Calculation of the additional recycling potential in the European Union by implementing the circular economy package.

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Abstract

As part of the Circular Economy Package, the European Union has amended three waste directives to increase the recycling rates for municipal and packaging waste and to limit the landfill rate for municipal waste in a stepwise approach. The initiative has the aim to redirect waste streams, which are going to landfills at the moment, towards recycling in the future. Usually, scenarios for the impact of policy instruments on the waste management system work with complex models. This work uses the differences between existing recycling rates and future target values as a proxy indicator to calculate the additional recycling potentials of municipal and packaging waste.

According to data reported by the Member States, the European Union as a whole generated 250,642 kt of municipal waste in 2018, 117,844 kt (i.e. 47%) of which are recycled. The calculation of the additional recycling potential results in a quantity of 46.3 million tonnes of municipal waste until 2040. The biggest effort to increase municipal waste recycling (17.6 million tonnes) has to take place between the latest reporting year 2018 and the target year 2020. Regarding packaging waste, the Member States report a generated quantity of 89,005 kt and a recycling rate of 67%, which equals a recycled waste quantity of 59,643 kt. For packaging waste an additional recycling potential of 3.2 Million tonnes was calculated, the majority of which (2.1 Million tonnes) is due between 2025 and 2030. The packaging materials, which contribute most to the recycling potential, are plastic packaging (50%) and paper/cardboard packaging (29%).

Although the generated municipal waste exceeds the packaging waste only by a factor of three, the recycling potential of municipal waste is almost 15 times higher than the one of packaging waste. The higher potential of municipal waste can be explained by the historical development. The first obligation to achieve a recycling rate for packaging waste came into force in 1999, while for municipal waste it was the year 2020.

The applied calculation method works with waste data reported by the Member States. Although the quality of reported data on municipal waste has improved over the last 10 years, the harmonisation of definitions and calculation methods is not yet completed. Uncertainties exist especially regarding the revised rules, which waste fractions belong to municipal waste and which part of the material can actually be accounted as recycled. That means that an accurate application of the latest calculation rules will lead to a remarkable decrease in the reported recycling rates and therefore increased recycling potentials for several Member States. On the other hand, it has to be taken into consideration that not all Member States will be able to comply with future target values, given the existing status of reported data, which will lead to a small decrease of the calculated recycling potential.

Keywords: Recycling potential, Waste, Waste management.

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Introduction

The European Union aims at transforming its economy into a circular economy. According to Korhonen et al. [1], the Circular Economy concept "is loosely based on a fragmented collection of ideas derived from some scientific fields including emerging fields and semi-scientific concepts". The EU Commission does not provide a distinct definition, but understands Circular Economy as a concept, in which "the value of products and materials is maintained for as long as possible, waste and resource use are minimised, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value" [2]. Therefore, the European Commission has adopted a Circular Economy Package, which included proposals for the amendment of waste legislation as well as a comprehensive action plan. In the meantime, all 54 actions foreseen under this plan have either already been completed or are in an implementation phase [3].

The legally binding measures of the Circular Economy Package are implemented by amending six waste directives [4-7]. After multi-annual negotiations, the amended directives entered into

force in June 2018. The transition period for implementing the directives into national legislation ended in July 2020.

Among the policy measures of the Circular Economy Package are the introduction and/or increase of recycling rates on the one hand and the redefinition of the landfilling rate on the other hand. Increased recycling rates are introduced for municipal waste as well as for packaging waste, while the maximum landfilling rate applies only to municipal waste.

Recycling rate for municipal waste

Adaptation and increase of the recycling rate for municipal waste: The Waste Framework Directive (WFD) 2008/98/EC [6] introduced already a recycling rate for household and similar waste. In Article 11, Member States are required to take the necessary measures designed to achieve the following target: "by 2020, the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50% by weight" [6].

The amended Waste Framework Directive 2018/851/EU [6] extends the definition of the recycling rate from four selected fractions to the full waste stream of municipal waste. The recycling rate is increased step by step, from 55% in 2025 over 60% in 2030 to 65% in 2035. Member States may postpone the deadlines by up to five years provided their recycling rate is lower than 20% or the landfill rate is higher than 60% of municipal waste generated in 2013. In this case, the Member States have to notify the Commission 24 months in advance about the planned postponement and have to submit an implementation plan. According to data provided by Eurostat [8], there are 11 Member States, which fulfil the criteria for postponing the deadlines, i.e. Bulgaria, Croatia, Cyprus, Estonia, Greece, Hungary, Malta, Latvia, Lithuania, Romania and the Slovak Republic.

In addition, the amended Waste Framework Directive contains a definition of municipal waste (Art. 3 Nr. 2b) as well as more specific rules for calculating the attainment of the targets (Art. 11 a) [6].

