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Research study on holistic indicators for waste prevention

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1. Introduction, objectives and structure of this report

According to article 29 no. 3 WFD the member states shall determine appropriate specific qualitative or quantitative benchmarks for waste prevention measures adopted in their national waste prevention programmes (NWPPs) in order to monitor and assess the progress of the measures. The member states are free to determine specific qualitative or quantitative targets, and indicators for the evaluation of their efforts. This is in contrast to specific weight-based tar-gets, for example for the recovery and recycling of different waste streams as set in article 11 'in order to move towards a European recycling society with a high level of resource efficiency' (recital 41 WFD).

In the general context of environmental programs, indicators offer the opportunity to reflect specific effects and changes in complex systems. They provide the basis to evaluate existing and planned projects, to review the achievement of targets, and to facilitate dialogue with policy makers and public stakeholders. Benchmarking between different spatial entities motivates local actors to invest more time, effort and responsibility in the objectives (see OECD, 2004). In addition, indicators can also fulfil a second important function: facing the huge number of possible prevention measures that theoretically could be taken by the public sector, and, taking into account limited financial resources and also organisational capacities, indicators allow comparison of the effectiveness of different measures, and thus to select and prioritize, as an important step for the development of a NWPP.

On one hand, it is indicative that quantitative targets as an element of NWPPs could increase the binding nature of such programs. On the other hand, quantitative targets only make sense if these targets can be derived from a sound theoretical foundation and can be monitored by appropriate indicators.

Taking the European Waste Framework Directive as a reference, every waste prevention measure has to be based on article 1 of the WFD, which states that the directive 'lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use'. NWPPs shall concentrate 'on the key environmental impacts and taking into account the whole life-cycle of products and materials […] and should pursue the objective of breaking the link between economic growth and the environmental impacts associated with the generation of waste' (recital 40 WFD).

In addition to these overall goals the directive describes sub-goals regarding the prevention of waste which can be derived from article 3 no. 12 WFD. The given definition states that waste prevention means 'measures taken before a sub-stance, material or product has become waste, that reduce:

- the quantity of waste, including through the re-use
- of products or the extension of the life span of products;
- the adverse impacts of the generated waste on the
- environment and human health; or

- the content of harmful substances in materials and
- products.'

These sub-goals are no ends in themselves. Rather, it is assumed that their implementation normally supports to achieve the main goal of minimizing the ad-verse effects of waste generation on human health and the environment (see Dehoust et al., 2011). Nevertheless, this leads to a relativisation of the objective to reduce the total amount of waste. The generation of waste has to be put in relation to economic growth and its prevention is also subject to the condition that – taking into account life cycle thinking on the overall impacts of the production and management of waste – it shows the best results in terms of environmental protection (see article 4 no. 2 WFD).

Given this variety of potentially conflicting targets, it is important to develop a systemic and holistic approach that takes into account these interdependencies in order to choose the targets of a waste prevention programme. By choosing such a chain approach it is possible to assess which particular measures support each other, to identify the areas in which measures may be missing and how the most efficient combination of measures can be achieved.

Indicators and benchmarks for waste prevention are, of course, an intensively discussed topic (see Bio Intelligence Service, 2009). A variety of indicator systems have been developed, which differ significantly in topics, target groups and scope. Nevertheless, there are huge knowledge gaps in their application: 'Very little is understood about how to monitor and evaluate waste prevention particularly among local authority waste managers who are most likely to implement intervention campaigns' (Sharp et al., 2010).

Most existing approaches to the evaluation of waste-prevention measures are based on waste statics and focus on the amount of waste per capita or per household. Such waste-based approaches for the 'measurement' of waste prevention focusing on waste quantities are always confronted with a general problem: How to measure something that does not exist because it has been prevented?

Every statement about the success of a specific waste prevention measure requires comprehensive assumptions about what amount of waste would have been generated without the measure. For example, measures focusing on the design of durable goods have to take into account that effects occur with time delays depending on the products' lifetimes (see BIfA, 2004).

Because prevention is closely linked to complex consumption patterns, even cultural changes, such as increasing environmental awareness, changes in the average size of households or changes in the industrial structure of an economy, are relevant factors for the interpretation of changes in the generation of waste—it is more or less impossible to isolate the effect of specific waste prevention measures in this complex system. This must be considered, in particular, in international comparisons of policies and their potential transferability. The guidelines of the European Commission on waste prevention (Arcadis et al., 2010) also point to the particular problem of data availability in the area of prevention: as waste statistics focus mainly on the treatment and fate of wastes, they are often of limited value for prevention of waste because they don't give sufficient information about their origins or reasons for their generation.

Against this background, this report has the following objectives:

- Chapter 2 discusses strengths and weaknesses of typical waste-based prevention indicators;
- Chapter 3 analyses possible indicators that consider an upstream perspective and take into account the ecological rucksacks of products and components that have become waste;
- Chapter 4 focuses on specific product groups that could be targeted by waste prevention indicators.

In general, the report describes the complexity of measuring waste prevention and outlines pros and cons of possible approaches. The final chapter aims to draw rather pragmatic conclusions on possibly most preferable options for future policy-making.

2. Status quo and available alternatives

In a first step, this chapter discusses strengths and weaknesses of typical waste-based prevention indicators that have been identified in the national waste prevention programmes. They have been classified using the DPSIR approach in order to clarify their interlinkages and objectives.

2.1. Strengths and weaknesses of the indicator "municipal waste generation"

Municipal waste is mainly produced by households, but it includes wastes from sources such as commerce, offices, public institutions and selected municipal services as well (Eurostat n.y.). While bulky waste is included, waste from municipal sewer networks and municipal construction and demolition waste are not covered by the term municipal waste. It is collected by or on behalf of local authorities or directly by the private sector (business or private non-profit institutions) not on behalf of municipalities. Directive (EU) 2018/851 amending Directive 2008/98/EC on waste defines municipal waste as follows in Table 1.

Table 1: Definition of municipal waste (Directive (EU) 2018/851)

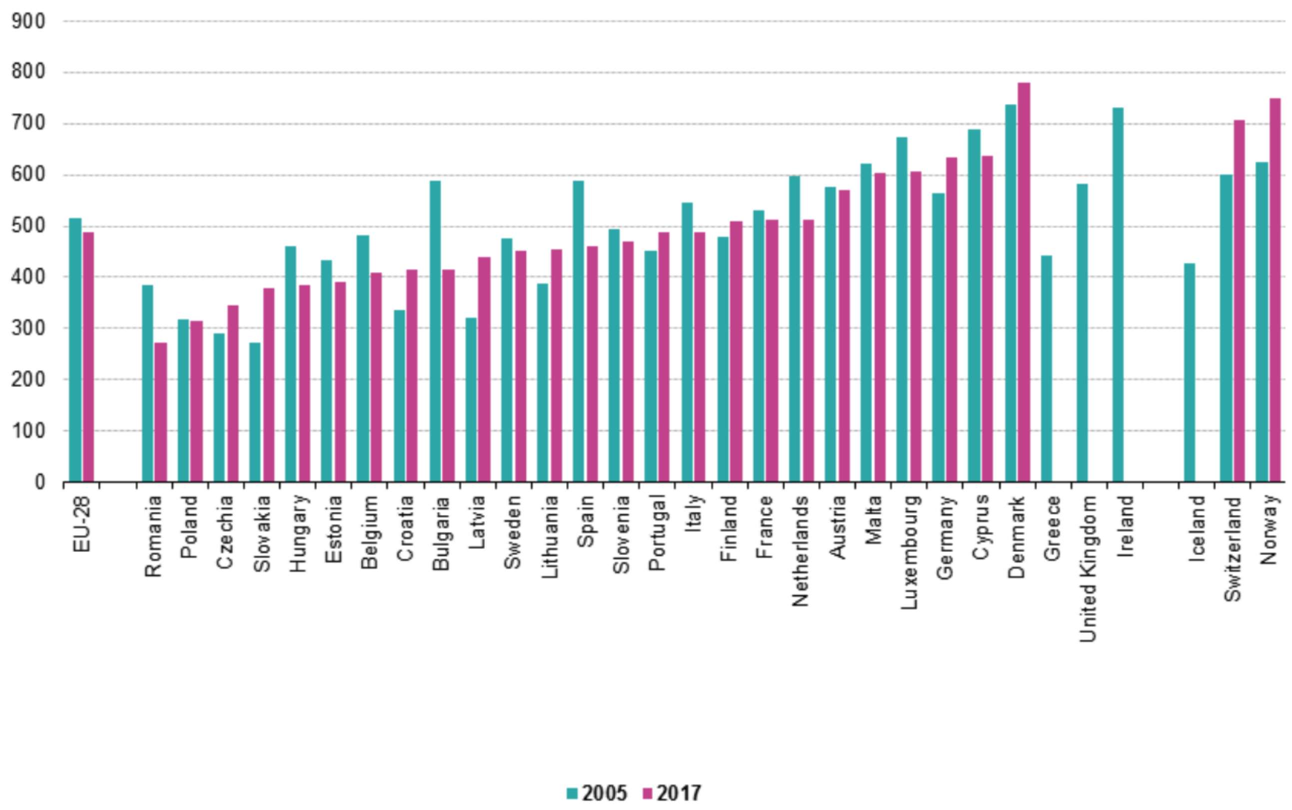
Definition of municipal waste according to Directive (EU) 2018/851 amending Directive 2008/98/EC on waste
"municipal waste" means: (a) mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, bio-waste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, and bulky waste, including mattresses and furniture; (b) mixed waste and separately collected waste from other sources, where such waste is similar in nature and composition to waste from households; Municipal waste does not include waste from production, agriculture, forestry, fishing, septic tanks and sewage network and treatment, including sewage sludge, end-of-life vehicles or construction and demolition waste. This definition is without prejudice to the allocation of responsibilities for waste management between public and private actors"

Source: European Parliament and Council (2018)

It is pointed out that the term "municipal" is used in several ways in the EU member states to reflect different waste management practices. Differences between countries can result from divergences in the coverage of these similar wastes. Waste generation rates for municipal waste are therefore influenced by, for example, the proportion of commercial waste. Due to the different approaches of the individual countries, caution is required when comparing the volumes (Eurostat n.y.).

In 2017, 487 kg of municipal waste per capita was generated in the European Union (Eurostat 2019a). Figure 1 illustrates the municipal waste generated by EU-28 countries in 2005 and 2017 in kg per capita. The total amount of municipal waste in 2017 ranges from 272 kg per capita in Romania to 781 kg per capita in Denmark. These large differences are caused on the one hand by different consumption patterns and economic prosperity. On the other hand, the data also depends on the type of collection and management of municipal waste. Countries differ in the extent to which waste from trade, commerce and administration is collected and managed along with household waste (Eurostat 2019a).

