Dynamic visualisation of municipal waste management performance in the EU using Ternary Diagram method

R. Pomberger, R. Sarc*, K.E. Lorber

Department of Environmental and Energy Process Engineering, Chair of Waste Processing Technology and Waste Management, Montanuniversitaet Leoben – Franz-Josef-Straβe 18, 8700 Leoben, Austria

Abstract

This contribution describes the dynamic visualisation of European (EU 28) municipal waste management performance, using the Ternary Diagram Method. Municipal waste management performance depends primarily on three treatment categories: recycling & composting, incineration and landfilling. The framework of current municipal waste management including recycling targets, etc. is given by the Waste Framework Directive – 2008/98/EC. The proposed Circular Economy Package should stimulate Europe's transition towards more sustainable resources and energy oriented waste management. The Package also includes a revised legislative proposal on waste that sets ambitious recycling rates for municipal waste for 2025 (60%) and 2030 (65%). Additionally, the new calculation method for monitoring the attainment of the targets should be applied.

In 2014, ca. 240 million tonnes of municipal waste were generated in the EU. While in 1995, 17% were recycled and composted, 14% incinerated and 64% landfilled, in 2014 ca. 71% were recovered but 28% landfilled only. Considering the treatment performance of the individual EU member states, the EU 28 can be divided into three groups, namely: “Recovery Countries”, “Transition Countries” and “Landfilling Countries”.

Using Ternary Diagram Method, three types of visualization for the municipal waste management performance have been investigated and extensively described. Therefore, for better understanding of municipal waste management performance in the last 20 years, dynamic visualisation of the Eurostat table-form data on all 28 member states of the EU has been carried out in three different ways: 1. “Performance Positioning” of waste management unit(s) at a specific date; 2. “Performance dynamics” over a certain time period and; 3. “Performance development” expressed as a track(s).

Results obtained show that the Ternary Diagram Method is very well suited to be used for better understanding of past developments and coherences, for monitoring of current situations and prognosis of future paths. One of the interesting coherences shown by the method is the linked development of recycling & composting (60–65%) with incineration (40–35%) performance over the last 20 years in the EU 28.

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1. Introduction

The European Directive on waste (2008/98/EC) (Waste Framework Directive – WFD) sets definitions and issues the basic concept for development of sustainable waste management in the EU. In the directive, the definition of, among others, “waste management”, “treatment”, “recycling”, “recovery” and “disposal” is given as follows (EU, 2008):

- “waste management” means the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker,
- “treatment” means recovery or disposal operations, including preparation prior to recovery or disposal,
- “recycling” means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

* Corresponding author.
E-mail address: renato.sarc@unileoben.ac.at (R. Sarc).
• “recovery” means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfill a particular function, or waste being prepared to fulfill that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery operations; and
• “disposal” means any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. Annex I sets out a non-exhaustive list of disposal operations.”

To reach the sustainability in waste management (i.e. treatment of waste in proper way and production of secondary raw materials and energy resources), following waste hierarchy should be applied according to the directive (EU, 2008):

1. “Prevention,
2. Preparing for re-use,
3. Recycling,
4. Other recovery, e.g. energy recovery; and
5. Disposal.”

When applying the waste hierarchy, member states shall take measures to encourage the options that deliver the best overall environmental outcome, take into account the principles of environmental (human, nature, etc.) protection as well as technical feasibility and economical viability. In Article 11 of the directive, re-use and recycling measures and goals are set. Therefore, a separate collection for at least paper, plastic, metal and glass from households and possibly from other origins as far as these waste streams are similar to waste from households was to be set up by 2015, considering technical, environmental and economical aspects. Finally by 2020, the preparation for re-use and the recycling of before mentioned waste fractions shall be increased to a minimum of overall 50% by weight. (EU, 2008). For verifying compliance with the targets (regarding Article 11 - WFD) and the performance of member states, Commission has established rules and calculation methods (EU, 2011). In the Commission decision (EU, 2011) the definition for different waste is given that is relevant for present paper:

• “household waste” means any waste generated by households,
• “similar waste” means waste in nature and composition comparable to household waste, excluding production waste and waste from agriculture and forestry; and
• “municipal waste” means household waste and similar waste.