Reporting on municipal waste recycling under the WFD of 2008: In order to establish detailed rules on the application and calculation methods for verifying compliance with the recycling targets for municipal waste, the European Commission has adopted Commission Decision 2011/753/EU [9]. According to this document, Member States can choose one out of the four following calculation methods:

- Method 1: Recycling rate of paper, metal, plastic and glass household waste, in %=Recycled amount of paper, metal, plastic and glass household waste/Total generated amount of paper, metal, plastic and glass household waste
- Method 2: Recycling rate of household and similar waste, in %=Recycled amount of paper, metal, plastic and glass waste and other single waste streams from households or similar waste stream/Total generated amount of paper, metal, plastic and glass waste and other single waste streams from households or similar waste
- Method 3: Recycling rate of household waste in %=Recycled amount of household waste/Total household waste amounts excluding certain waste categories
- Method 4: Recycling rate of municipal waste, in %=Municipal waste recycled/Municipal waste generated

In a study, Greenfield [10] has carried out an analysis of diverse sources to provide an overview of the methods, which are used by the European Member States to calculate the recycling rate:

- Method 1: Ireland and Malta
- Method 2: Austria, Croatia, Cyprus, Czech Republic, Estonia, France, Greece, Hungary, Italy, Lithuania, Poland, Portugal, Romania, Slovakia and Sweden
- Method 3: Bulgaria, Luxembourg and United Kingdom
- Method 4: Belgium, Denmark, Finland, Germany, Latvia, The Netherlands, Slovenia and Spain

Analysing the reported data, Greenfield [10] comes to the conclusion, that the different data parameters, definitions, interpretations and methodologies presently used by the Member States limit the potential for accurate reporting and comparability of Member States' recycling performance (see also section 1.4).

Introduction of maximum landfilling rate for municipal waste

The Landfill Directive 1999/31/EU of 2008 [5] contains maximum landfilling rates only for biodegradable municipal waste (Art.5). The amended Landfill Directive 2018/850/EU requires the Member States in Art. 5 "to ensure that by 2035 the amount of municipal waste landfilled is reduced to 10% or less of the total amount of municipal waste generated" [5]. That means that the newly introduced landfill rate broadens the scope of the waste stream from only biodegradable municipal waste to total municipal waste and reduces the landfill rate towards a stricter value.

The Landfill Directive also offers the possibility to postpone the deadline for the Member States to implement the maximum landfill rate by up to five years, which have landfilled more than 60% of its municipal waste generated in 2013. In this event, Member States have to comply with a reduced maximum landfilling rate of 25% for 2035. The list of the Member States, which can apply for this rule, comprises according to Eurostat data [8] Bulgaria, Croatia, Cyprus, Greece, Hungary, Malta, Latvia, Lithuania, Romania and the Slovak Republic.

The amended Landfill Directive contains no specific recycling target for packaging waste, but it prohibits in Article 5 (3) the landfilling of waste, "that has been separately collected for preparing for re-use and recycling pursuant to Article 11(1) of Directive 2008/98/EC" [5].

Increased recycling rates for packaging waste

In Art. 6 of the amended Packaging and Packaging Waste Directive 2018/852/EU [7] the recycling rates for packaging waste as a whole as well as for the specific packaging materials are increased. At the same time, the packaging material of "metals" is divided up into "ferrous metals" and "aluminium". So far, the reporting on these two subcategories had been

voluntary. The existing and upcoming targets for recycling rates for packaging waste are shown in Table 1.

Existing recycling targets have a broad range from 15% for wood to 60% for glass and paper/cardboard packaging. The new targets of the amended Packaging Waste Directive mean a doubling of the recycling rate for wood packaging and even more for plastic packaging until the year 2030. Although the existing target for paper/cardboard packaging is already high, the new recycling rate is increased by 25 percentage points, which means an additional increase of about 40%.

The Packaging and Packaging Waste Directive provides in Art. 6 No 1a also for a possibility to postpone deadlines for certain packaging materials by up to five years, however not for the deadline of total packaging waste. This option is not restricted to certain Member States and leaves open, which packaging materials may be selected [7].

Quality of reported data

Regular EU statistics on waste management are required for monitoring the implementation of waste policy [11]. In addition, waste data serve as the basis for waste management planning, i.e. the forecasting of waste streams and shaping the corresponding waste management system [12]. For these purposes, the quality of the data has to be of a high level. In a study for DG Environment, Eunomia [13] conducted a review on the quality of EU waste statistics. The study identified gaps and weaknesses in the reporting of waste data. Main issues include:

1. The accuracy and comparability of data provided by different Member States or even by different organisations within the same Member State. Reasons include different approaches of data collection (e.g. surveys, questionnaires, IT-based reporting systems) and/or different data sources (e.g. waste producer, transporter, and operator of treatment plants)
2. Inconsistencies between data sets reported for specific waste streams across different reporting mechanisms. Based on different purposes of data management (e.g. monitoring of target compliance, waste management planning), different definitions of key terms are used
3. Member States not collecting or reporting data in line with the requirements of EU legislation and/or guidance
4. Lack of procedures for verifying data at the national and European level [13]

As an example, Obermeier and Lehmann [14] analysed the recycling rate of municipal waste in Germany. They found out that the proper application of the revised definition of the term "recycling" would lead to a major reduction of the recycling rate from 68% to 52% [14].

Forecasts and scenario analyses in the waste management system

Waste management planning includes-among others-forecasts for specific waste streams and scenarios of policy instruments for reaching waste targets. The main tool for calculating forecasts and scenarios is the development of models. These models work with different mathematical approaches, such as statistical tools (e.g. correlation and regression analysis) or artificial neural networks. In the case of Municipal Waste (MSW), a high number of models have been developed. Kolekar et al. [15] have conducted a review on 20 municipal waste generation models. In addition, models regarding the recycling of MSW in specific countries have been published; examples are Hill et al. [16] for Denmark or Sahimaa [17] for Finland. Concerning packaging waste, also some models have been developed, for example by Loukil and Rouached for the MENA-region and Oliveira et al. for Portugal [18,19].