Figure 1: Municipal waste generated by country in 2005 and 2017, sorted by 2017 level (kg per capita)



Source: Eurostat (2019a)

The municipal waste indicator is a widely used indicator for the monitoring of waste generation with relatively good availability of data. However, it must be noted that the share of municipal waste is only about 10 % of the total waste volume reported in accordance with the Waste Statistics Regulation (Eurostat 2019a). In many countries, waste generation by economic activities and households is dominated by construction and demolition waste. In countries such as Denmark, Germany, France, Luxembourg, Malta, the Netherlands, Austria and Liechtenstein, this type of waste accounted for more than half of the waste generated by households and economic activities in 2016 (Eurostat 2018a). Nevertheless, municipal waste is a relevant waste stream because of its high heterogeneity, complexity and resource relevance, as well as its reflection of the behaviour of a broad spectrum of waste producers and the high political profile due to its link to consumption patterns (Eurostat 2019a, UBA 2018a, UBA 2018b). As municipal waste covers a wide range of different waste types and has a high relevance regarding resources, it can be seen as representative for the challenges of the waste management sector as a whole (UBA 2018a, UBA 2018b). For the Member States of the European Union, data on municipal waste are published from 1995 onwards[1] (data from Croatia are complete only from 2007 onwards). Data are available in thousand tonnes and kilograms per person. Eurostat notes that "[f]rom 2004 onwards, methods were finalised in most countries so that the time series of waste generation from 2004 and later are more accurate and stable than those from 1995 to 2003"(Eurostat 2019a). Regarding geographical comparability, Eurostat states: "The concept of municipal waste includes different waste streams in different municipalities. Especially, the extent to which waste generated by offices and small businesses are included differs from municipality to municipality. Thus, different levels of municipal waste generation can reflect different coverage of the generation of waste, but also differences in the organisation of municipal waste management." (Eurostat 2017). Limitations on internal coherence are outlined as follows: "The reported quantities of waste generated and treated do not match exactly for some Member States, for the following reasons: estimates for the population not covered by collection schemes, weight losses due to dehydration, double counts of waste undergoing two or more treatment steps, exports and imports of waste and time lags between generation and treatment (temporary storage)." (Eurostat 2017).

The results of a RACER evaluation for this indicator are presented in Chapter 2.3.

2.2. Indicators in Waste Prevention Programmes[2]

The amended European Waste Framework Directive (Directive 2008/98/EC) reaffirmed waste prevention as the top priority of waste management and planning of waste management infrastructures. The introduction of an additional stage of the waste hierarchy also strengthened the preparation for reuse. To support the Member States in their efforts to prevent waste, Article 29 of the Directive stipulates the development of national waste prevention programmes in which both existing measures and future fields of action for waste prevention are to be described. The Directive requires the Member States to identify appropriate benchmarks for waste prevention measures and provides the possibility to identify concrete quantitative or qualitative indicators.[3] Furthermore, Article 30 of the Directive mandates the European Environment Agency (EEA) to provide annual progress reports on waste prevention in the Member States. The identification of

[1] "Data are published for the European Union as well as for each Member State separately. The European Union is presented in its current composition (EU-28) and EU-27, as data from Croatia are complete only from 2007 on. The publication also contains data for EU-Candidate Countries and EFTA countries (Norway, Iceland, Switzerland and Liechtenstein) as well as some Balkan Countries." (Eurostat 2017).

[2] A detailed assessment of waste prevention indicators at the German level is provided by the study of Wilts et al. (2019) (forthcoming).

[3] Waste Framework Directive, Article 29 paragraph 3: "Member States shall determine appropriate specific qualitative or quantitative benchmarks for waste prevention measures adopted in order to monitor and assess the progress of the measures and may determine specific qualitative or quantitative targets and indicators, other than those referred to in paragraph 4, for the same purpose. "

specific quantitative or qualitative indicators is a particular challenge considering the complexity and variety of the specific waste prevention measures, related waste streams and stakeholder groups involved at different levels (federal, state, local). In addition, due to structural and economic developments, it is not feasible to link the decline in the amounts of individual waste streams directly to the effect of waste prevention measures.

Against this background, a comprehensive survey of possible indicators was carried out as a first step. On the basis of an extensive literature review and, in particular, an analysis of European and international waste prevention programmes, a first list of possible indicators was drawn up, which was intended to reflect as comprehensively as possible all currently used prevention indicators. A total of more than 400 indicators were identified, whereby it should be noted that particularly certain non-European indicators are based on a broader understanding of waste prevention than defined in the EU Waste Framework Directive. The analysis of existing indicators on waste prevention also focused on the intersections on resource efficiency.

Interim results from the analysis of waste prevention programmes of European Member States

Article 29 of the Waste Framework Directive obligates the Member States to establish waste prevention programmes. They have the opportunity to identify appropriate waste prevention indicators or benchmarks. On this basis, approaches to the development of indicators (e.g. with regard to selection criteria and operationalisation) from 32 available waste prevention programmes of European countries and regions that refer to Article 29 of the Directive were evaluated. Most of these programmes are only available in the respective national language. However, it was possible to refer on the one hand to the evaluations for the EEA's first progress report and on the other hand to the English summaries of the different programmes approved by the national contact points. The 32 European countries and regions whose waste prevention programmes were analysed are shown in Table 2.

Table 2: Overview of the 32 countries and regions whose waste prevention programmes have been analysed

Austria	Finland	Italy	Portugal
Brussels (*)	Flanders (*)	Latvia	Scotland (*)
Bulgaria	France	Lithuania	Slovakia
Cyprus	Germany	Luxembourg	Slovenia
Czech Republic	Greece	Malta	Spain
Denmark	Hungary	Northern Ireland (*)	Sweden
England (*)	Iceland	Norway	The Netherlands
Estonia	Ireland	Poland	Wales (*)

** Regions*
Source: Own compilation

The programmes analysed show a wide range of indicators in terms of their characteristics, number and feasibility, but there is little clarity on which of these indicators should be further examined and implemented. In addition, some countries have their own core indicators which are prioritised for monitoring, whereas other/possible indicators are not.

Interim results from the analysis of additional international waste prevention programmes

In addition to the European framework, waste prevention programmes of further countries were evaluated. For this purpose, interim results of a study carried out by the Wuppertal Institute for the

OECD could be used. The information on waste prevention policies presented in this study is mainly based on answers to a questionnaire developed in close cooperation with the OECD and sent to all OECD countries in February 2015 (Wilts 2017). The questionnaire was divided into three sections:

- The policy framework for waste prevention
- Specific waste prevention measures
- Available information on the effects of these measures.

In total, the questionnaire comprised 18 questions covering, inter alia, waste prevention indicators and related targets. 22 countries and 2 regions compiled existing information, mainly from different departments and ministries, and answered the questions so that these could then be analysed. Of these, eight were non-EU countries, which could be evaluated additionally:

- Australia
- Canada
- Chile
- Israel
- Japan
- Mexico
- New Zealand
- Turkey

The number of indicators varies significantly between countries: Some countries have defined a list of four to ten core indicators, others, such as Mexico, describe 125 different waste prevention indicators, but evaluate only three core indicators.

Based on this comprehensive list of over 400 indicators, the next step was to remove duplications, obvious references to recycling instead of waste prevention and country-specific regulations without transferability. The result was a list of 90 waste prevention indicators. For the selection of indicators to be submitted to a RACER evaluation, this list was reduced to 25 topics, i.e. different operationalisation approaches were grouped, e.g. waste generation per capita, per unit of GDP or per household.

2.2.1. Systematisation of indicators using the DPSIR impact model

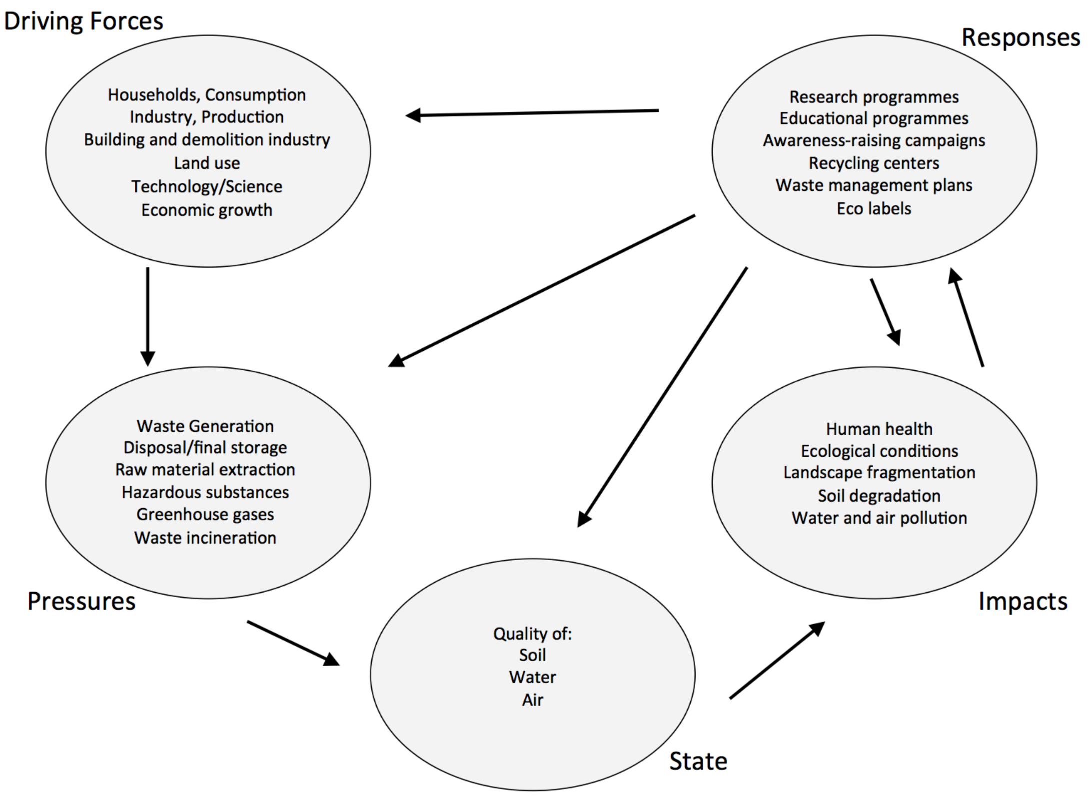
To further systematise the identified indicators, they were structured using the DPSIR impact model (Kristensen 2004). The EEA uses the DPSIR approach for integrated environmental assessment. Through the system-analytical perspective, the focus is on the interactions between environment and socio-economic activities. In a chain of causal links, a distinction is made between driving forces (economic sectors; human activities), pressures (environmental pollution), states (state of soil, water, air; changes in physical, biological or chemical processes), impacts (influence on ecosystems or human health) and responses (socio-political reactions). Indicators can thus be structured in terms of ecological quality and the resulting influence of political decisions (see Annex IV).

The DPSIR concept can serve as a tool for a descriptive analysis of the relationship between causes and consequences, focusing on the individual economic, social and environmental elements. However, in order to investigate the dynamic interactions, it is necessary to consider the link between the DPSIR elements. The relationship between drivers and pressures is expressed by eco-efficiency indicators such as waste intensity or emission factors. An increased eco-efficiency means that economic activities "without an equivalent increase in pressure on the environment" (Gabrielsen and Bosch 2003, p. 9) can be expanded.

The dynamics between pressures and states is characterized by paths and dispersion models. These relationships of indicators reflect the time lag of natural processes ("time bombs", e.g. in the form of deposited hazardous waste). If the corresponding patterns are known, current and future changes in the environmental state and its influences can be modelled. Similar dose-effect relations can also be found in the relationship between state and impact. They can be used, for example, to predict and quantify health effects or to identify suitable indicators as early warning systems. Whether society responds to ecological or health impacts depends on how they are perceived and evaluated. Central to this is a risk assessment and a cost-benefit analysis of the planned measures.

The results or the success of responses by societies depend on the effectiveness, i.e. the link between strategies and objectives: "Policy-effectiveness indicators generally summarise the relations between the response and targets for expected change in driving forces or pressures and sometimes in responses, state or even impacts" (Gabrielsen and Bosch 2003, p. 9). The following figure illustrates these relationships using the example of the generation and prevention of waste.