For the purposes of verifying compliance with the targets on municipal waste according to the WFD, member states shall apply one of the following calculation methods (EU, 2011):

1. “The preparation for reuse and the recycling of paper, metal, plastic and glass household waste” (note: abbreviation for paper, metal, plastic and glass household waste is PMPG HW), see Eq. (1).

\[
\text{Recycling rate of PMPG HW, in } \% = \frac{\text{Recycled amount of PMPG HW}}{\text{Total generated amount of PMPG HW}} \quad (1)
\]

2. “The preparation for reuse and the recycling of PMPG HW and other single types of household waste or of similar waste from other origins”, see Eq. (2).

\[
\text{Recycling rate of household and similar waste, in } \% = \frac{\text{Recycled amount of PMPG and other single waste streams from households or similar waste streams}}{\text{Total generated amount of PMPG and other single waste streams from households or similar waste}} \quad (2)
\]

3. “The preparation for reuse and the recycling of household waste”, see Eq. (3).

\[
\text{Recycling rate of household waste, in } \% = \frac{\text{Recycled amount of household waste}}{\text{Total household waste amounts excluding certain waste categories}} \quad (3)
\]


\[
\text{Recycling of municipal waste, in } \% = \frac{\text{Municipal waste recycled}}{\text{Municipal waste generated}} \quad (4)
\]

1.1. Current status of municipal waste management in the EU

In the EU 28, ca. 2.5 billion tonnes of waste are produced annually (Eurostat, 2016a). Municipal waste accounts for ca. 10% (ca. 240 million tonnes in 2014) of total waste generated only (Eurostat, 2016b). However, it is very important because of, among others, its complex characteristics, due to its composition and biological activity, etc.

Eurostat has collected and published data on municipal waste since 1995. Fig. 1 shows municipal waste generation by country (data in thousand tonnes per year) for 2014 (Eurostat, 2016b).

Fig. 1. Municipal waste generation by country, in thousand tonnes per year, data for 2014. (Note: 2013 data instead of 2014 for Ireland, Greece and Romania; position of single countries in Figure according to the groups defined – see Fig. 3)(Eurostat, 2016b).
As shown in Fig. 1, six out of 28 member states in the EU 28 only, i.e. Germany, France, United Kingdom, Italy, Spain and Poland are generating more than 10 million tonnes of municipal waste per year. The amount of municipal waste generated per person varies significantly across the EU, from 759 kg/person in Denmark (highest value) to 254 kg/person in Romania (lowest value). In Austria (565 kg/person), Germany (618 kg/person) and UK (482 kg/person) the municipal waste amount per person is above the European average (i.e. 475 kg/person), while in Slovakia (321 kg/person) is well below (Eurostat, 2016b).

Considering the before mentioned four calculation methods for verifying compliance with the targets on municipal waste in the EU, the treatment categories (i.e. “Recycled & Composted”, “Incinerated” as well as “Landfilled” and “Other Treatment”) according to the waste hierarchy (EU, 2008) in the EU can be evaluated, cf. Fig. 2.

As depicted in Fig. 2, the treatment strategy within the EU has been positively changed, i.e. from 64% of landfilling in 1995 to 28% in 2014. Therefore, recycling & composting and incineration (note: as no EU wide unique classification criteria have been applied yet, there is no distinction between incineration with energy recovery (i.e. “R 1” operation according to the Annex II of WFD (EU, 2008)) and without (i.e. “D 10” operation according to the Annex I of WFD (EU, 2008))) have developed from 17% and 14% in 1995 to 44% and 27% in 2014 respectively. There is no doubt that since 1995 the European municipal waste management has been developing to an important secondary resources and energy generating sector. Therefore, the reduction of landfilling rate by 36% (period 2014 vs. 1995) resulted in simultaneous increase of recycling & composting rate (by about 27%) and incineration rate (by about 13%). As a result, recycling & composting and incineration have been successfully developed hand in hand and are showing strong dependence at a ratio of 60–65% to 40–35%.

Additionally, the “Other Treatment” category may be calculated as the difference between the sum of the amounts treated and the amounts of waste generated. Hence, it reflects the effects of import and export, weight losses, double-counting of secondary waste (e.g. landfilling and recycling of residues from incineration), temporary storage as well as the use of pre-treatment, such as mechanical-biological treatment (MBT). Finally, it has to be noted that MBT and sorting of waste are not recordable directly as “treatment categories” as these types of pre-treatment steps require an additional downstream/final treatment plant (i.e. recycling, composting, incineration plant and/or landfill) (Eurostat, 2016b).

As presented in Fig. 3, the municipal waste treatment performance varies significantly in the single member states. On one hand, there are countries like Germany, Belgium, Netherlands, Austria, etc. that reach almost 100% “Recycling & Composting” and “Incineration” rate, while on the other hand countries like Latvia,
Malta, Croatia, Romania and Greece still have a “landfilling” rate higher than 80% in 2014. Based on these facts, member states/countries can be divided into three groups regarding their municipal waste treatment performance, cf. Tables 1 and 2.

