filtering out the relations that were not significant. The significant relations in waste generation showed correlation with:

- waste treatment variables (these were included, because treatment and generation data are from separate data reporting, and are not calculated from each other),
- population age indicators,
- material footprint indicators,
- environmental expenditure and performance indicators (government and households),

- the fields of education,
- GDP, final consumption expenditure, exports and imports of goods,
- individual consumption – COICOP (classification of individual consumption by purpose) – indicators,
- final consumption of households based on durability of goods.
- Two more indicators were assumed to have relation with municipal waste generation: consumption footprint obviously linking consumption with environmental effects. The Gini coefficient on income inequality was also chosen for the hypothesis that wealth distribution may influence waste prevention.

The next step was setting up the null hypothesis (H_0) followed by the verification or rejection of the causality between municipal waste generation and the independent variables. For running a regression, the sample size of the 27 EU member states was fairly small. The GPower examination proved that 2–3 independent variables could be integrated in one model. For this reason, multiple small models were built following the above mentioned material use and consumption logic, as well as for identifying demographic characteristics affecting waste generation (Table 1). These small models provide variables mainly for the *driver* and *pressure* phase of DPSIR model. The selection of the indicators within the above list was based on including indicators from the demographic, consumption and material use topics diversifying the models, so that the overlap in their explanatory effect was kept under control to clarify the specific effects of the single indicators.

Regression was made for all four models leading to the outcome presented in Table 1. In each case the explanatory level was calculated, and the significance of the relation of the model to municipal waste generation per capita was observed based on ANOVA. The variance inflation factor (VIF) was accounted for to check multicollinearity (has to be under 4 if no collinearity). The unstandardized beta was checked for all independent variables to determine if parallel or opposite motion of independent variable and dependent variable apply in the relation, and the strength of relation was also analysed for each indicator. The residual statistics were analysed following the test. The Cook's distance was checked for outlier detection. Homoskedasticity was also examined via preparing the residuals standardized plots (\hat{x} = standardized predictor, \hat{y} = standardized residual) to view if the pattern was skewed, and if the variances are homogeneous or not.

Table 1
Regression analysis of municipal waste generation per capita (kg)

Domain	Independent variable	Rationale for inclusion in model	Explanatory level (R ²)	Significance (p) of model	VIF of independent variables	Un-standardized beta of independent variables	Cook's distance	Homo-skedasticity
Population	Median age of population	As people age, they accumulate goods in their lives reaching saturation as getting older, in addition, children in the household generate lots of waste (nappies, outgrown clothes, toys, lot of damages, etc.)	Model1 0.272	0.022 significant	1.021	p=0.046, significant, negative	0.290	no skewness
	Average household size	The size of the household has a positive effect on the amount of municipal solid waste (MSW) generated, but less on per capita.						
Consumption/ population	Government spending on education (COFOG (classification of functions of government): education)	Government spending on education, leads to higher levels of education, increasing consumption, knowledge and consciousness.	Model2 0.587	<0.001 strongly significant	1.054	p=0.069, weakly significant, positive	0.208	no skewness
	Mean consumption expenditure by degree of urbanisation, cities	Consumption expenditure of population living in cities is particularly important as they are the main waste generators, and waste increases as consumption increases.						

(Table continues on the next page.)

(Continued.)

Domain	Independent variable	Rationale for inclusion in model	Explanatory level (R ²)	Significance (p) of model	VIF of independent variables	Un-standardized beta of independent variables	Cook's distance	Homo-skedasticity
Consumption/ population	Real gross disposable income of households	The income level defines consumption level.	Model3 0.654	<0.001 strongly significant	1.059	p=0.086, not significant	0.217	no skewness
	Consumption footprint	The higher the consumption footprint, the higher the amount of waste generated.			1.070	p<0.001, strongly significant, positive		
	Gini coefficient	The level of wealth distribution influences waste generation, higher inequality could lead to higher waste generation caused by wasteful consumption.			1.013	p=0.49, significant, negative		
Material/ consumption	Total individual consumption (COICOP (classification of individual consumption by purpose) total per capita)	As consumption of all purposes increases, waste generation is expected to increase.	Model4 0.684	<0.001 strongly significant	2.170	p=0.014, significant, positive	0.284	no skewness
	Raw material consumption per capita	Increasing material consumption probably leads to increasing waste.			1.098	p=0.917, not significant		
	Recycling per capita	Recycling may increase waste generation having a 'pull' effect.			2.077	p=0.016, significant, positive		