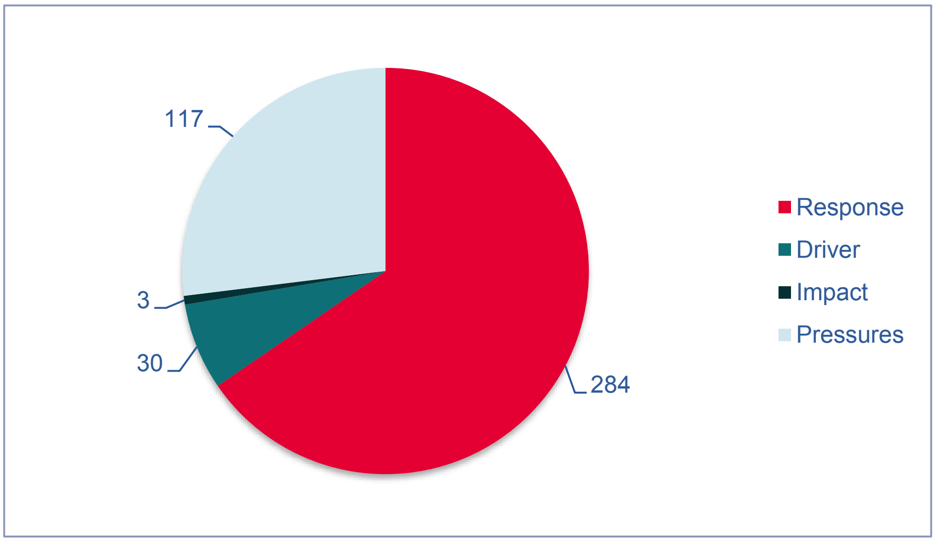
Figure 2: DPSIR framework for waste



Source: Own illustration based on Kristensen (2004)

A clear result of this differentiation step is, as shown in Figure 3, that there are hardly any impact or state-related waste prevention indicators. This gap is due to structural methodological problems, as the direct relationship between waste generation and direct environmental impacts depends on so many spatial and time-related factors that it cannot be reflected by national indicators.

Figure 3: Differentiation of the identified waste prevention indicators according to DPSIR



Source: Own illustration

Based on the analysis of the existing waste prevention indicators, a differentiation of indicators has been undertaken which relates to the DPSIR concept presented above: The first set of indicators addresses the question whether overall progress is being made in the area of waste prevention; many of these indicators focus on individual waste streams. A second group of indicators refers to the responses, i.e. concrete measures identified within the framework of waste prevention programmes, which in practice often contribute to the prevention of waste in a very limited way. A general problem with the measurement of waste prevention activities is that the development of individual waste streams cannot be seriously traced back to concrete waste prevention measures.

2.3. RACER evaluation for 16 selected waste prevention indicators

For the RACER evaluation, 16 indicators were selected (see Table 3 and Table 4). These include 8 indicators at target level representing the most relevant waste streams. The 8 response indicators reflect different approaches to waste prevention, such as general waste prevention, products, businesses and improving the level of information on waste prevention.

Table 3: Selection of indicators at target level for the RACER evaluation

No.	Indicator
1	Municipal waste generation
2	Hazardous waste generation
3	Food waste generation
4	Packaging waste generation
5	Construction and demolition waste generation
6	Amount of waste of electrical and electronic equipment
7	Waste prevention by reuse of packaging
8	Waste prevention by reuse of electronic equipment

Source: Own compilation

Table 4: Selection of response indicators for the RACER evaluation

No.	Indicator
Approach: General waste prevention	
1	Number/percentage of municipalities that have developed waste prevention programmes, plans or strategies (including those integrated into municipal waste management concepts)
2	Funding provided for waste prevention technologies and utilisation concepts
3	Number/percentage of municipal statutes obliging organisers of events in public spaces to use reusable dishes
4	Number of activities carried out as part of the European Week for Waste Reduction
Approach: Products	
5	Facilities for the sale or exchange of second-hand goods supported by local authorities (technical, organisational or monetary)
6	Number of repair networks or businesses
Approach: Businesses	
7	Number of consultations conducted for businesses concerning resource/material efficiency and waste prevention

No.	Indicator
Approach: Improving the level of information on waste prevention	
8	Number/percentage of schools that have implemented concepts on waste (if applicable only those concepts that also take waste prevention aspects into account)

Source: Own compilation

The European Commission's RACER methodology of the Impact Assessment Guidelines (EC 2009) was used to assess the suitability of the indicators determined for the monitoring of waste prevention. Accordingly, all indicators should be "RACER" as far as possible:

- (politically) relevant, i.e. closely linked to the main objective or operational targets to be achieved and therefore appropriate and meaningful in terms of progress,
- accepted by different stakeholders,
- credible for non-experts, as well as unmistakable, unambiguous and easy to interpret,
- easy to observe, monitor and communicate,
- robust against manipulation and mistakes, and robust in quality of the data base.[4]

In order to operationalise the RACER methodology, the five criteria were further differentiated. Table 5 provides an overview of the differentiated RACER matrix, which is based on studies on resource efficiency and material input indicators (Bio Intelligence Service et al. (2012), Giljum et al. (2011); Eisenmenger et al. (2014), Wiedmann (2009)).

Table 5: Criteria for the RACER evaluation

Differentiation of the RACER evaluation process
Relevant
Linkage to policy objectives • Suitable for measuring progress • Identification of trends • Rebound effects
Accepted
Policy makers • Statistics • Academia • Business/Industry • Civil society
Credible
Unambiguous • Transparent
Easy
Availability of data • Technical feasibility • Communicability
Robust
Data quality • Reproducibility • Accordance with official statistical/accounting standards

Source: Own compilation based on EC, DG ENV (2009), Bio Intelligence Service et al. (2012), Giljum et al. (2011); Eisenmenger et al. (2014), Wiedmann (2009)

[4] Additions based on Best et al. (2008): Potential of the Ecological Footprint for monitoring environmental impacts from natural resource use: Analysis of the potential of the Ecological Footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources. Report to the European Commission, DG Environment; EC, DG ENV (2012): Consultation Paper: Options for Resource Efficiency Indicators; Giljum. et al. (2011): A comprehensive set of resource use indicators from the micro to the macro level, Resources, Conservation and Recycling 55 (3): 300–308.

2.3.1. Results from the RACER evaluation

The following summarises the results of the RACER evaluation for the indicators at target level. Subsequently, the relevance of the respective waste stream to which the indicator refers and the results of the racer analysis are presented. The RACER methodology has proven to be a valuable approach for systematically highlighting the challenges for different issues in the development of indicators.

Municipal waste generation

The significance of the indicator "municipal waste generation" has already been described in chapter 2.1. The RACER evaluation showed that all criteria were fully met. In terms of relevance, municipal waste is considered to be a politically relevant stream. The linkage to policy objectives depends on the quality of the data. Provided the data quality is good, the indicator is suitable for measuring progress. Quantitative developments can be presented in absolute figures. Rebound effects are potentially covered for absolute targets and per capita data as well as per unit value added. With regard to acceptance, it can be noted that the indicator has been used by all relevant stakeholder groups – in most cases already for a considerable time – as well as in political communication. The credibility (unambiguity and transparency) depends on the clarity of the definition of municipal waste as well as the share of and differentiation from other wastes, such as packaging waste, waste of electrical and electronic equipment, paper, bio waste, food waste and in particular the differentiation from industrial waste. The availability of data and the technical feasibility are assessed rather good, the communicability depends on the clarity of the definition of municipal waste. The quality of the data is assessed as good in terms of household waste, hence also the reproducibility. The accordance with official statistical/accounting standards is assessed as rather good. A summary of the results for this indicator can be found in Table 6.

Table 6: Feedback RACER – Municipal waste generation

Feedback RACER
Relevant waste stream; accepted indicator; clarity of definition and differentiation from other waste streams (e.g. industrial waste) important; good data availability (data on municipal waste are published from 1995 onwards by Eurostat; from 2004 onwards, methods were finalised in most countries).

Source: Own compilation

Hazardous waste generation

The waste stream "hazardous waste" is considered a qualitatively important stream. The importance of the prevention of hazardous waste is primarily based on its high risk to the environment and human health compared to other types of waste. The total amount of hazardous substances used in products and production processes would be a preferred indicator, as this could be used to derive an overall effect on the environment and human health. The indicator "hazardous waste generation" can be seen as the second best available alternative – even if the total amount provides little information about the toxicity of the waste.

Properties of waste which render it hazardous can be found in regulation 1357/2014 (European Union 2014) replacing Annex III to Directive 2008/98/EC. These include: explosive, oxidising, flammable, irritant – skin irritation and eye damage, specific target organ toxicity (STOT)/aspiration toxicity, acute toxicity, carcinogenic, corrosive, infectious, toxic for reproduction, mutagenic, release of an acute toxic gas, sensitising, ecotoxic as well as waste capable of exhibiting a hazardous property listed above not directly displayed by the original waste.

According to the report "Prevention of hazardous waste in Europe - the status in 2015" (EEA 2016a), approximately 100 million tonnes of hazardous waste were generated in 2012, representing 4 % of the total amount of waste in the EU. Eurostat estimates the volume for 2016 at 100,4 million tonnes (Eurostat 2019b). The largest quantities of hazardous waste occur by the waste management, construction, and mining and quarrying sectors, as well as households. With regard to data quality, the study draws the following conclusion:

> "Data quality issues and changes in waste classification are expected to create, in some countries, discontinuity in time series of long-term trends, including on the generation of hazardous waste. This is likely to affect (at present) the setting of waste prevention targets and indicators, and it limits assessments of the effectiveness of implemented measures to qualitative terms at both European and national/regional levels. "(EEA 2016a, p. 13).

Table 7: Feedback RACER – Hazardous waste generation

Feedback RACER
Relevant waste stream; accepted indicator for qualitative waste prevention; easy to communicate; good data availability (at least for total amount); problem robustness, as significant quantity changes may result from redeclarations

Source: Own compilation

Food waste generation

It is estimated that around 88 million tonnes of food waste are generated annually in the EU-28 (Stenmarck et al., 2016). Food losses and waste cause significant environmental impacts (FAO 2013, pp. 7–37). The resources used to produce, process, transport and store food intended for human consumption which ends up as waste are responsible for greenhouse gas emissions and the loss of land, water and biodiversity. At the international level, in 2015 the United Nations committed to halve per capita global food waste at the retail and consumer levels and to reduce food losses in the production and supply chains, including post-harvest losses, by 2030 (target 12.3 of the Sustainable Development Goals (United Nations n.y.)). The EU action plan for the Circular Economy (European Commission 2015) refers to the UN's target and indicates that the EU and its Member States are committed to meeting this target. The revised Waste Framework Directive (Directive (EU) 2018/851) calls on the EU Member States to reduce food waste at every stage of the food supply chain, monitor the amount of food waste and report on progress made. A methodology for the monitoring of food losses and waste is currently being developed by the European Commission with the members of the EU Platform on Food Losses and Waste. This would allow the quantification of food waste in a consistent and comparable way at national and EU level. According to the current timetable, January 2020 is the start of the first reporting period (Zambrzycki 2017).

Table 8: Feedback RACER – Food waste generation

Feedback RACER
Extremely relevant waste stream; in particular high environmental relevance; main problem: data availability (a methodology at EU level is currently being developed)

Source: Own compilation

Packaging waste generation

Packaging fulfils a variety of functions (WRAP 2010; Denkstatt 2018) – it protects goods by preventing damage during transport and storage caused by vibration, fall and pressure, simplifies storage and transport, and offers the possibility of providing a customer with information about the contents of the product. This can be promotional, factual or mandated by law. It also provides product safety, e.g. by increasing tamper resistance, and protects the product from external influences, as mechanical (e.g. shock or friction), climatic (e.g. heat, cold or humidity) and contaminant (e.g. insects and chemicals) influences can affect the shelf life, cleanliness and quality of products. Depending on the product, however, it may also be necessary to protect the environment from it, e.g. if hazardous substances such as chemicals or acids are involved or in the case of smells. Through optimum handling, stackability, space utilisation and stability, packaging can make an important contribution to protecting resources and avoiding losses during transport.