The development of a waste model, including generation, recycling and disposal of specific waste streams, is time-consuming and requires high efforts. In addition to waste data, parameters have to be included, especially from the economic and socio-demographic field [15].

In the present paper, a less complex method is used for a rough estimation of a recycling potential for municipals waste and packaging waste in the European Union.

Aim of investigation

The main purpose of introducing and/or changing recycling and landfilling rates is to redirect waste streams, which are going to landfills at the moment, towards recycling and recovery options in the future. Aim of the present paper is to utilize the newly added and updated recycling rates of the amended Waste Framework Directive, Landfill Directive, and Packaging and Packaging Waste Directive as a proxy indicator to quantify the additional recycling potentials of municipal waste and packaging waste. Regarding packaging waste, the recycling quantity is additionally calculated and analysed for the individual packaging materials. Regarding municipal waste, exemplary Member States with different performances of their waste management systems are compared. Finally, the main influencing parameters of the calculation method are described and discussed.

Materials and Methods

The materials and methods are described for municipal waste

Table 1. *Recycling rates for packaging waste according to EU Packaging Waste Directive 2018/852/EU [7].*

Packaging/Material	Minimum target 2008 [%]	Minimum target 2025 [%]	Minimum target 2030 [%]
Total packaging waste	55	65	70
Plastic	22.5	50	55
Wood	15	25	30
Metals	50	-	-
Ferrous metals	-	70	80
Aluminium	-	50	60
Glass	60	70	75
Paper and cardboard	60	75	85

and packaging waste in separate sections. The data sources and applied methods for both waste streams are principally comparable. Therefore, the first section on municipal waste contains a full description, while the second section on packaging waste highlights only the differences in materials and methods.

Municipal Waste

Waste data: The starting point for estimating the additional recycling potential is the currently available status of generation and treatment of municipal waste in the EU Member States. For this purpose, data are extracted from the database "env_wasmun" which is accessible via the Eurostat homepage [8]. Data are taken from the most recent reporting period, which is the year 2018. Only for three countries (Ireland, Greek and Cyprus) data are not available for 2018, so they had to be taken from the reporting period 2017. Waste generation quantities for the base year are kept constant for the whole period of calculation. The forecast of municipal waste quantities in each single Member State until 2035/2040 would require the development of a complex model (see section 1.5), which is not carried out in the present publication. In addition, changes which may occur by the UK leaving the European Union (Brexit) are not considered.

Treatment operations: Data about the treatment of municipal waste have to be reported according to a classification system of five treatment operations. For the purpose of the present paper, the five treatment operations are aggregated to the following three treatment classifications:

1. Landfilling: "Landfill/disposal (D1-D7, D12)"
2. Incineration: "Incineration for disposal (D10)" and "Incineration for energy recovery (R1)"
3. Recycling: "Material recycling" and "Composting and digestion"

Due to losses (e.g. water and carbon dioxide losses during biological treatment) the sum of the treatment operations equals not always the quantity of waste generated. For the calculation of the rates of the separate treatment operations, the quantity of each treatment operation is related to the waste generated and not to the sum of the treatment operations. The reason is that the official calculation of the recycling and landfilling rates relates to waste generated.

Calculation method and assumptions: The recycling potential is estimated by calculating for each European Member State the difference between the existing recycling (2018/2017) and the recycling rates of the subsequent target year (2020) as well as between the recycling rates of two consecutive target years (2020-2025, 2025-2030, 2030-2035). The additional recycling quantity is compensated by reducing the landfilled waste. After the target for the landfilling rate of 10% is reached, incinerated waste quantities are reduced. If the landfilling rate of a Member State is already below 10%, it is not further reduced.

The data in the Eurostat database are used in the published way. No check of the correct application of definitions (e.g. recycling) and calculation rules is carried out. When calculating the recycling potential, it is assumed, that the Member States actually succeed in achieving requested target values. If a Member State reaches or over-achieves already the recycling rate of a specific target year, the reported data are not changed.

Regarding the Member States, which have the option to postpone the deadline for the recycling rate and/or the deadline for the landfilling rate; it is assumed that this option is actually used. In this case, it has to be taken into consideration that a landfilling rate of 25% has to be achieved for the year 2035.

Packaging waste

Total packaging waste: The methodology for estimating the additional recycling potential regarding packaging waste is principally comparable to the methodology for municipal waste. Some differences, however, exist:

Data are extracted from the database "env_waspac" [20]. The reporting period is the year 2017, for which all necessary data are available for all Member States.

The data for packaging waste has to be reported according to five "waste management operations". For the purpose of this calculation, these waste management operations are aggregated to the following two treatment classifications:

1. Recycling: "Recycling-material" and "Recycling-other (including organic recycling, excluding material recycling)"
2. Incineration/Other Recovery: This classification includes the three waste management operations "Recovery-energy recovery (R1)", "Incineration with energy recovery (incineration at municipal waste incineration facilities that do not meet the energy efficiency criteria)" and "Other recovery"

The treatment classification does not add up to 100%, because no data about the disposal of packaging waste have to be reported. Therefore, the difference between packaging waste generated and packaging waste, which is recycled or otherwise recovered, is regarded as disposal.