No collinearity and no outliers were found in any model. In *Model1* the assumptions of the direction of relations between the independent and dependent variables were verified. In *Model2* the expectation that higher government spending on education would lead to reduced municipal waste generation by achieving higher consciousness was not proven. The explanation may be that higher level of education increases wellbeing, thus consumption and waste generation. The mean consumption expenditure and the consumption footprint from *Model3* understandably have a strong positive effect on municipal waste generation, particularly in an urban environment. The assumed effect of the Gini coefficient on the dependent variable was confirmed but with a negative relation. Higher level of Gini coefficient (with value between 0–1) means a higher level of equality in the distribution of wealth within a country. As an outcome, a more balanced level of wealth distribution leads to a higher level of waste generation. This may occur because in a balanced wealth distribution, more households participate in the consumption, thus multiplying household-specific products. Total individual consumption increases municipal waste, and recycling also has a positive relation. The pull effect of recycling on consumption was proven in *Model4*: if the waste problem seems solved by waste management companies, the individual does not have to pay close attention to reducing waste. This underpins the vastly different individual drivers in waste prevention and recycling.

The above regressions prove that *Model1–4* are all in a causal relationship with municipal waste generation. The variables of the models all have an effect on the amount of municipal waste generated per capita, except for two where null hypothesis, H_0 was accepted: one was the real gross disposable income of households in *Model3*, but was kept in the model to control. The other not significant indicator is raw material consumption per capita, currently calculated based on estimations. Most probably, due to the limited available sample size (EU27 countries), this regression model was unable to verify the causal relationship, which does not mean that it does not exist.

Results: a new indicator set for waste prevention

“How can waste prevention be monitored in the European Union?” was the main question of the research. The outcome is that the dual approach in waste prevention is unavoidable. As waste prevention depends on diverse, generally small-scale actions difficult to standardize, it is not enough to set top–down targets, especially when current monitoring is based on national or EU-level aggregates, that frequently do not have settlement level breakdowns. The EU expects members states to report in a standardized format, to be able to aggregate and put forward the outcomes of the joint efforts of the union. Comparability is also important as the relative efforts of the member states should also be recognized. However, the development of indicators

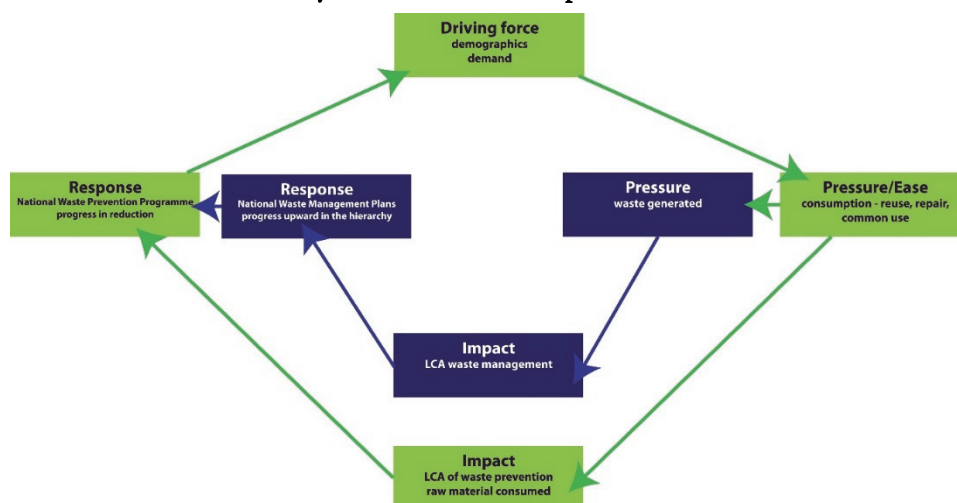
should not only serve the top–down expectations, but also monitor the bottom–up reality and support local authorities. The reveal of the causal relations will improve the forecasting ability.