On the other hand, packaging is also responsible for large quantities of waste. In 2016, 86.7 million tonnes of packaging waste were generated in the EU-28. This corresponds to 169.7 kg per inhabitant, ranging from 54.9 kg per inhabitant in Croatia to 220.6 kg per inhabitant in Germany. The main packaging waste materials have been paper and cardboard (35.4 million tonnes), followed by plastics (16.3 million tonnes) and glass (16.3 million tonnes). In the recent years, the generated waste increased steadily as well as the rate of recovered and recycled packaging. (Eurostat 2019c).

Especially for resource intensive products, optimised packaging can be important to protect the product and prevent it from becoming waste itself. A study examining the impact of conversion of packaging on food waste rates concluded that if in the case of roast beef, a vacuum skin packaging is chosen, the carbon footprint of the product is 200 times larger than the one of the packaging and the CO2 benefit from the reduced meat waste is 10 times higher than the total packaging effort (Denkstatt 2018). However, food waste generation has complex drivers and while some packaging has a role to play in protecting food and extending shelflife, many packaging practices increase wastefulness of both food and packaging; e.g. with regard to their role in determining the grading standards for food that often contribute to food waste (Schweitzer et al. 2018).

Table 9: Feedback RACER – Packaging waste generation

Feedback RACER
Relevant waste stream; accepted indicator; easy to communicate; rather good data quality and availability

Source: Own compilation

Construction and demolition waste generation

Construction and demolition waste "has been identified as a priority waste stream by the European Union. "(EC 2018a). The reduction of construction and demolition waste is, due to the quantities generated, an important factor for reducing the use of resources and for achieving European and national targets for the reduction of waste. However, the measures implemented in this field focus on recycling. Likewise, Directive 2008/98/EC on waste stipulates that the preparing for reuse, recycling and other material recovery of non-hazardous construction and demolition waste shall be increased to a minimum of 70 % by weight by 2020. Construction and demolition waste arises in particular during the construction, renovation and demolition of buildings, roads and bridges. The volume of this waste in the EU-28 in 2016 amounted to about 924 million tonnes, which corresponds to 36.4 % of the waste generation by economic activities and households (Eurostat 2018a). Therefore, construction and demolition waste provides a high potential for waste prevention as well as recycling and recovery and thus the conservation of natural resources. With regard to data quality, it is pointed out that "different definitions are applied throughout the EU, which makes cross-country comparisons cumbersome. "(EC 2018a)

Table 10: Feedback RACER – Construction and demolition waste generation

Feedback RACER
High acceptance, used among others by OECD; relevant waste stream (i.a. high quantity); data quality: different definitions throughout the EU; would in principle require differentiation between construction and demolition; problem of time gap

Source: Own compilation

Amount of waste of electrical and electronic equipment

Waste of electrical and electronic equipment (WEEE) consist of a complex mixture of materials and components which, due to their hazardous content and if handled improperly, can cause significant environmental and health problems (EC 2018b). Between 2014 and 2015, the volume of electrical and electronic equipment placed on the EU market increased from 9.3 million tonnes to 9.8 million tonnes. A decline between 2010 and 2013 is considered most likely due to the recession following the global financial and economic crisis (Eurostat 2018b). Electrical and electronic equipment is a diversified and very dynamic product group characterised by increasingly shorter life cycle. Analyses of life and service life trends in Germany for a total of 13 product groups in the electrical and electronic equipment sector „have confirmed that the first useful service life of a range of product groups examined has declined in recent years (e.g. TV sets or large household appliances such as washing machines, dishwashers, freezers and refrigerators). "(Oehme et al. 2017, p. 7).

Within the framework of the "WEEE package" adopted by the European Commission in 2017, the regulation 2017/699 was implemented, establishing a common methodology for the calculation of the quantity of waste electrical and electronic equipment (WEEE) generated by weight in each Member State (EC 2018b).

Table 11: Feedback RACER – Amount of waste of electrical and electronic equipment

Feedback RACER
Relevant waste stream; accepted indicator; easy to communicate; rather good data quality and availability (common methodology for the calculation of the quantity of WEEE established in 2017)

Source: Own compilation

Waste prevention by reuse of packaging

The causes of the increase in the amount of packaging waste are, among other things, changes in lifestyle and consumption patterns and a change in socio-demographic structures. This is reflected, for example, in the increased use of delivery services, the out-of-home consumption of food and beverages and the increased purchase of convenience foods (Schüler 2017). As described in the context of the indicator "Packaging waste generation", packaging has a variety of functions, such as the protection of a product. In this way, packaging can also contribute to a reduction in the use

of resources. In order to prevent the packaging itself from becoming waste, it is advisable to promote reusable packaging. Reusable packaging can cover consumer packaging, such as returnable and reusable bottles, as well as transport packaging. Industries in which reusable packaging are used include, but are not limited to, beverage and food industry, automobile industry, pharmaceutical industry and textile industry.

The EU Directive 2018/852 amending Directive 94/62/EC on packaging and packaging waste sets out that the Member States shall encourage the increase in the share of reusable packaging placed on the market and of systems to reuse packaging without compromising food hygiene or safety. This may include i.a. the use of deposit-return schemes, the setting of qualitative or quantitative targets, the use of economic incentives and the setting up of a minimum percentage of reusable packaging placed on the market every year for each packaging stream.

WRAP (Waste and Resources Action Programme) points out that Life Cycle Assessments of single-trip and reusable packaging systems „demonstrate that the relative merits of single use and reusable packaging are dependent on the specific circumstances of the individual product, packaging format, supply chain and logistics in a given situation. It is not possible to state outright that one packaging format is generically environmentally preferable to the other, as it may vary according to these factors. "(WRAP 2010, p. 30).

Table 12: Feedback RACER – Waste prevention by reuse of packaging

Feedback RACER
Packaging waste politically and quantitatively relevant waste stream; accepted indicator; problem: data availability for reuse of packaging

Source: Own compilation

Waste prevention by reuse of electrical and electronic equipment

The reuse of electrical appliances is particularly relevant from the perspective of qualitative waste prevention and with regard to the use of resources required for the production of these devices. In addition to the hazardous contents already mentioned, "the production of modern electronics requires the use of scarce and expensive resources (e.g. around 10% of total gold worldwide is used for their production)." (EC 2018)

Large household appliances account for the largest share of electrical and electronic equipment placed on the market in all EU Member States. Their share ranges from 37.7% (Belgium) to 70.2% (Bulgaria). IT and telecommunications equipment is the second largest product category in most Member States (22 of the 28 countries). Small household appliances and consumer equipment are the third or fourth in most of the countries. In 2015, large household appliances accounted for the largest share of all WEEE collected in the EU-28, at around 2.0 million tonnes or 51.5%. This was followed by IT and telecommunications equipment with 16.5% (639 964 tonnes) and consumer equipment with 15.3 % (592 584 tonnes). Small household appliances accounted for 9.7% (270 291 tonnes) of WEEE collected. (Eurostat 2018b)

The aim of the WEEE Directive is to foster the reuse, separate collection and recycling and other forms of recovery of WEEE in order to reduce the amount of waste to be disposed of. The revision of the WEEE Directive (2012/19/EU) leads to a gradual increase in the collection targets. The collection target for the reference year 2019 will be set at 65% of the average weight of electrical and electronic equipment placed on the market in the three previous years. Depending on the category, since 2018 the targets have been that 75–85 % of WEEE shall be recovered and 55–80 % shall be prepared for reuse and recycled.

Table 13: Feedback RACER – Waste prevention by reuse of electrical and electronic equipment

Feedback RACER
Waste prevention of electrical and electronic equipment politically and quantitatively relevant waste stream; accepted indicator; rather good data availability

Source: Own compilation

Results from the RACER evaluation of response indicators

The indicators assessed for the evaluation of prevention measures are response indicators. According to the DPSIR system (see Chapter 2.2.1), this means indicators that measure the degree of societal reaction to an environmental problem, such as market penetration by a comparatively environmentally friendly technology or the establishment of certain institutions and policies. The indicators presented thus provide information on activities in the field of waste prevention. It is hardly possible to link the fields of action directly to waste streams, i.e. to assign them "pressure" indicators (i.e. indicators that measure the release of emissions and the use of resources). The disadvantages of the assessed response indicators are that the information that an activity has been carried out alone does not allow conclusions about the quality or success of that activity. In addition, most of the required data are not available in official statistics and have to be collected for this purpose. The advantage of these types of indicators is, however, that they show in which areas measures have been taken, where gaps remain and where they can initiate a political debate on the implementation of waste prevention programmes. In order to increase the informative value of the indicators, it may be useful to complement the numerical values with qualitative information.

The RACER evaluation carried out for the response indicators differed from the evaluation of the target indicators, in particular by the fact that most of the selected indicators for waste prevention measures have not yet been collected. Therefore, the analysis was mainly a hypothetical examination, investigating existing data options and possible availability of data, to test the suitability of the measure-related indicators for the monitoring of progress.

Within the framework of this hypothetical RACER evaluation, on the one hand not all categories of criteria of the evaluation were applied – for example, the criterion of acceptance by different stakeholder groups was not evaluated, since the question of acceptance of indicators that do not yet exist cannot be answered a priori via desktop research. On the other hand, the RACER analysis has revealed a number of questions relating in particular to the following criteria:

- Credible: unclear terminology or blurred delimitations can impair the transparency and unambiguity of the indicators (e.g. what does a municipal waste prevention programme have to include to be considered as such)

- Easy: unclear terminology, as well as missing, unknown or sporadically available data, complicate a final evaluation of data availability, technical feasibility and communicability

- Robust: in combination with unclear terminology, the question of data quality and reproducibility arises. If data is lacking or the quality is not known, the reproducibility of the results is not guaranteed.

Table 14 illustrates the results of the RACER evaluation for the response indicators. These show that most of the evaluated criteria were fulfilled or rather fulfilled. The criterion „Accordance with official statistical/accounting standard "was not met for any of the response indicators. The reason is that these indicators have generally not yet been used. The indicator "Number/percentage of municipalities that have developed waste prevention programmes, plans or strategies" could only partially fulfil the criterion "unambiguous" as explained above. The indicator "Number/percentage of schools that have implemented concepts on waste" could only partially fulfil the criterion "credible" (unambiguous and transparent) due to unclear terminology and blurred delimitations.