Like for municipal waste, the additional recycling quantity is compensated by reducing the landfilled waste. As the Landfill Directive 2018/850 /EU does not contain a specific maximum target for landfilling of packaging waste, but the obligation not to landfill waste that was separately collected for recycling purposes (see section 1.2), the landfilling of packaging waste is reduced to zero, before the incineration is reduced.

Individual packaging materials: The Packaging Waste Directive includes not only target values for the total packaging waste (whole group), but also for five packaging materials (within the group). The calculation of recycling potentials is also carried out for each packaging material, except for metals. The reason is that existing target values and reporting on recycling rates covers metal packaging as a whole, while the future provisions are specified for ferrous metals and aluminium separately. For the year 2017, already 10 Member States have voluntarily reported data on the two subcategories. These reports show no uniform proportion between the quantities of ferrous metals and of aluminium, which varies from approximately 10%/90% in France to 45%/55% in Sweden. Therefore, a consistent estimation of a recycling potential for metals is not possible.

Furthermore, 22 Member States have reported data on "other

packaging", which can comprise materials like textiles, ceramic or cork. For these materials, the Packaging Waste Directive does not prescribe target values for recycling rates. As reported quantities are small (about 253,000 tonnes for all 22 Member States), the recycling potential for this fraction is not calculated.

In contrast to municipal waste, the possibility for Member States to postpone the deadlines for certain packaging materials is not considered in the calculation of the recycling potential. The reason is, that there are too many options for the Member States to choose from and it cannot be estimated, which ones will be actually selected.

Results

Municipal waste

The results regarding municipal waste are presented for the European Union as a whole and for three Member States as examples for countries with different waste management systems.

European union: Figure 1 shows the temporal development of municipal waste treatment when recycling and landfill rates are implemented according to the Circular Economy Package. The first column presents the actual data of all treatment classifications (i.e. recycling, incineration and landfilling), reported by the Member States for the reporting period 2018. The following columns highlight the recycling quantities, divided into previous recycling and additional recycling for the respective target year. In the last column with the final target year, all treatment classifications are included. The target value for the year 2020 applies to all Member States, as it was already introduced by the Waste Framework Directive 2008. The target year 2025 is only valid for those Member States, which have no option to postpone the implementation of the target values, while the target year 2040 applies only to the Member States, which have this option.

For the year 2018, EU Member States have reported a total quantity of generated municipal waste of 250,642 kt, 117,844 kt of which are recycled, either by material recycling or by biological treatment (composting and digestion). 70,474 kt of municipal waste are reported as incinerated (R1 as well as D10) and 56,742 kt as landfilled. The difference between the sum of the treatment operations and the quantity generated amounts

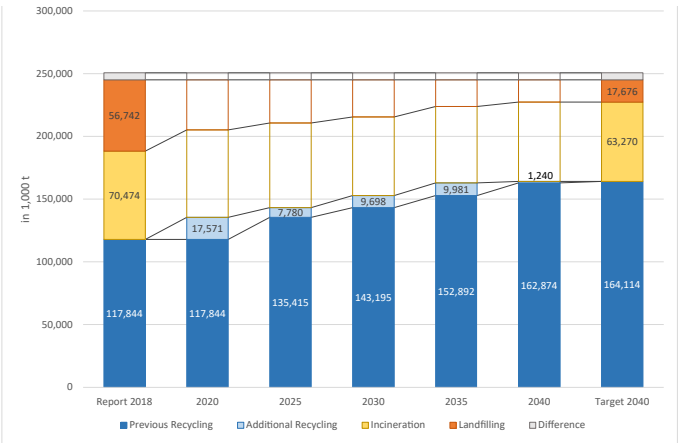

Figure 1. *Calculated time series of municipal waste treatment in the EU due to the implementation of the Circular Economy Package.*

to 5,582 kt. Related to the municipal waste quantity generated, the share of recycling is 47.0%, while 28.1% is incinerated and 22.6% is landfilled.

The calculation of the development of the individual treatment options by implementing the Circular Economy Package results in an increased recycling quantity of about 46.3 million tonnes for the whole European Union. In return, the quantity landfilled is reduced by about 39.1 million tonnes. Interestingly, also the incineration of municipal waste has to be reduced by about 7.2 Million tonnes to achieve the specified recycling rates. This is due to those cases, in which recycling needs to be further increased, but the landfilling rate has already reached 10%. The final situation with 66% recycling rate and 7% landfilling rate is even slightly better than the target values of the European Commission because some Member States have reported overachievement of the final targets already in 2018.

Recycling rate: The biggest increase in municipal waste recycling to achieve the target value has to take place between 2018 and 2020. The quantity of about 17.6 Million tonnes equals about 38% of the total additional recycling. The additional recycling for the target years 2025 until 2035 range between about 7.8 million tonnes (17%) and 10.0 Million tonnes (22%). The last step between 2035 and 2040 with 1.2 Million tonnes is the smallest one (3%), because only those Member States, which postpone the deadline, contribute to the additional recycling.

The development of individual Member States differs remarkably. Nine Member States have reported the achievement of the recycling rate of one of the target years already in 2018: Denmark, Italy, Lithuania, and Luxembourg for the target year 2020; Austria, Belgium, Slovenia and the Netherlands for the target year 2025; Germany all target years.