An indicator set may be a convenient form, rather than a composite index to reduce risks from methodology, to avoid over-aggregation causing information loss, and to diversify among the various drivers and impact areas. The basic monitoring framework chosen was the widely used DPSIR model (Smeets–Weterings 1999). The main drawback with this framework is that it focuses on the environmental burden particularly in the *pressure* phase, but there is no space for including parallel reduction of stress on the environment, i.e. waste prevention that could be named *ease* leading to DESIR in the future. This could only take place if there was standardized data collection on waste prevention. Another problem facing DPSIR was that in the case of waste generation the *state* of the environment is hard to describe, and even if we could quantify the GHG emission or the soil or other damage caused by waste management operations, those are just one, smaller portion of the waste’s environmental effect. The main problem – especially in the context of waste prevention – goes back to the roots, it is the depletion of natural resources. The real *pressure* put on the environment is consumption. The *state* includes indicators causing change in the state of the environment, that is e.g. the quality of soil by landfills, quality of air at incinerators, but if we look at it from the use of natural resource, the state could be best described by the raw material consumed, i.e. what is missing from the natural resources. The *impact* is the consequence of change in state, such as the environmental, health, social and economic impacts. Waste management operations could cause illness, but also the loss of biodiversity, as well as exploiting the natural resources. *Response* includes political indicators referring to the waste prevention programmes, and this is where the local level should step in, besides providing data on prevention action. It is necessary to present national level data to the European Union, but in order to follow-up on the national waste prevention programmes, it is crucial to measure at settlement level. The aggregation of settlement level data leads to robust, reliable national data with its diversified source.

The new model of DPSIR including waste prevention is presented in Figure 10. Keeping the causal framework, the model becomes integrated. The *driving force* is based on demographic indicators. These indicators define the demand that ultimately triggers consumption. The consumption in terms of waste prevention is the real pressure, while *easing* factors step in the model by including reuse, repair and common use performance. Home composting is arguable, the author accepts the fact that it belongs to prevention as it does not leave the source site. At the same time, there is an official estimation method regulated by the European Commission which can calculate home composting, despite being only an estimation, and add it to the recycling performance of the country. Obviously, double count should be avoided.

Figure 10

The new indicator system for waste and prevention based on DPSIR



Source: own compilation based on Smeets–Weterings (1999).

The DPSIR framework is simplified by integrating *state* into *impact*. The *state* according to Smeets–Weterings (1999) includes indicators related to state of the environment caused by emission, in other words immission. Immission by definition is the aggregate level of pollutants in the environment, a general state of the environment following *pressure*. Even though it is one of the most important indicators in environmental protection, it is difficult to disentangle the single effects of the indicators on the general state of the environment. There are indicators describing the state of the environment, but in today’s statistical datasets it is not realistic to establish the connection between the ‘pressuriser’ and the general state. At the same time, the impact is crucial to understand the effect of a specific human activity, and from the impact one can indirectly conclude on the state of environment. The indicators suggested in Table 2 that have causal effect on municipal waste are based on the literature review, the policy and legislative analysis, and the regression model.

Table 2

Proposed indicators for prevention of municipal waste

Headline indicator	General indicator	Source/methodology
	Municipal waste generation (kg per capita)	official statistics
	Performance indicators	
	Waste intensity of raw material consumption per capita (MSW/RMC)	official statistics
	Waste intensity of total individual consumption per capita (MSW/COICOP total)	official statistics

(Table continues on the next page.)

(Continued.)