Table 14: Results from the RACER evaluation of response indicators

Indicator	Relevant		Credible		Easy				Robust	
	Suitable for measuring progress	Identification of trends	Unambiguous	Transparent	Availability of data	Technical feasibility	Communicability	Data quality	Reproducibility	Accordance with official statistical/ accounting standards
Approach: General waste prevention										
Number/percentage of municipalities that have developed waste prevention programmes, plans or strategies (including those integrated into municipal waste management concepts)	completely fulfilled	completely fulfilled	partly fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	completely fulfilled	rather fulfilled	rather fulfilled	not fulfilled
Funding provided for waste prevention technologies and utilisation concepts	completely fulfilled	completely fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	completely fulfilled	completely fulfilled	rather fulfilled	not fulfilled
Number/percentage of municipal statutes obliging organisers of events in public spaces to use reusable dishes	completely fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	rather fulfilled	rather fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	not fulfilled
Number of activities carried out as part of the European Week for Waste Reduction	completely fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	completely fulfilled	not fulfilled
Approach: Products										
Facilities for the sale or exchange of second-hand goods supported by local authorities (technical, organisational or monetary)	completely fulfilled	completely fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	not fulfilled
Number of repair networks or businesses	completely fulfilled	completely fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	not fulfilled
Approach: Businesses										
Number of consultations conducted for businesses concerning resource/material efficiency and waste prevention	completely fulfilled	completely fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	not fulfilled
Approach: Improving the level of information on waste prevention										
Number/percentage of schools that have implemented concepts on waste (if applicable only those concepts that also take waste prevention aspects into account)	completely fulfilled	completely fulfilled	partly fulfilled	partly fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	rather fulfilled	not fulfilled

Source: Own compilation

criterion completely fulfilled	criterion rather fulfilled	criterion partly fulfilled	criterion not fulfilled

3. Upstream Indicators

As outlined in section 2, the aggregated, volume-based waste indicators which are employed by Eurostat mostly refer to the weight of generated waste, yet do not take into account its upstream resource consumption. However, even within the same waste streams, upstream resource consumption induced by one kilogramme of waste differs, such as between garden cuttings and (different kinds of) discarded food in biowaste. As a consequence, informational limitations emerge for the analysis and development of waste prevention policies, especially with regard to four aspects: first, insufficient information on upstream resource consumption could pose barriers to an ecologically oriented prioritization of product groups in waste prevention policies. Thus, some lightweight products, such as mobile phones, may be critical in ecological terms but may scarcely influence the weight of the generated waste. Second, current waste statistics do not reflect ecological deteriorations induced by particular kinds of material substitutions. This becomes particularly relevant in cases, when materials are substituted by such more lightweight alternatives, which induce higher upstream resource consumption. One example is the substitution of steel by more lightweight but also more resource-intensive materials, such as aluminium, fibrous composite materials or titanium. Third, waste statistics neglecting upstream resource consumption are not providing information on the effects of ecological changes in upstream production processes, which are, however, targeted by other EU policies, such as by the EU resource efficiency roadmap (EC, 2011b). Fourth, effects of shifting production processes abroad, such as to countries with less restrictive environmental standards, are not reflected in the existing statistics. Such geographic burden shifting may reduce the waste figures of EU statistics, even if the resource consumption induced along the supply chain of the respective product increases.

In sum, lacking upstream perspectives in currently existing EU waste statistics may imply that a) prioritizations of product groups in waste prevention policies can be biased, that b) false conclusions on ecological developments can be drawn, and that c) an integrated consideration of waste and resource efficiency data is hampered. However, such an integrated consideration could support policy integration, for example, by providing insights into the extent to which waste prevention actually supports the EU in achieving its resource efficiency objectives (EC, 2011b).

3.1. Upstream indicators focusing on aggregated waste streams

On this background, the question emerges, which alternative indicators may address the described informational limitations. As shown in section 2, in Europe, several alternative indicators have been developed, such as circular economy indicators applied by Eurostat (Eurostat 2019d) or indicators applied on the national or regional level (EEA 2016b). However, among these alternative indicators, upstream perspectives are only beginning to be developed in some experimental attempts (EEA 2016b).

By contrast, extensive discussions on the analysis and measurement of upstream resource consumption have evolved in the field of resource efficiency policy and some upstream indicators are already applied in the official resource efficiency statistics of some European countries and regions (for an overview of resource efficiency indicators, of the state of their political application and of data availability, see Table 21 in the Annex II). Again, these indicators have not been related to specific circular economy aspects so far, such as the reuse of products or the use of secondary raw materials in production.

Therefore, the question emerges how circular economy indicators could be developed in a way that a) includes upstream perspectives and b) allows coherence to existing resource efficiency indicators. One attempt of developing a circular economy indicator in this way is currently conducted in Germany. In particular, the revised German Resource Efficiency Programme (Deutsches Ressourceneffizienzprogramm II; ProgRess II) demands further research on the upstream indicator "Direct and Indirect Effects of Recovery" (DIERec). DIERec represents a virtual indicator showing the total amount of raw materials that would have to be additionally extracted (domestically and abroad) if no secondary raw materials were used in production processes (BMUB, 2016). Being closely related to the non-upstream indicator "Direct effects of recovery" (DERec), DIERec thus allows measuring the direct and indirect effects of substituting primary by secondary raw materials. Table 15 depicts the differences between the two indicators.

Table 15: Newly considered circular economy indicators in the German Resource Efficiency Programme II

Indicator	Depicted aspect	Upstream indicator
DERec	DERec represents the amount of primary raw materials, semi-finished goods and goods which would have to be imported or extracted domestically if no secondary raw materials were used (Quelle: ProgRess II).	no
DIERec	As an extention of DERec, DIERec additionally depicts the amount of raw materials which would have to be additionally extracted both domestically and abroad. DIERec is calculated on the assumption of similar production processes and technologies being applied domestically and abroad.	yes

Employing DIERec as an additional, upstream circular economy indicator might particularly support an integration of circular economy and resource efficiency indicators, as DIERec data can be set into relation to the upstream resource use indicator "raw material input" (RMI) (BMUB, 2016, see Table 21 in the Annex II for a description of the indicator RMI). Thus, based on DIERec data, a virtual RMI could be calculated showing the RMI value which existed if no secondary raw materials were employed.

Concerning the interpretation of DIERec, a high DIERec may especially provide information on a particular aspect of waste prevention, namely on waste prevention occurring in the first stages of the supply chain. In particular, a high DIERec implies that a lower amount of waste is generated during the extraction of raw materials (e.g., in the form of waste sludges) and during refinery. While thus providing information particularly on waste prevention *upstream*, DIERec may not be employed as a general indicator of the state of waste prevention. Thus, waste prevention further downstream, such as in the use phase, may even decrease the value of DIERec. This results from the fact that increased reuse or repair activities reduce the amount of waste generated and thus the amount of secondary raw materials which can possibly be produced. In the same sense, when set into relation to resource efficiency indicators, DIERec may particularly provide information on resources saved upstream, but not on resources saved due to more sustainable consumption patterns.

3.2. Upstream indicators focusing on specific products

In comparison, upstream indicators for specific products and services are comparatively well developed and could support waste prevention policy, particularly as far as prioritizations of product groups are concerned. Especially two ways of analysing upstream environmental effects of products are established so far, which are partially interlinked and described below.

3.2.1. Comparison of life cycle assessments (LCAs) and footprint indicators in the evaluation of environmental impacts

Conducting LCAs can be considered as a *first* way of assessing environmental impacts of products from a lifecycle perspective. LCAs describe all material and energetic flows entering and leaving a product system, such as energy, raw materials, working materials, waste products, emissions or waste water (ISO 14040: 2006). While life cycle assessments allow a holistic consideration of the environmental impacts connected to particular products, the employed indicator sets may often inhibit a comparison between products. Thus, figures depicting the different kinds of flows, such as of raw materials and waste water, may not be evaluated against each other in product comparison, as this would resemble a comparison between "chalk and cheese" (Ayres 1995). Furthermore, qualitative assessments included in LCAs, such as predictions of environmental impacts, also face limitations due to the variety of interacting environmental effects and related knowledge gaps or due to limitations in data availability (McManus et al. 2015). Therefore, a comparison of products based on LCAs may be hampered by the availability of comparable data in sufficient quality and might lack robustness against knowledge gaps concerning the environmental effects of resource flows.

By contrast, the described problems are reduced if only (elaborated forms of) footprint indicators are employed. While footprint indicators can be calculated within the broader scope of an LCA, they can also be employed as self-standing environmental impact indicators. In the following, such a self-standing use of footprint data will be considered as a *second* way of assessing environmental impacts of products.

A major advantage of exclusively employing footprint data in product comparison is their comparability. Thus, footprint indicators, such as the material footprint, employ one condensed figure to describe "the whole of interactions between humans and their ecosphere" (Schmidt-Bleek 1994) which occur along supply chains of particular products. Footprint indicators are robust against knowledge gaps relating to the environmental effects of material flows and can be calculated in a consistent way.

However, footprint indicators also dispose of several weaknesses. Thus, the condensed character of the provided information does not allow detailed insights, such as into the scarcity of the employed raw materials or into the environmental effects of their processing. Therefore, footprint data may foremost be considered as transparently calculated estimates, but not as exact measurements, of environmental impacts induced by the production of particular products.

Based upon the strengths and weaknesses of LCAs and footprint indicators discussed above, an intermediate way between these two approaches might prove suitable for prioritizing product groups in waste prevention policies. Thus, we suggest to evaluate product groups based on a limited set of analytical criteria, of which footprint data represent one criterion. The approach we suggest is described in more detail in section 0.

3.2.2. Comparison of existing footprint indicators

Out of the variety of footprint indicators, such as water, carbon, material or land footprints, in the following, two methodologically mature and interlinked indicators will be described in more detail: cumulative raw material demand (Kumulierter Rohstoffaufwand; KRA) and cumulative energy demand (Kumulierter Energieaufwand; KEA). Both, KRA and KEA can be calculated based on guidelines developed by the German association of engineers (Verband Deutscher Ingenieure, VDI; see VDI 2012, 2018). In comparison, KRA and KEA dispose of different advantages. Thus, empirical indication from regression analysis with up to 1200 products suggests that environmental impacts of products are more precisely depicted by KEA (Huijbregts et al., 2006; Huijbregts et al. 2010; Müller et al. 2016), due to the various impacts fossil energy generation has on the natural environment. By contrast, KRA provides particular opportunities to be linked to other data from the field of circular economy and resource efficiency, due to its material focus. Such opportunities of achieving data coherence particularly emerge, as KRA is methodologically equivalent to RMC in economy-wide material flow analysis (Müller et al. 2016.; see Table 21 in Annex II for a description of RMC). Table 16 summarizes the aspects depicted by KRA and KEA.

Table 16: Aspects depicted by the indicators KRA and KEA

Indicator	Depicted aspect	Upstream indicator
KRA	KRA comprises all raw materials used for the production and transport of a product along the supply chain, including energy raw materials. As in RMC, unused extraction is not depicted in KRA figures.	yes
KEA	KEA comprises all primary energy, which is required for the production, use, and disposal of a product or which is otherwise caused by this product.	yes

Source: UBA, 2012

3.3. Targets for upstream indicators

In general, it has been argued that targets for material footprints on the level of products or product groups could provide false incentives, as material footprints are not sensitive to the ecological effects of the material flows they depict (Müller et al. 2016). Compared to such product-oriented footprints, economy-wide material flow indicators dispose of a highly aggregated character, which to a certain extent balances the different ecological effects of the material flows occurring in economic areas. If targets for economy-wide material flow indicators are set, they would, in particular, provide guidance for the required intensity of waste prevention policy by depicting the required level of impacts.

However, in line with the infant state of aggregated upstream indicators on waste prevention (see section 3.1), concrete targets for their development have not been suggested so far. A current attempt to develop such targets has been launched by the German Resource Efficiency Programme II, which demands scientific research on targets referring to DIERec (see section 3.3). In particular, research projects are supposed to develop targets on shares of DIERec in RMI (as well as of DERec in DMI; BMUB 2016).

In general, upstream-oriented indicators of waste prevention could build upon the limited, though growing number of studies, which have developed transparently calculated targets for decreases in resource consumption based on upstream indicators (UNEP 2011; UNEP and IRP 2014; Bringezu et al. 2014; for an overview, see Box 1). Thus, upstream-oriented targets could define the extent to which different aspects of waste prevention should contribute to reductions in resource consumption. For this purpose, the development of further upstream circularity indicators besides DIERec would represent a necessary next step.

In order to develop such further indicators, the development of an extended product data basis might be particularly relevant. Such a data base could, for example, focus on particularly resource-intensive product groups and contain data

- on the upstream resource consumption of the sold products (e.g., KRA data),
- on products put on the market, or
- on products prepared for reuse.

First approaches into this direction already exist. For example, the Austrian food retailing company Hofer has introduced a declaration on upstream resource consumption for all the products offered under its bio-brand "Zurück zum Ursprung". Furthermore, WEEE and old vehicles statistics of Eurostat already include data of products put on the market respectively on reuse (see Table 23 in Annex III).