Among the Member States, which have the option to postpone the deadline by five years, are seven countries, which had a recycling rate below 20% in 2013, i.e. Croatia, Cyprus, Estonia, Greece, Malta, Romania and the Slovak Republic. Except for Malta and Romania, all of these Member States have improved their recycling rate until 2018. In total, four of them have not yet reached 20% so far, i.e. Cyprus, Greece, Malta and Romania.

Landfill rate: The time series of the landfilled MSW mirrors the development of recycled MSW, but in the opposite direction. The biggest decline in the landfill rate takes place between 2018 and 2020 (43%), the smallest between 2035 and 2040 (9%).

Again, the development of individual Member States differs remarkably. Nine Member States (i.e. Austria, Belgium, Denmark, Finland, Germany, Luxembourg, Slovenia, Sweden and The Netherlands) have 2018 already reached or gone below the maximum landfill rate of 10%, six of which are already below 1% (i.e. Belgium, Denmark, Finland, Germany, Sweden and The Netherlands).

Ten Member States, which have the option to postpone the deadline by five years, had a landfilling rate exceeding 60% in 2013 (see section 1.2). Except for Malta and Romania, all of these Member States have reduced their landfilling rate until 2018, but six of them (i.e. Bulgaria, Croatia, Cyprus, Greece, Malta and Romania) have not yet reached 60% so far.

Selected member states: Pomberger et al. [21] group

Member States according to their municipal waste treatment performance, which is the result of their waste management system. The three groups are recovery countries, landfilling countries and transition countries. One Member State of each group is extensively analysed in the following paragraphs.

Romania: According to Pomberger et al. [21], Romania belongs to the group of landfilling countries. In the year 2018, still, the majority (74%) of waste is going to landfills and recycling is limited to a rate of 11%. Therefore, Romania is one of the Member States that may use the option to postpone the deadline for complying with both, the recycling rate and the landfilling rate. As the starting point of the recycling rate is low, the biggest increase has to be achieved until 2020 (Figure 2). Due to the postponement of the deadline by 5 years, there is no change necessary in 2025. The following target values for 2030, 2035 and 2040 lead to identical increases in the recycling potential because each target is raised in equal steps of 5%.

Austria: Austria has already diverted a high quantity of municipal waste away from landfills and therefore belongs to the group of recovery countries. The reported recycling rate for 2018 has reached 58% and complies already with the target value for 2025. Therefore, only two steps of increased recycling have to be achieved (Figure 3). Due to the landfilling ban of 2004, the landfilling rate is already at a very low level (2%). Therefore, no additional efforts for reducing landfilling have to be made; additional recycling can only be compensated by decreasing incineration of municipal waste.

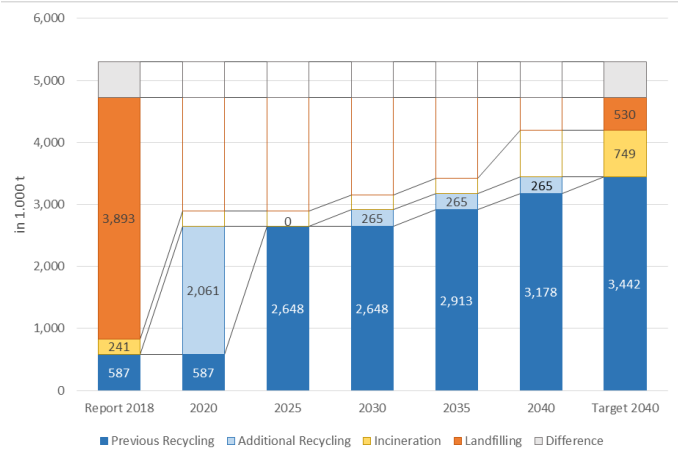

Figure 2. *Calculated time series of municipal waste treatment in Romania due to the implementation of the Circular Economy Package*

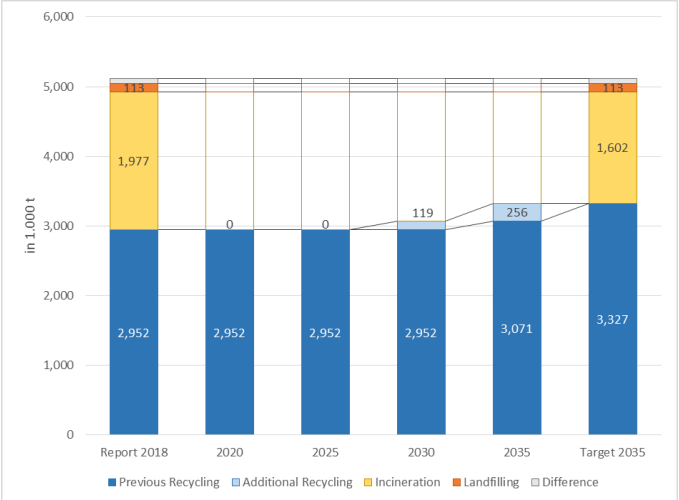

Figure 3. *Calculated time series of municipal waste treatment in Austria due to the implementation of the Circular Economy Package.*

France: With a recycling rate of 44% and a landfilling rate of 21% in 2018, France ranges in a medium level and therefore belongs to the transition countries according to Pomberger et al [21]. The waste management system has to be developed with continuous effort until 2035 (Figure 4). The steps for increased recycling and reduced landfilling have approximately the same size. The final recycling target can only be reached by reducing the incineration of municipal waste or by over achieving the landfill rate.