From Table 2, it becomes obvious that “Transition Countries” generated the largest amount of municipal waste, i.e. around 140 million tonnes or ca. 60% of the total municipal waste generated within the EU 28 in 2014. “Recovery Countries” generated around 80 million tonnes and “Landfilling Countries” ca. 20 million tonnes (or less than 10%) only. By looking at Fig. 3 only, one could expect that “Landfilling countries” are having the poorest performance in the EU. Considering these rates only, this is true, as their average landfilling rate is 78.8%, but by taking into account the municipal waste quantities landfilled, it becomes evident that “Transition Countries” still are landfilling 3.3 times more. In total, 107 million tonnes of MW were recycled & composted, 65 million tonnes were incinerated but unfortunately 69 million tonnes were still landfilled in the EU 28 in 2014. The average recycling & composting rate is around 60% for “Recovery Countries”, 40% for “Transition Countries” and 20% for “Landfilling Countries”.

1.2. Proposed development of municipal waste management in the EU

In July 2014, the European Commission has proposed one directive package on circular economy. By means of this package, the transition of the European waste management towards a stronger, more sustainable and more circular aligned economy was aimed to be achieved by 2030. The official name of the package was “Towards a circular economy: a zero waste programme for Europe” (EC, 2014). Finally, this package from 2014 was withdrawn and a new package programme was announced by the new Commission for 2015. Further information on this issue is given in detail by Pomberger (2015).

Then, on 2nd December 2015, an ambitious new Circular Economy Package was adopted by new Commission led by Juncker. The plans aimed to extract the maximum value and use from all raw materials, products and waste, fostering energy savings and reducing greenhouse gas emissions. The new proposals cover the full lifecycle: from production and consumption to waste management and the market for secondary raw materials (EC, 2015a).

Waste management plays a central role in circular economy: it determines how the EU waste hierarchy is put into practice. As already mentioned, the waste hierarchy establishes a priority order for the strategies of prevention, preparation for reuse, recycling and energy recovery to disposal, such as landfilling. This principle aims to encourage the options that deliver the best overall environmental outcome. The revised legislative proposal on waste sets clear targets for the reduction of waste and establishes an ambitious and credible long-term path for waste management and recycling. To ensure effective implementation, the waste reduction targets in the new proposal are accompanied by concrete measures to handle obstacles at the source and tackle the different situations across member states (cf. Fig. 3). Key targets/aspects of the revised waste proposal regarding municipal waste are, among others, as follows (EC, 2015b):

- preparing for re-use and recycling rate for municipal waste of 60% by 2025,
- preparing for re-use and recycling rate for municipal waste of 65% by 2030,
- maximum 10% landfill rate for municipal waste by 2030 and
- development of quality standards for secondary raw materials.

As a part of the new circular economy package, the Proposal for a Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste (EU, 2008) was published too. (EC, 2015b) In this document, the definition of “municipal waste” was extended and more clearly defined (EC, 2015b):

“Municipal waste” means:

(a) “mixed waste and separately collected waste from households including:
- paper and cardboard, glass, metals, plastics, bio-waste, wood, textiles, waste electrical and electronic equipment, waste batteries and accumulators,
- bulky waste, including white goods, mattresses, furniture,
- garden waste, including leaves, grass clipping;
(b) mixed waste and separately collected waste from other sources that is comparable to household waste in nature, composition and quantity;
(c) market cleansing waste and waste from street cleaning services, including street sweepings, the content of litter containers, waste from park and garden maintenance.

Municipal waste does not include waste from sewage network and treatment, including sewage sludge and construction and demolition waste.”

Table 1

<table>
<thead>
<tr>
<th>Group nr.</th>
<th>Countries</th>
<th>Recycling &amp; composting rate</th>
<th>Landfilling rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. “Recovery Countries”</td>
<td>Germany, Belgium, Netherlands, Sweden, Denmark, Austria, Estonia, Finland and Luxembourg</td>
<td>&gt;80%</td>
<td>&lt;20%</td>
</tr>
<tr>
<td>2. “Transition Countries”</td>
<td>France, United Kingdom, Italy, Slovenia, Ireland, Portugal, Poland, Spain, Czech Republic and Hungary</td>
<td>80–40%</td>
<td>20–60%</td>
</tr>
<tr>
<td>3. “Landfilling Countries”</td>
<td>Lithuania, Bulgaria, Cyprus, Slovakia, Greece, Romania, Croatia, Malta and Latvia</td>
<td>&lt;40%</td>
<td>60–100%</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Group nr.</th>
<th>MW generation [1000 t/y]</th>
<th>[% of total]</th>
<th>Recycled &amp; composted [1000 t/y]</th>
<th>Rate [%]</th>
<th>Incinerated [1000 t/y]</th>
<th>Rate [%]</th>
<th>Landfilled [1000 t/y]</th>
<th>Rate [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. “Recovery Countries”</td>
<td>80,641</td>
<td>33.5</td>
<td>47,274</td>
<td>58.6</td>
<td>31,903</td>
<td>39.6</td>
<td>1463</td>
<td>1.8</td>
</tr>
<tr>
<td>2. “Transition Countries”</td>
<td>140,387</td>
<td>58.3</td>
<td>55,830</td>
<td>39.8</td>
<td>32,877</td>
<td>23.4</td>
<td>51,679</td>
<td>36.8</td>
</tr>
<tr>
<td>3. “Landfilling Countries”</td>
<td>19,924</td>
<td>8.3</td>
<td>3765</td>
<td>18.9</td>
<td>457</td>
<td>2.3</td>
<td>15,702</td>
<td>78.8</td>
</tr>
<tr>
<td>Total</td>
<td>240,952</td>
<td>100</td>
<td>106,870</td>
<td>44.4</td>
<td>65,237</td>
<td>27.0</td>
<td>68,845</td>
<td>28.6</td>
</tr>
</tbody>
</table>
Additionally, following point that is relevant for the calculation of recycling rates is inserted (EC, 2015b):