An analysis of product groups, which might be suitable for respective prioritization in terms of data generation, will be conducted in the following section.

Box 1: Targets for resource consumption based on upstream indicators

Targets for resource consumption based on upstream indicators

Targets for resource consumption have been developed in several studies. For example, Bringezu et al. (2014) have taken the global metabolism of the year 2000 as a point of departure (which is lower than the current one) and have calculated the amount of resources which in the year 2050 could be consumed equally per capita worldwide in order to arrive at the global metabolism of the year 2000. For this purpose, Bringezu et al. assume a global population of 9 billon people in 2050. They calculate that in this case, 10 t TMC_{abiot} could be equally consumed globally per person per year. Within the EU27, this would imply a decrease in 68% compared to the level of the year 2008 which was 31 t TMC_{abiot} per year per person.

Calculated analogously for RMC, a reduction to 5,2 t RMC per capita per person per year could be consumed by all people worldwide in 2050 in order to realize the global metabolism of the year 2000. Similar to TMC figures, this would amount to a reduction of 68 % in the EU27 compared to the year 2008.

Such a return to the global metabolism of the year 2000 could already be considered as an ambitious target, as global population grows and as resource consumption has increased since 2000 with an even stronger growth rate in the subsequent decade (Lettenmeier et al. 2018). However, such progress would probably not suffice in terms of sustainability. In fact, it has been argued that a sustainable level of global resource consumption might require efforts to reduce resource consumption to a level far below that of the 1990s (Bringezu 2009; Schmidt-Bleek 1993; Weizsäcker et al. 1997).

Another approach has been chosen by Günther et al. (2015), who have developed targets for the upstream indicator of "total raw material productivity", which is measured as GDP+Imports/RMI (see **Error! Reference source not found.** in Annex II for a description). Examining the case of Germany, Günther et al. focus on the *technically feasible* potentials of increasing total raw material productivity. Departing from an estimation of these potentials, they calculate that in Germany, an annual increase of 2 to 2,5 % in total raw material productivity could be feasible, which would amount to an increase of 40 to 60 % in 2030 compared to the year 2010.

4. Product priorities (WP3)

Waste prevention indicators with a focus on particular product groups might in various ways complement the existing circular economy indicators (Eurostat 2019d). Thus, the currently existing information on aggregated waste streams only partially allow strategic analyses of waste prevention, as causes of waste generation differ widely between product groups, such as between mobile phones or motor vehicles. Therefore, analysing framework conditions for waste prevention may have to take into account product-specific aspects, such as developments of second-hand markets, innovation cycles, or meanings assigned to the purchase and consumption of particular products by consumers. On this background, the provision of data depicting the development of waste prevention in particular product groups could support the identification of framework conditions supportive of waste prevention. Furthermore, the effects of introducing respective policies could be monitored based on such product-specific data. On this background, initially the question arises which product-specific data on waste prevention are available at present in the EU.

4.1. Status quo of product-specific waste prevention indicators in the EU

Currently, a limited number of indicators focusing on waste prevention in particular product groups exists. Thus, directive (EU) 2015/720 (EU, 2015), which amends the packaging directive, demands Member States to report on the consumption of lightweight plastic carrier bags. Further reporting duties on plastic waste are currently discussed with regard to the single use plastics directive, which has been proposed by the European Commission in May 2018 (EC, 2018c). According to the proposed directive, waste data are supposed to be monitored across several single-use plastic products.

Furthermore, several EU directives on extended producer responsibility require member states to provide data on waste generation with regard to the focused product groups. At present, these legislations include the Waste Electrical and Electronics Equipment (WEEE) directive (EU, 2012), the batteries directive (EC, 2006), and end-of-life vehicles directive (EC, 2000). An overview of data member states have to provide under these schemes is provided in Table 23 in Annex III.

While these directives demand member states to report on product-specific waste volumes, they also have several weaknesses. Thus, only the end-of-life vehicles directive requires member states to report on the actual volume of *reused* products.

Furthermore, no data are collected on more differentiated aspects of waste prevention, such as on refurbishing, remanufacturing or reselling activities. Similarly, no product-specific data exist on resource-efficient forms of consumption, which also support waste prevention, such as sharing or leasing practices. Due to these shortcomings, analyses of policies addressing product-specific aspects of waste prevention based on quantitative data are facing considerable limitations so far.

4.2. Analytical criteria for prioritizing product groups for waste prevention monitoring

In order to improve the product-specific database on waste prevention indicators, the question emerges which product groups should be prioritized for a respective monitoring. Besides the upstream indicators analysed in section 3.2, further criteria for such prioritization can be derived from current political discussions on product and waste prevention policy. In particular, political documents and accompanying research referring to the revisions of the Waste Framework Directive (EU, 2015; EEA 2018; EEA 2017) and of the Ecodesign Directive (EC, 2016) are relevant in this regard. Table 17 provides an overview of the discussed, critical aspects, which might be taken into account when prioritizing product groups in waste prevention monitoring. Furthermore, the identified discussed aspects are assigned to two assessment dimensions.

Table 17: Product-specific aspects shaping the relevance of monitoring waste prevention in

Discussed critical aspect (citing document)	**Assessment dimension**
Relevance of critical raw materials (1)	Ecological, social and economic relevance of waste prevention
Resource consumption (3)	
Critical social impacts of upstream production processes (1) (3)	
Critical ecological and social impacts in the end-of-life phase (1) (2) (3) (4)	
Gaps between conceivable and actual realization of ecodesign (1) (2) (3) (4)	Potentials for improving waste prevention in particular product groups
Potentials of increasing market shares of reuse, repair and reselling activities (1) (2) (3) (4)	
Potentials of increasing market shares of sharing and leasing models supportive of resource protection (1) (2) (3)	
Availability of data based on already implemented or planned EU legislations	Pre-existence of political processes supportive of waste prevention or its monitoring

(1) EC, 2015, Circular Economy Action Plan (EC 2015)
(2) EEA, 2018, Waste prevention in Europe (EEA 2018)
(3) EEA, 2017, Circular by design (EEA 2017)
(4) EC, 2016, Ecodesign Working Plan 2016-2019 (EC 2016)

As shown in Table 17, four of the critical aspects emerging in the reviewed literature refer to the "ecological, social and economic relevance of preventing waste" in particular product groups. Taking into account the critieria from this dimension in product prioritization can ensure that such product groups are prioritized whose production, use and disposal or recycling induce particularly problematic effects. In the following, the relevance of these (ecological, social and economic) aspects in prioritizing product groups for waste prevention monitoring is discussed in more detail.

- *Relevance of critical raw materials in production processes*

  First, the use of critical raw materials is considered as an aspect suggesting the prioritization of the product group in question. In a broad definition, critical raw materials are conceived as such raw materials, which are critical either with regard to their reserves, or with regard to environmental or social aspects of their sourcing and refinery (EC, 2014). The use of critical raw materials can be considered as particularly problematic in cases when the materials are not recovered, for example as a consequence of lacking recycling opportunities or product design.

- *Resource consumption*

  Furthermore, a high resource consumption of products along their lifecycle represents a further aspect suggesting their prioritization in waste prevention monitoring. As discussed in section 3, an assessment of this analytical category will be conducted based on upstream indicators, particularly the indicator KRA, and not based on LCAs due the condensed information provided by KRA. However, KRA can only be calculated for particular products and not for whole product groups. Furthermore, the resource consumption of product groups can also be high if large numbers of products with low KRA are put on the market. Therefore, a product group will be considered as highly relevant in terms of resource consumption, if characteristic products of the product group are estimated to have high KRA *or* if mass products prevail in the product group.

- *Critical social impacts of upstream production processes*

  Critical social aspects of upstream production processes might similarly be considered when prioritizing product groups for waste prevention monitoring. For example, the violation of the norms set out by the International Labour Association (ILO) may represent such a critical aspect. The ILO norms include a) freedom of association and the effective recognition of the right to collective bargaining, b) the elimination of all forms of forced or compulsory labour, c) the effective abolition of child labour, and d) the elimination of discrimination in respect of employment and occupation (ILO, 2019). Besides the realization of ILO norms, the question whether fundamental aspects of occupational safety and health are realized also belong to this analytical aspect.

- *Critical ecological and social impacts in the end-of-life phase*

  Several aspects concerning the end-of-life phase of products also influence the importance of waste prevention. In this regard, it will particularly be evaluated to which extent waste generation in different product groups contributes to littering, including marine littering, or induces problems of illegal waste exports.

Furthermore, Table 17 shows that in the literature review, three critical aspects emerged referring to "Potentials for improving waste prevention in particular product groups". By considering these aspects, such product groups could be prioritized for waste prevention monitoring, which offer particular opportunities to be influenced by policies supportive of waste prevention. In the following, the emerging aspects are discussed.

- *Gaps between conceivable and actual realization of ecodesign*

  With regard to product design, reparability, durability, upgradability, and recyclability have repeatedly been considered as prerequisites of waste prevention (EC 2015, 2016, EEA 2017, 2018). Gaps between the technically conceivable and the actual realization of such ecodesign aspects are considered as an argument for prioritizing the product group in terms of waste prevention monitoring.

- *Potentials of increasing market shares of reuse, repair or reselling*

  Access to repair and reuse services, such as provided by municipal reuse centers (see EEA 2018), as well as the development of second-hand markets represent an important aspect of waste prevention (EC 2015, 2016, EEA 2017, 2018). However, exceptions exist. For example, in some cases, environmental impacts from energy or water consumption of old items can outweigh the resource consumption induced by the production of a new, more efficient model. Such a situation may particularly occur in cases when the resource consumption during the use phase outweighs the resource consumption during production. Therefore, products groups are particularly suggested for prioritization, if relevant gaps between the conceivable and actual market relevance of *resource-protective* forms of repair, reuse and reselling practices can be recognized.

- *Potentials of increasing market shares of resource-protective sharing and leasing models*

  Recently, it has been discussed that sharing and leasing practices can induce negative impacts on resource consumption especially due to rebound effects (Fischer et al, 2015, Schmitt et al. 2017). However, other practices, such as car sharing or tool sharing, are supposed to enable decreases in resource consumption and thus to support waste prevention (EC 2015, EEA 2017, 2018). Similarly, resource-protective leasing models exist, such as the business-to-business leasing of highly energy-efficient lighting equipment. In this sense, relevant opportunities of increasing market shares of resource-protective sharing and leasing models will be considered as a supportive argument for monitoring product groups in terms of waste prevention.

4.3. Evaluation of product groups

In the following, the assessment criteria outlined in section 0 are applied to different product groups. The evaluated product groups are chosen based on several criteria. *First*, only consumer products are considered, as causes for waste generation – and thus suitable indicators for monitoring waste prevention – may differ between private and business customers. *Second*, products groups are chosen in line with the specifications of product groups applied in existing EU waste legislations. In this way, extensions of existing data are supposed to be conducted in a way that is consistent to the pre-existing data sets (for an overview, see section 4.1). Therefore, product groups are specified in line with their differentiations in producer responsibility schemes (EU, 2012; EC, 2006; EU, 2000), the directive (EU) 2015/720 amending the packaging directive (EU, 2015), and the single-use plastics directive (EC, 2018c). *Third*, the remaining product groups (i.e., those, which are not considered under the mentioned EU legislations) are specified in line with the differentiations applied by Eurostat in its database on household expenses (Eurostat 2019e).