Packaging waste

Total packaging waste: For the year 2017, EU Member States have reported a total quantity of generated packaging waste of 89,005 kt. Already 59,643 kt of this quantity is reported as recycled and 11,565 kt are reported as other recovery, which is mostly incineration (Figure 5). The difference between total

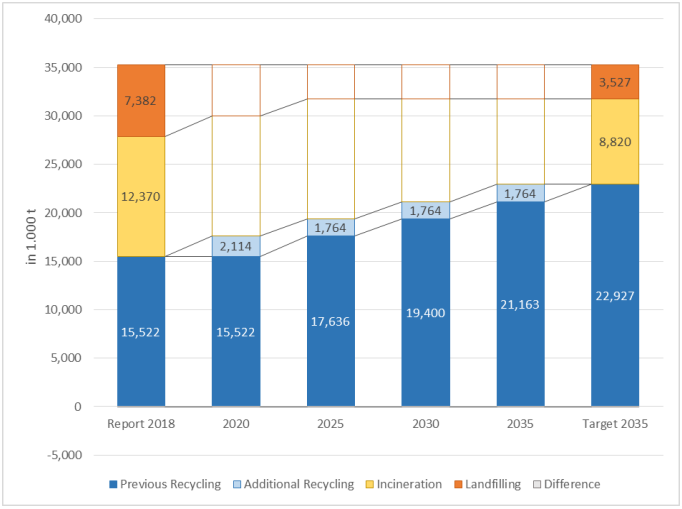

Figure 4. *Calculated time series of municipal waste treatment in France due to the implementation of the Circular Economy Package.*

Figure 5. *Calculated time series of packaging waste treatment in the EU due to the implementation of the Circular Economy Package.*

packaging waste generated and the sum of packaging waste recycled or recovered can be regarded as disposal and amounts to 17,798 kt. Based on these data, the share of the individual treatment options is 67% recycling, 13% incineration/other recovery and 20% disposal. 18 Member States (i.e. Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Slovenia, the Slovak Republic, Spain, Sweden and The Netherlands) comply already with the target value of 2025, 7 of which (i.e. Belgium, the Czech Republic, Denmark, Germany, Slovenia, Sweden and The Netherlands) achieve even the target of 2030.

The calculation of the development of the individual treatment options by implementing the Circular Economy Package results in increased recycling of about 3.22 million tonnes for the whole European Union until 2030. The increased recycling is compensated by a decrease in disposal of 3.09 million tonnes. Thus, incineration/other recovery decreases only by 0.13 million tonnes.

Due to the already high recycling rate, the increase of the recycling potential between 2016 and 2025 is low. Most of the additional recycling potential has to be created between 2025 and 2030.

Packaging waste by materials: In addition to total packaging waste, the Packaging Waste Directive contains recycling targets for five packaging materials; Table 1 in section 1.3. For all Member States, the reported quantity of the total packaging waste equals the sum of the individual packaging materials. Table 2 contains the packaging material quantities generated and recycled for the base year 2017 as well as the calculated recycling potentials of four packaging materials for the target years 2025 and 2030. The calculation of the recycling potential of metals as well as of other packaging (e.g. textiles, ceramic) is not possible, because target values do not exist in the amended Packaging Waste Directive (see section 2.2).

Paper and cardboard packaging: Paper/cardboard constitutes by far the biggest share (41%) of all packaging materials. The target values for the recycling rate of the amended Packaging Waste Directive are increased by 25 percentage points until 2030. However, the average recycling rate across the European Union reaches already 85% in 2017. 22 Member States have achieved the recycling target of 2025, 10 of which even the target of 2030. Still, there exists an additional recycling potential of 1,290 kt until 2030 from those Member States, which have not reached the target values. This quantity equals 29% of the recycling potential of all packaging materials.

Plastic packaging: Plastic packaging accounts for about 19% of generated packaging materials. The average recycling rate for the EU is 42%. Eight Member States have already achieved the target value for 2025 (50%) and five of them even the target value for 2030 (55%). As the future target values are remarkably higher than the existing recycling rate, there is a high additional recycling potential of 2,176 kt. This quantity is the biggest recycling potential of all packaging materials (50%).

Wood packaging: The share of wood packaging out of all packaging materials is about 16%. As the existing target value is comparably low, the increase from 15% in 2008 to 30% in 2030 means a doubling of the specific recycling rate. On the other hand, the actual recycling rate for the EU as a whole is already 42%, with 19 Member States achieving already the target value for 2025, 18 of which achieving the value for 2030. Due to the already high recycling rate, the additional recycling potential of about 216 kt is very low, representing only 5% of this potential.

Metal packaging: Metals are the packaging material with the lowest reported waste generation; their share is only 5%. The existing recycling rate across all EU Member States amounts to 79%. The future target values do not apply on the metal packaging material as a whole, but is subdivided in the two fractions of ferrous metals and aluminium. Therefore, an additional recycling potential cannot be calculated for the metals fraction.

Glass packaging: Glass packaging represents a share of 19% of all packaging materials. The existing target value for the recycling rate of 60% is already very high. The future target value of 75% until 2030 means an increase of 15 percentage points. However, the existing average recycling rate, which is reported for 2017, accounts already for 75% across the EU. 14 Member States have achieved the recycling target of 2025, 12 of which even the target of 2030. The additional recycling potential for glass, coming from the Member States, which have not achieved the targets so far, is calculated as 701 kt, representing about 16% of this potential.