	DPSIR/DESIR indicator	Source	Based on
Driver	Median age of population	official statistics	regression (negative relation)
	Average household size	official statistics	regression (negative relation)
	Government spending on education - COFOG (classification of functions of government): education (% of GDP)	official statistics	regression (positive relation)
	Gini coefficient	official statistics	regression (negative relation)
Pressure	Total individual consumption – COICOP (classification of individual consumption by purpose) total per capita (chain-linked volume (2015), million EUR)	official statistics	regression (positive relation) literature (Coggins 2001)
	Mean consumption expenditure by degree of urbanisation (purchasing power standard [PPS] per household)	official statistics	regression (positive relation)
Ease	Reuse rate (tonnes or if GVA-based: million EUR)	data from reuse centres and/or online platforms, NACE retail of second-hand goods to be built in official statistics	regulation
	Repair rate (million EUR)	NACE repair sector, GVA and survey	literature (Due et al. 2023) with complementary methodology
	Common use (million EUR)	NACE rental sector, GVA and survey	literature (Due et al. 2023) with complementary methodology
	Home composting (kg/household/year)	settlement survey	literature (Zorpas–Lasaridi 2013, Cox et al. 2010)
	Other individual and community waste prevention actions: – number of households reached, – number of households taken action, – changes in municipal waste generation (before–after). (%)	survey and collection round or local MSW data compared to the outcome of the survey	literature (Zorpas–Lasaridi 2013, Cox et al. 2010)
	Raw material consumption (tons per capita)	official statistics	literature (Due et al. 2023, Zaman 2014) and correlation
(State)/Impact	Consumption footprint per inhabitant	official statistics	regression (positive relation)
	LCA waste prevention: – environmental emission of waste prevention actions (WMP), – environmental impact of waste prevention actions: global warming potential, water depletion, metal depletion, human toxicity.	calculations to be made for typical cases – estimation based on that	literature (Cleary 2010, Hutner et al. 2018)
	National waste prevention programme: – availability of quantitative targets Y/N – availability of relevant indicators (recycling excl.) Y/N – dedicated budget to the programme Y/N – rate of progress in MSW per capita reduction (%)	official programmes, country factsheets and statistics	literature (Due et al. 2023, Karigl et al. 2022, Wilts et al. 2015)
Response	Rate of settlement level with implemented waste prevention programmes to total number of settlements	administrative data collection to be built in official statistics	own proposal

The final performance can still be best measured by the municipal waste generation per capita; however, the added indicator set gives an insight into the details of policy effectiveness. The first two performance indicators are extremely important in assessing the overall outcome of consumption and production related policy actions. These three headline indicators give a good overview of how effectively the closing, and the shrinking of the loop is happening. It provides a process-oriented approach from raw material use to consumption linked to waste at the end of the process.

The settlement level disaggregation supports local governments' decision-making. Demographic data is fairly available at settlement level, but for a better forecast on waste generation, at least household consumption data would also be useful in every country. The indicators of the *ease* phase are essential in order to get feedback on local community and household actions. The *state/impact* phase could hardly be monitored directly at the settlement level for cost-effectiveness reasons, but estimations could take place.

The Commission decision laying down the rules of reuse data collection (EC 2021) is currently inexecutable for countries where reuse centres do not exist. The estimation for reused textile, and electrical and electronic equipment, furniture and construction material and products are extremely difficult to estimate in mass units, if final consumers would be the data sources. Reuse might be better covered by defining the relevant NACE¹ categories. In the case of waste prevention, not only repair (Due et al. 2023), but second-hand commerce and leasing related NACE groups and classes may also be considered. In the official structural business statistics (SBS) value added, or net turnover data of the following groups/classes are proposed to be taken into account (referred to as 're-sector' by the author): 47.79 covers retail sale of second-hand goods; 77.2 covers rental and leasing of personal and household goods; 77.33 covers rental and leasing of office machinery, equipment and computers; 77.39 covers renting and leasing of other machinery, equipment, and tangible goods n.e.c., 95.1 covers repair of computers and communication equipment; 95.2 covers repair of personal and household goods.

Complementary to that, there are deeper changes in classifications that could be supportive: classifications of official business statistics should be adapted to such demands, and reused goods should be distinguished in PRODCOM² similarly to secondary raw materials. To gain more granular data, the physical infrastructure should first be established for collecting items for reuse, repair and rental besides recycling on usual data collection can be built.

¹ Nomenclature statistique des activités économiques dans la Communauté européenne (NACE), classification of economic activities in official statistics.

² PRODUCTION COMMUNAUTAIRE' (Community Production). Prodcum data cover the economic activities of mining and quarrying, manufacturing, and materials recovery, which refer to the sections B, C, and E of the 'Statistical classification of economic activities in the EU' (NACE).

Home composting is now included in recycling data reported to the EU based on an estimation formula. Home composting should be excluded from recycling and should get an independent indicator as one of the most important household actions of waste prevention.

Other local actions (reducing packaging waste, nappies campaigns, avoidance of single-use cutlery at events, short supply chain-based shopping, etc.) could be collected via surveys. Indicators for important waste streams may also be included (e.g. food waste, e-goods, furniture, etc.).