Methodologically, the analysis has to deal with difficulties relating the heterogeneous character of product groups. For example, with regard to the quantitative criterion of resource consumption, the existing KRA database only allows calculations with regard to individual products, while for aggregated product groups, only estimations on an ordinal scale are possible (see discussion in section 0). Similarly, only an ordinal scale can be applied when analysing the qualitative criteria, such as social impacts in upstream supply chains. Subsequently, the different product groups are analysed by evaluating the outlined criteria based on the values of a) highly relevant, b) relevant or c) lowly relevant. The evaluation is conducted based on background knowledge of the authors and by conducting internal interviews with other experts from Wuppertal Institute.

Table 18: Assessment of priority product groups for waste prevention monitoring

Assessment dimension/ criteria Product group	Ecological, social and economic relevance of waste prevention				Potentials for improving waste prevention		
	Relevance of critical raw materials	Resource consumption*	Critical social impacts of upstream production	Critical ecological and social impacts in the end-of-life phase	Gaps between conceivable and actual realization of ecodesign	Potentials of increasing market shares of reuse, repair and reselling	Potentials of increasing market shares of sharing and leasing models
Product groups considered under WEEE directive							
Large household appliances							
Small household appliances							
IT and telecommunications equipment							
Consumer equipment	d	d	d	d	d	d	d
Photovoltaic panels							
Lighting equipment							
Gas discharge lamps	c	c	c	c	c	c	c
Electrical and electronic tools							
Toys, leisure and sports equipment							
Medical devices	c	c	c	c	c	c	c
Monitoring and control instruments	c	c	c	c	c	c	c
Automatic dispensers	c	c	c	c	c	c	c
Product groups considered under End-of-Life vehicles directive							
Motor vehicles							
Product groups considered under batteries directive							
Portable batteries and accumulators							
Product group considered in the proposal of the EU Commission for a single-use plastics directive and in the directive (EU) 2015/720 amending the packaging directive							

Assessment dimension/ criteria Product group	Ecological, social and economic relevance of waste prevention				Potentials for improving waste prevention		
	Relevance of critical raw materials	Resource consumption*	Critical social impacts of upstream production	Critical ecological and social impacts in the end-of-life phase	Gaps between conceivable and actual realization of ecodesign	Potentials of increasing market shares of reuse, repair and reselling	Potentials of increasing market shares of sharing and leasing models
Single-use plastic items considered in the proposal of the EU Commission for on single-use plastics directive							
Plastic bags							
Further product groups							
Clothing and footwear							
Materials for the maintenance and repair of dwelling							
Furniture and furnishings							
Carpets and other floor coverings							
Household textiles							
Bicycles							
Spare parts and accessories for personal transport equipment	d	d	d	d	d	d	d
Fuels and lubricants for personal transport equipment							
Musical instruments and major durables for indoor recreation	d	d	d	d	d	d	d
Jewellery, clocks and watches	d	d	d	d	d	d	d
Food and non-alcoholic beverages							

Assessment dimension/ criteria / Product group	Ecological, social and economic relevance of waste prevention				Potentials for improving waste prevention		
	Relevance of critical raw materials	Resource consumption*	Critical social impacts of upstream production	Critical ecological and social impacts in the end-of-life phase	Gaps between conceivable and actual realization of ecodesign	Potentials of increasing market shares of reuse, repair and reselling	Potentials of increasing market shares of sharing and leasing models
Alcoholic beverages, tobacco and narcotics			d	d			

/ / Aspect highly relevant / relevant / lowly relevant in the product group

* Based on the duiscussion in section 0, the resource consumption of a product group is conceived as „highly relevant“ if either the upstream resource consumption, calculated by RMEs, or the number of products put on the market is high.

d Product category too diverse for assessment

c Product category does not belong to consumer products and is therefore not suitable for assessment

Based on Table 18, products can be prioritized for the further development of waste prevention monitoring. Concerning the evaluation, product groups will be suggested for prioritization if at least one critical aspect of each assessment dimension is evaluated as highly relevant (i.e., at least one aspect from the dimensions "Ecological, social and economic relevance of preventing waste" and "Potentials for improving waste prevention").

In this way, such product groups are prioritized, where lacking waste prevention causes severe problems, while at the same time high potentials for improvements exist. 9 product categories fulfil these criteria based on the assessment from Table 18:

- large household appliances
- small household appliances
- IT and telecommunications equipment
- toys, leisure and sports equipment
- electrical and electronic tools
- garment and footwear
- motor vehicles
- furniture and furnishing
- food and non-alcoholic beverages

In order to avoid shortcomings caused by product group categorization, two of these product groups might be extended based on other data also provided by Eurostat. Thus, "garment and footwear" might be extended to the product group "textiles", which would include further items, such as household textiles. Similarly, the product group "food and non-alcoholic beverages" might be extended to the product group "food and beverages" by adding alcoholic beverages. In this sense, the authors suggest the following list of product groups for prioritization in terms of waste prevention monitoring:

- large household appliances
- small household appliances
- IT and telecommunications equipment
- toys, leisure and sports equipment
- electrical and electronic tools
- textiles
- motor vehicles

- furniture and furnishing
- food and beverages

Furthermore, it is suggested to additionally integrate such product-specific data on waste prevention which are already provided by member states based on existing EU legislations (see section 4.1) in order to develop a data base as comprehensive as possible. This would include the data already generated in line with the EU producer responsibility schemes (EU, 2012; EC, 2006; EC, 2000), the directive (EU) 2015/720 amending the packaging directive (EU, 2015) (i.e., data on plastic bags) and the proposed single-use plastics directive (EC, 2018).

4.4. Possible waste prevention indicators and policy instruments

When developing waste prevention indicators, an indicator set might be employed which provides data on two levels of abstraction: *first*, indicators might be employed which provide information *on general tendencies* how waste prevention develops. *Second*, specific indicators might be employed which describe *how the concrete problems causing waste generation are developing*.

General indicators

Concerning indicators depicting general tendencies how waste prevention develops, it is suggested to employ the volume of waste in the distinguished product groups. Respective data depicting the weight-based volume are already collected by Eurostat for the product groups covered by producer responsibility schemes (see Table 23 in Annex III). Concerning the products suggested for prioritization (see section 4.3), such data already exist for the following product groups:

- large household appliances,
- small household appliances,
- IT and telecommunications equipment,
- toys, leisure and sports equipment
- electrical and electronic tools
- food waste (indicators currently under development, EC, 2018d), and
- motor vehicles.

For the product groups, "textiles" and "furniture and furnishing" no respective data exist so far.

Specific indicators

In addition to the suggested general indicators, which would be applied across product groups, a set of specific indicators could provide insights into the development of concrete obstacles to waste prevention. As such problems differ across product groups, developing respective sets of specific indicators would also require a product-specific perspective. A first suggestion for such problem-oriented sets of indicators is provided in Table 19, which refers to the critical aspects of waste prevention discussed in section 4.3.

Table 19: Problem-oriented waste prevention indicators suggested for different product groups

Waste prevention obstacle / Focused product group	Lacking ecodesign allowing durability, recyclability, reparability and upgradability	Insufficient development of reselling / second-hand markets	Insufficient development of markets for repair services	Insufficient development of markets for (resource-protective forms of) sharing and leasing models
Large household appliances	Market shares of labelled front-runner products	Market shares of second-hand products sold • in second-hand shops, • via internet platforms • in municipal (and other) reuse centers • in waste collecting points / scrapyards	• number of orders conducted by repair services • financial volume of conducted repair services	Market shares of resource-efficient forms of sharing and leasing models
Small household appliances	Market shares of labelled front-runner products	Market shares of second-hand products sold • in second-hand shops, • via internet platforms • in municipal (and other) reuse centers • in waste collecting points / scrapyards	• number of orders conducted by repair services • financial volume of conducted repair services	Market shares of resource-efficient forms of sharing and leasing models
IT and telecommunications equipment	Market shares of labelled front-runner products	Market shares of second-hand products sold • in second-hand shops, • via internet platforms • in municipal (and other) reuse centers • in waste collecting points / scrapyards	• number of orders conducted by repair services • financial volume of conducted repair services	Market shares of resource-efficient forms of sharing and leasing models

Electrical and electronic tools	Market shares of labelled front-runner products	Market shares of second-hand products sold • in second-hand shops, • via internet platforms • in municipal (and other) reuse centers • in waste collecting points / scrapyards	• number of orders conducted by repair services • financial volume of conducted repair services	Market shares of resource-efficient forms of sharing and leasing models
Toys, leisure and sports equipment	Market shares of labelled front-runner products	Market shares of second-hand products sold • in second-hand shops, • via internet platforms • in municipal (and other) reuse centers • in waste collecting points / scrapyards	• number of orders conducted by repair services • financial volume of conducted repair services	Market shares of resource-efficient forms of sharing and leasing models
Textiles	Market shares of labelled front-runner products	Market shares of second-hand products sold • in second-hand shops, • via internet platforms • in municipal (and other) reuse centers • in waste collecting points / scrapyards	• number of orders conducted by repair services • financial volume of conducted repair services	n/r*
Motor vehicles	n/r*	n/r**	n/r**	Market shares of resource-efficient forms of sharing and leasing models
Furniture and furnishings	n/r*	Market shares of second-hand products sold • in second-hand shops, • in municipal (and other) reuse centers • in waste collecting points / scrapyards	n/r*	n/r*

Food and beverages	n/r*	Volume of food given to food pantries or to food-sharing initiatives by food retailers	n/r*	n/r*

* not relevant due to product characteristics
**not relevant due to well-functioning markets

As suggested in Table 19, the development of specific obstacles to waste prevention could be monitored by the same indicators with regard to the product groups

- large household appliances,
- small household appliances,
- IT and telecommunications equipment,
- toys, leisure and sports equipment, and
- electrical and electronic tools.

By contrast, different indicators were suggested for product groups if required by product-specific characteristics or by different characteristics of product-specific market structures. In this sense, Table 19 suggests respectively different sets of problem-specific indicators for the product groups

- textiles
- furniture and furnishings,
- motor vehicles, and
- food and beverages.

In order to improve waste prevention in the outlined product groups, various policy instruments might be introduced. This may include economic incentives, such as tax reductions, or administrative facilitations, for

- repair services,
- (resource-protective forms of) sharing and leasing services,
- second-hand products,
- labelled products, or
- for such vegetables and fruits sold by retailers, which do not fulfil norms regarding their look and therefore tend to end up as waste.

Furthermore, improved regulatory framework conditions are required, such as further intensifications of ecodesign requirements relating to waste prevention aspects (e.g., repairability, upgradability). Moreover, product groups considered under the ecodesign directive might be further extended, for example to textiles.

Finally, informational instruments might be improved, such as indications of product declarations on resource consumption. As outlined in section 3.3, one good example has been implemented by the Austrian food retailer Hofer, who declares the resource consumption for all products under its bio-brand "Zurück zum Ursprung" based on relative calculations in comparison to other products.

5. Conclusions

This report has analysed different aspects of potential waste prevention indicators and clearly highlights the need for a comprehensive monitoring approach that takes into account the volumes of waste generation as well as their impacts on the environment, the key drivers for waste generation and especially the upstream impacts of the production phase.

At the same time the discussion of specific indicators also shows the severe challenges of finding the right balance of first-best indicators on the one side and on the other side that can actually be monitored: Data availability is one of the key barriers that will have to be addressed. The current system of waste statistics is designed in order to ensure that waste is properly managed but it often doesn´t allow to identify the sources or resource intensity of waste or the reasons why products have become waste.

Against this background, the following conclusions can be drawn:

- waste based indicators like total waste generation have clear limitations: The amount of waste does especially not allow assessing the quality or ambition of waste prevention policies. But nevertheless they allow comparisons between countries, especially if designed as per capita or per unit of GDP figures. Such indicators can easily be implemented and monitored using official Eurostat statistics and the announced harmonisation of national waste statistics will hopefully improve the consistency of these data.