Other packaging: Only a small amount of other packaging is reported (253 kt), accounting only for 0.3% of the generated quantity of all packaging materials. The existing recycling rate is very low with reported 8%. As no target values for this material exist, an additional recycling potential cannot be calculated.

Discussion and Conclusion

Additional recycling potential

Regarding municipal waste, the additional recycling potential is calculated to be about 46.3 Million tonnes until 2040. The

Table 2. *Existing waste streams and additional recycling potential for each packaging material.*

Packaging material	Packaging Waste Generated 2017	Packaging Waste Recycled 2017	Additional Recycling 2016 - 2025	Additional Recycling 2025 - 2030
Total packaging waste	89,004,759	59,642,550	11,413,10	20,800,56
Paper/cardboard	36,178,879	30,615,910	73,788	12,158,49
Plastic	16,808,499	71,078,73	13,573,71	8,185,90
Wood	14,590,270	58,735,03	44,363	17,184,7
Metals	47,149,24	37,361,45	n/a	n/a
Glass	16,459,344	12,289,492	36,333,9	33,742,3
Other packaging	25,284,2	19,627	n/a	n/a
SUM of all packaging materials	89,004,758	59,642,550	18,388,61	25,437,09

recycling potential is increased in five steps with five years each, starting with the year 2020. The additional recycling potential for packaging waste is calculated to be about 3.2 Million tonnes until 2030. The recycling potential is increased in two steps, i.e. the target years 2025 and 2030. The size of the recycling potential depends on the size of the waste stream, the existing recycling rates and the future target values for recycling rates.

Comparison of municipal and packaging waste: The recycling potential of municipal waste is almost 15 times higher than the one of packaging waste. It has to be taken into consideration, however, that the two waste streams have an overlap, i.e. packaging waste from municipal sources. It is not possible to calculate the quantity of this overlap, based on the available date.

Regarding the size of the waste stream, municipal waste has nearly three times higher waste quantities than packaging waste.

The legal background of the recycling targets for municipal waste on the one hand and packaging waste, on the other hand, shows historical differences. For packaging waste, the first recycling targets have been introduced already in the original Packaging Waste Directive of 1994. Since then, target values for recycling rates have been increased for the target years 2001 and 2008. That means that there is already a long history of Member States improving the recycling rates of packaging waste. Regarding municipal waste, the first target values have been introduced in the Waste Framework Directive 2008 with the target year of 2020. Therefore, the actual recycling rates of packaging waste (67%) are already higher than the recycling rates of municipal waste (47%), so that there is more room for increasing the recycling quantities of municipal waste, which leads to a higher recycling potential (Figure 6) [21]. A comparison of the recycling rates in the ternary diagram leads to the following conclusions:

1. The recycling rate of packaging waste is generally higher than the recycling rate of municipal waste, while for the incineration rate it is vice versa.

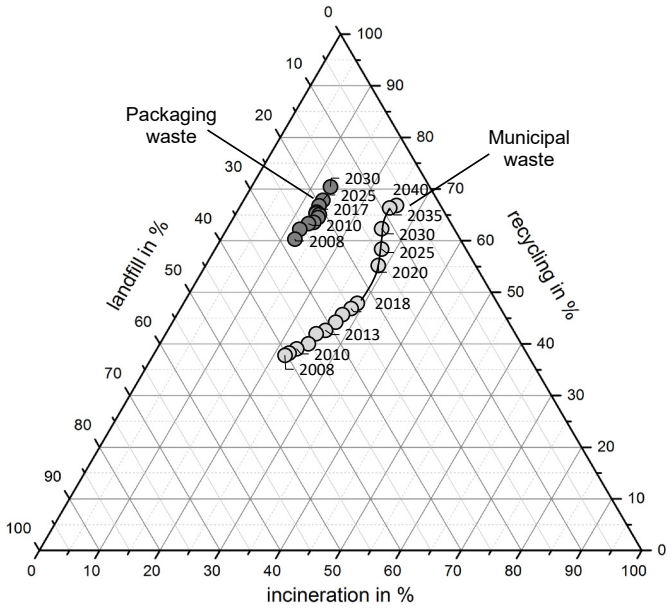

Figure 6. *Ternary diagram of existing and calculated recycling rates of municipal and packaging waste for the European Union.*

2. The recycling rate of packaging waste develops in small steps over the whole time. The new target values, introduced with the amended Packaging and Packaging Waste Directive, follow the trend of the existing recycling rates. For municipal waste, major changes are necessary, i.e. the redirection of the existing trend from an approximately similar increase in recycling and incineration towards an exclusive increase of recycling. Also, much bigger steps for more recycling from 2018 on will be necessary to achieve the future target values for municipal waste.

Comparison of packaging waste materials: The biggest contribution to the increase in packaging recycling potential has plastic packaging with 50%. This is because the existing recycling rate is comparatively low and the new target value means more than a doubling of the previous one. Paper and cardboard packaging contributes 29% to the total recycling potential. Although the existing recycling rate is on EU-average already as high as the new target value, there are still Member States, which need to increase the recycled quantities. The reason for the high contribution is that paper and cardboard packaging constitutes by far the biggest share (41%) of all packaging materials. Glass packaging waste represents only about 16% of the total recycling potential because existing average recycling rate (75%) has almost reached the final target value of 75% and the share of glass packaging waste is comparably low. Wood packaging has the lowest contribution to the recycling potential with only 5%. It has the lowest share in all included packaging materials and the average recycling rate of wood packaging waste is already higher than the forthcoming target value.