Conclusions

The limitations of natural resources have become palpable in our lifetime due to disturbances in the supply chain, while the economy of the European Union heavily relies on imports of goods and material, as well as the export of waste outside the borders of the union. The very basis for reducing its material dependency is to cut the material throughput and the total consumption in the economy, i.e. prevent waste generation.

The EU- and national-level policies contain a great variety of policy measures for waste prevention, but policy documents show much less consistency in measuring these actions. In addition, due to the variety of measures, comparability and aggregation of the data sets are not resolved. The presented indicator set for waste prevention meets these requirements. At the same time, it provides granular data that is below national level, which brings monitoring closer to the local level where actions are planned, supporting local governments with relevant data. The widely used DPSIR model of Steel (1996) could be used to show the improvements in environmental burdens using a process approach. However, it was expanded to not only measure the environmental pressure caused by waste generation, but also to monitor waste prevention actions and their positive effects.

The key indicators are composite indicators formed by the author relying on Eurostat official statistics on conceptual basis which connect material flow, consumption and waste generation of countries. Today these indicators are used at a national level breakdown to show the material use performance in a life cycle approach.

The subsequent indicators were pre-sorted based on the systematic literature review and the correlation analysis of existing Eurostat indicators. Eurostat database allowed the identification of the main *drivers* of waste prevention and the *pressures* put on the environment by municipal waste generation as well as points of intervention proving causality by regression analysis.

Waste prevention actions grouped under the dimension *ease* can partly be monitored by proposed methodological development based on official statistics. This is particularly the case for repair, reuse and common use. However, the existence and effectiveness of local actions can only be revealed by surveys based on the literature.

In the case of the *state (impact)* indicators, the causal relation of raw material consumption, the consumption footprint and the municipal waste generation was proven via statistical analysis. There is an ever increasing need to develop underlying databases of LCA calculations in order measure the environmental relief caused by waste prevention actions. Two important methods in the relevant LCA calculations from Cleary (2010) and Hutner et al. (2018) which could well serve the impact monitoring have therefore been built in the indicator set.

Finally, the *response* indicators are typically non-statistical, policy indicators based on the elementary expectation taking account of the existence of a waste prevention policy, including the monitoring system and dedicated resources. The rate of ‘zero waste’ settlements is a performance indicator providing basic input for national policymaking.

The desired decoupling stemming from produces and consumer consciousness is not expected to take place in most member states. Unless waste prevention doesn’t have binding and conceptually sound targets and indicators, with formalised and standardized reporting schemes, not much will happen. The new indicator system was developed to support the evidence-based policymaking in the field of waste prevention. An improved and accountable waste prevention policy could push towards a paradigm shift in consumption and production. Waste prevention is shaking the foundations of today’s social and economic settings, by calling for the rationalisation of consumption. The present concept of economic growth must be challenged, if sustainability is a truly an objective.

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Appendix

Table A1

Phases and indicators of the DPSIR model

Phase	Explanation	Indicators
Driving force	Causes of pressure (e.g., consumption structure, urbanisation) of human goals.	describe the social, demographic, and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns. Primary driving forces are population growth and developments in the needs and activities of individuals (e.g. degree of urbanisation).
Pressure	The human activity's effect on the environment (e.g. waste).	describe developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land (e.g. waste generation per capita).
State	The pressure causing change in the state of the environment.	describe the quantity and quality of physical, biological and chemical phenomena in a certain area (e.g. quality of soil by landfills, quality of air at incinerators).
Impact	Consequence of change in state: environmental, health, social and economic impacts.	describe the impacts of the social and economic functions on the environment, caused by the state change (e.g. resources availability, number of respiratory illnesses).
Response	Responses given to the impacts by policies (laws, plans, standards, etc.)	describe responses by individuals, groups, and government to prevent, compensate, ameliorate or adapt to changes. Some societal responses may be negative driving forces, since they aim at redirecting prevailing trends in consumption and production patterns. Other responses aim at raising the efficiency of products and processes (e.g. expenditure on waste prevention).

Source: Smeets–Weterings (1999), Kristensen (2004), OECD (2004) and own amendment.

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