- Preferably such indicators should focus on highly aggregated waste streams like total solid waste generation without mineral wastes in relation to GDP. This "waste intensity" of an economy could be considered a lead indicator, illustrating the decoupling of waste generation from economic growth. In addition, specifically relevant waste streams like food waste, hazardous waste and WEEE should be monitored. The amount of separately collected recyclable waste like paper or packaging bears the risk that environmentally preferable behaviour like better sorting leads to negative outcomes of a prevention indicator. With regard to packaging waste also potential trade-offs with food waste would have to be taken into account.

- These waste based indicators reflect trends in consumption and production patterns in the past, statistics are often only available years later. As discussed they also only poorly reflect the level of efforts and activities to actively support waste prevention. Against this background they should be amended with governance indicators that illustrate the success of specific responses, e.g. the rate of reused products for electronic devices and packaging. Also the number of companies participating in eco-management schemes, the size of the repair sector or the level of awareness for waste prevention could be indicators that illustrate if waste prevention is actually considered as top priority of the waste hierarchy.

- The selection of these products should definitely take into account the environmental impacts alongside the whole value chain; the amount of waste is here only a rather poor basis: Plastic bags have been in the focus of public attention not because of the total amount but mainly due to their potential contributions to marine littering; electronic products are of specific relevance because of hazardous materials and critical raw materials etc. From a viewpoint of policy consistency, this discussion should be closely linked to the development of product environmental footprints.

- The Commission has announced to develop a methodology for the monitoring of reuse rates inter alia for packaging. This discourse should definitely be used to expand the scope of products and to include indicators that monitor the amount of products put on the market. This would also open up a discussion about more specific waste prevention policy instruments that could include reduced VAT rates for repaired products. From an environmental as well as economic point of view it is clear that especially the resource intensity of a product has to become a major component for its taxation.

6. Literature

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7. Annex I Municipal Waste statistics

Table 20: Definition of municipal waste (Eurostat)

Definition of municipal waste according to the OECD/Eurostat Joint Questionnaire
"According to the OECD/Eurostat Joint Questionnaire *municipal waste* includes the following types of materials: paper, paperboard and paper products, plastics, glass, metals, food and garden waste and textiles. The definition also includes: • bulky waste (e.g. white goods, old furniture, mattresses); and • garden waste, leaves, grass clippings, street sweepings, the content of litter containers, and market cleansing waste, if managed as waste. It includes waste originating from: • households, • commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings). It also includes: • waste from selected municipal services, i.e. waste from park and garden maintenance, waste from street cleaning services (street sweepings, the content of litter containers, market cleansing waste), if managed as waste. It includes collected waste from these sources: • door-to-door through traditional collection (mixed household waste), and • fractions collected separately for recovery operations (through door-to-door collection and/or through voluntary deposits). For the purpose of this questionnaire, municipal waste refers to waste defined as above, collected by or on behalf of municipalities. The definition also includes waste from the same sources and similar in nature and composition which: • are collected directly by the private sector (business or private non-profit institutions) not on behalf of municipalities (mainly separate collection for recovery purposes), • originate from rural areas not served by a regular waste service, even if they are disposed by the generator. The definition excludes: • waste from municipal sewage network and treatment, • municipal construction and demolition waste."

Source: Eurostat (2017)

8. Annex II Economy-wide material flow indicators

Table 21: Overview of economy-wide material flow indicators

Indicator	Depicted aspect	State of development and of data availability	Upstream indicator
Domestic material consumption (DMC)	DMC counts the raw material input stemming from domestic extraction and adds the weight of imported goods. Raw materials required for the production of the imported goods are not considered by DMC (Eurostat, 2018c).	DMC is part of the EU resource efficiency scoreboard. DMC-data are provided by Eurostat.	no
Domestic material input (DMI)	DMI equals DMC plus materials required for the production of exported goods, (UBA, 2012).	DMI-Data available for EU member states, as DMI is calculated based on DMC.	no
Resource productivity	Gross domestic product (GDP) per unit of DMC	Resource productivity is employed as Lead indicator in the EU resource efficiency scoreboard. Data are provided by Eurostat	no
Raw material consumption (RMC)	As a footprint indicator, RMC represents the total amount of extracted raw materials needed to produce the goods and services consumed in the economies of countries or regions. Foreign resource consumption is calculated referring to raw material equivalents (Eurostat, 2018c).	RMC is employed in official statistics of an increasing number of European countries, such as Germany, Finland, France or Switzerland. Eurostat will depict RMC data in its resource efficiency scoreboard as soon as data are available for all EU member states (EC 2015: 13; Eurostat 2016)	yes
Raw material input (RMI)	RMI equals RMC plus resources required for the production of exported goods, Like RMC, RMI is calculated based on raw material equivalents (UBA 2012; Eurostat 2018c)	RMI-Data available for EU member states, as RMI is calculated based on RMC.	yes
Total raw material productivity	Enhancement of raw material productivity as the material footprint of the imported goods is included (Günther und Golde 2015: 8)	(GDP + monetary value of imports) / raw material input (RMI)	
Total material consumption (TMC)	Employing a broader perspective than RMC, TMC also depicts hidden resource consumption induced by unused extraction (UBA 2012; OECD 2008)	No data provided by Eurostat. Problems of applying the indicator exist due to problems of data quality with regard to unused extraction (Quelle: Günther und Golde)	yes

9. Annex III Product categories and data in Eurostat statistics

In **Error! Reference source not found.**, product groups are identified, which are a) oriented at end consumers and which are b) not covered by EU producer responsibility schemes, by the directive (EU) 2015/720 amending the packaging directive or by the proposal of the EU Commission for a single-use plastics directive.

Table 22: Identification of product groups not covered by existing EU legislations on waste prevention

Product groups not covered by existing EU legislations on waste prevention	Selected sub-categories of product group oriented at material consumption of end-consumers
Food and non-alcoholic beverages	n/d
Alcoholic beverages, tobacco and narcotics	n/d
Clothing and footwear	No differentiation by sub-category suggested
Housing, water, electricity, gas and other fuels	Materials for the maintenance and repair of dwelling
Furnishings, household equipment, and routine household maintenance	Furniture and furnishings
	Carpets and other floor coverings
	Household textiles
Health	n/r
Transport	Bicycles
	Spare parts and accessories for personal transport equipment
	Fuels and lubricants for personal transport equipment
Recreation and culture	Major durables for outdoor recreation
	Musical instruments and major durables for indoor recreation
Education	n/r
Restaurants and Hotels	n/r
Miscellaneous goods and services	Jewellery, clocks and watches

Source: Eurostat 2019e

product group not oriented at the consumption by end-consumers
product group oriented at the consumption by end-consumers

n/r not relevant
n/d no differentiation by sub-categories applied

Error! Reference source not found. provides an overview of pre-existing data on waste prevention based on producer responsibility schemes.

Table 23: Pre-existing data on waste prevention in particular product groups based on EU producer responsibility schemes

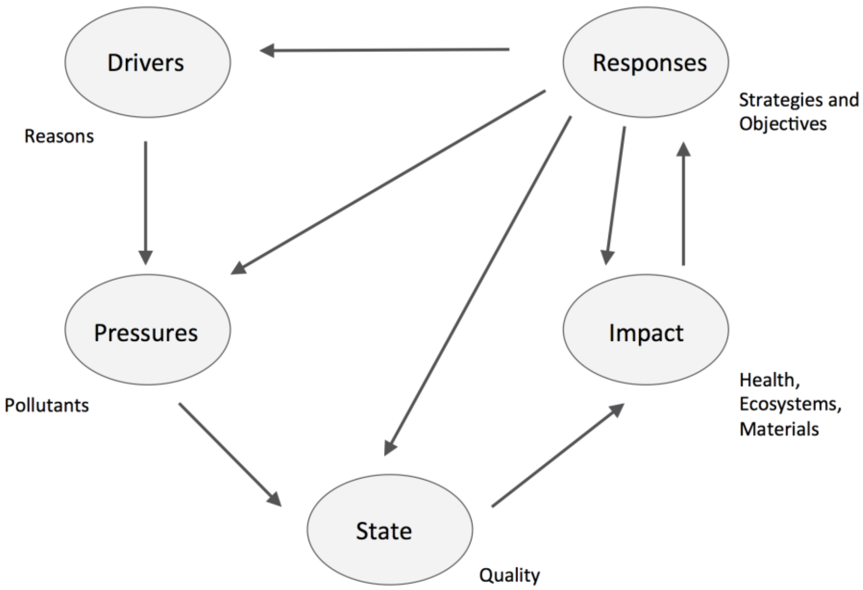
Legislation	Considered product groups	Data	Unit
WEEE directive	• Large household appliances • Small household appliances • IT and telecommunications equipment • Consumer equipment • photovoltaic panels • Lighting equipment • Gas discharge lamps • Electrical and electronic tools • Toys, leisure and sports equipment • Medical devices • Monitoring and control instruments • Automatic dispensers	Amount per capita per year	Kilogramme
Batteries directive	Portable batteries and accumulators	Sales and collection	Tonnes and percent
End-of-life vehicles directive	End-of-life vehicles	• waste generated, • disposal, • recovery, • Recovery - energy recovery (R1), • Recycling, and • Reuse	Tonnes

Source: Eurostat 2019

10. Annex IV The DPSIR model

The rationale of the DPSIR model is to differentiate waste prevention indicators according to their different approaches, which distinguish between driving forces, the environmental impacts they cause and the specific effects they have, the state of individual environmental media and concrete measures aimed at the prevention of waste.

Figure 4: DPSIR concept for environmental assessment



Source: Own compilation based on Kristensen (2004)

At this point it can be observed that social and economic developments exert pressure on the environment, resulting in changes within the environment. This leads to impacts on humans and the environment, which cause societal feedback, which in turn directly (active action) and indirectly (adaptation) affect *drivers, pressures, states* and *impacts*. Although this analytical framework cannot express the complex interactions in actual human-environment systems, a clear and specific definition of the individual factors is required in order to describe the relationship between the causes and consequences of environmental problems. These will be examined in more detail below (Kristensen 2004).

Driving Forces

In the DPSIR concept, driving forces are basic human, i.e. social, ecological and economic needs such as food, water, protection as well as secondary driving forces like mobility, culture and entertainment. They are reflected in social, demographic and economic developments and accordingly reflect changes in lifestyle, consumption and production patterns. These changes in production and consumption exert pressure on the environment through, among other things, the following driving forces:

- Population (number, demographics, growth)
- Transport (persons, goods; transport routes and means of transport)

- Energy use (fuel types, technology)
- Industry (type, number, age, resources)
- Agriculture (number of animals, types of crops, fertilisers)
- Disposal (landfills, sewage systems)
- Land use.

Pressures

Pressures on the environment are caused by human activities as a result of production and consumption processes. These can be divided into three categories: (a) excessive use of natural resources, (b) changes in land use, (c) emissions.

State

Pressures also affect the state of the environment, i.e. the quality of the different environmental areas such as air, water and soil is changed. The state depends on the physical, biological and chemical condition of the respective medium.

Impacts

Changes in the state of the environment determine not only the quality of ecosystems but also human welfare. The environmental state thus influences the functions of the environment that are central to human beings and, accordingly, their health and the economic and social performance of society.

Responses

Undesired effects of environmental impacts cause responses in society and politics in order to prevent, compensate or adapt to further consequences. These measures can relate to drivers and pressures as well as to states and impacts:

- Number of concrete measures (e.g. support of public transport)
- Number of laws passed (e.g. CO2 regulations)
- Increased efficiency of products and processes
- Increased environmental awareness (e.g. recycling rates).

Zero Waste Europe was created to empower communities to rethink their relationship with the resources. In a growing number of regions, local groups of individuals, businesses and city officials are taking significant steps towards eliminating waste in our society.

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