Discussion of data quality and assumptions

Reported data: Although there is already a long time series of data on generation and treatment of municipal waste, based on the OECD/Eurostat Joint Questionnaire, differences in definitions and calculation methods among Member States have been detected and discussed in the previous years (see section 1.4). Eurostat has taken efforts to harmonise definitions and agree on common calculation methods. Therefore, it can be assumed, that the data quality across the EU Member States has improved, but it is still far from being perfect. The biggest challenge in reporting is still the calculation of the quantity of recycled waste, especially regarding the included impurities. In a study, Obermeier and Lehmann [14] have reviewed the calculation of the recycling rate for municipal waste reported by Germany, Austria and Switzerland. They concluded that the actual recycling rate of municipal waste is on average about 10% lower than the reported one. Transferred to the situation of the whole European Union, this would mean an additional recycling potential of about 4.6 million tonnes. The situation on harmonisation of data collection, applied definitions and calculation methods needs further improvement by the Member States as well as the European Commission, especially Eurostat. In the study of Eunomia (2017) many priority actions for the improvement of the reporting is listed at national as well as at EU level.

Achievement of target values: The calculation of the additional recycling rates works with the assumption that the Member States will reach the target values, specified in the amended Directives. Having a look at the existing recycling

and landfilling rates for municipal waste leads to the conclusion that some Member States will not be able to achieve the target values in time. In the year 2018, four Member States still have a recycling rate for municipal waste of below 20% and six Member States still have a landfilling rate of above 60%. It does not appear feasible for these Member States to comply with the target values of the Waste Framework and the Landfill Directive. However, the recycling quantities of the mentioned Member States sum only up to approximately 10,000 tonnes, which constitutes only a small percentage of the total recycling potential of 4.6 million tonnes.

Declaration of Interest

None.

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References

1. Korhonen J, Honkasalo A, Seppala J. Circular economy: The concept and its limitations. Ecological Economics. 2018;143:37-46.
2. European Commission. European Commission-Fact Sheet. Circular economy package: Questions and Answers. Brussels. 2015.
3. European Commission. Report from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions on the implementation of the circular economy action plan. 2019.
4. European Union. Directive (EU) 2018/849 of the European parliament and of the council of 30 May 2018 amending Directives 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment. 2018 a.
5. European Union. Council directive 1999/31/EC of 26 April 1999 on the landfill of waste, amended by Directive (EU) 2018/850 of the European parliament and of the council of 30 May 2018. 2018 b.
6. European Union. Directive 2008/98/EC of the European parliament and of the council of 19 November 2008 on waste and repealing certain Directives, amended by Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018. 2018c.
7. European Union. European parliament and council directive 94/62/EC of 20 December 1994 on packaging and packaging waste, amended by Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018. 2018d.
8. Eurostat. Municipal waste by waste management operations [env_wasmun]. Retrieved June 10, 2020 from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasmun&lang=en. 2019.
9. European Union. Commission Decision establishing rules and calculation methods for verifying compliance with the targets set in Article 11(2) of Directive 2008/98/EC of the European Parliament and of the Council. 2011.
10. Greenfield D. Report for the Chartered Institution of Wastes Management (CIWM) EU recycling rate harmonisation project national definitions and accounting methods. Social, Environmental and Economic Solutions (SOENECS) Ltd. 2015.
11. European Union. Regulation (EC) No 2150/2002 of the European Parliament and of the Council of 25 November 2002 on waste statistics. 2002.
12. European Commission. Preparing a waste management plan-a methodological guidance note. European Commission-DG Environment. 2012.
13. Hogg D, Elliott T, Cordle M, et al. Study on waste statistics-A comprehensive review of gaps and weaknesses and key priority areas for improvement in the EU waste statistics. Eunomia. 2017.
14. Obermeier T, Lehmann S. Recycling quoten in Deutschland. Presentation at the 30. Kasseler Abfall- und Res source forum. 2018.
15. Kolekar KA, Hazra T, Chakrabarty SN. A review on prediction of municipal solid waste generation models. Procedia Env Sci. 2016;35:238-44.
16. Hill AL, Dall OL, Andersen FM. Modelling recycling targets: Achieving a 50% recycling rate for household waste in Denmark. J Env Prot. 2014;5:627-36.
17. Sahimaa O. Recycling potential of municipal solid waste in Finland. Doctoral Dissertations 184/2017 Aalto University. 2017.
18. Loukil F, Rouached L. Modelling packaging waste policy instruments and recycling in the MENA region. Resources, Conservation and Recycling. 2012;69:141-52.
19. Oliveira V, Sousa V Dias-Ferreira C. Artificial neural network modelling of the amount of separately-collected household packaging waste. J Clea Prod. 2019;210:401-9.
20. Eurostat. Packaging waste by waste management operations and waste flow [env_waspac] 2019b. [http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waspac&lang=en. 2019b].
21. Pomberger R, Sarc R, Lorber KE. Dynamic visualisation of municipal waste management performance in the EU using Ternary Diagram method. Waste Manage. 2017;61:558-571.

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