“final recycling process” means the recycling process which begins when no further mechanical sorting operation is needed and waste materials enter a production process and are effectively reprocessed into products, materials or substances.

In the Article 11, paragraph 2 (EU, 2008), the preparing for reuse and the recycling of municipal waste including their increase to a minimum of 60% (2025) and 65% (2030) by weight are added as new points (c) and (d). Here, it has to be noted that Estonia and six out of a total of nine countries – in present paper designated as “Landfilling Countries” – i.e. Greece, Croatia, Latvia, Malta, Romania and Slovakia may obtain five additional years for the attainment of the before mentioned targets for municipal waste (EC, 2015b).

Especially important is the new calculation of the attainment of the targets (i.e. Article 11, paragraph 2, new points (c) (i.e. 60% by 2025) and (d) (i.e. 65% by 2030) respectively). For this, “the weight of the municipal waste recycled shall be understood as the weight of the input waste entering the final recycling process”, i.e. “the weight of the output of any sorting operation may be reported as the weight of the municipal waste recycled provided that:

(a) “such output waste is sent into a final recycling process,
(b) the weight of materials or substances that are not subject to a final recycling process and that are disposed or subject to energy recovery remains below 10% of the total weight to be reported and recycled.”

Legal requirements, especially the EU directives, are a specific driver for further developing the European municipal waste management. The framework has to be designed specifically enough to enforce its implementation by all EU countries. The achievement of the new targets set for EU countries is a challenge but, as shown in Figs. 2 and 3, the countries are already on the way of their sustainable development. Additional, an even more difficult challenge will be to achieve the recycling targets for municipal waste in the capital cities within the EU member states.

As mentioned in the study on separate collection schemes in the 28 capitals of the EU (EC, 2015c), separate collection of individual waste fractions (i.e. paper, glass, metals, plastics and bio-waste) is seen as a pre-condition for fostering high quality recycling and high recycling rates. Results of the study show for year 2013 that, among others, on average, only 19% of generated municipal waste is collected separately in EU 28 capitals; in other words, more than 80% of the waste still ends up in the residual (mixed) waste bin that require different waste treatment options like splitting, MBT, incineration, production of Solid Recovered Fuels (SRF), co-incineration, landfilling, etc. Treatment of mixed municipal waste is extensively discussed in Lorber et al. (2012), Lorber and Sarc (2014), Pomberger and Sarc (2014), Sarc and Lorber (2013), Sarc et al. (2014), Sarc (2015) and Sarc et al. (2015).

2. Materials and methods

In present chapter, materials used and methods applied are explained in detail.

2.1. Materials

For present paper, European municipal waste data published on the website of “Eurostat → Environment and Energy → Environment → Waste → Municipal Waste Statistics”, especially the data base “env_wasmun”, (Eurostat, 2016b) was used. The mentioned data base contains information about municipal waste generation and treatment from 1995 to 2014 for all 28 countries of the European Union. Data used is available in a table format and contain following eight information incl. two kinds of units, namely “thousand tonnes” for total waste generated/treated and inhabitants specific unit “kilograms per capita” (Eurostat, 2016b):

1. “municipal waste generated,
2. total municipal waste treatment,
3. landfill/disposal (D 1 – D 7, D 12),
4. total incineration (including energy recovery),
5. incineration/disposal (D 10),
6. incineration/energy recovery (R 1),
7. material recycling and
8. composting and digestion.”

For development of methods applied in this investigation, six relevant parameters have been derived: “Country/Member State”, “Year”, “Municipal Waste Amount” as well as treatment categories “Recycled & Composted”, “Incinerated”, “Landfilled”.

2.2. Methods

In present chapter, the development of method applied starting with the history of Ternary Diagrams up to the computer-aided modelling and its reading as well as application for dynamical visualisation of the European municipal waste management performance is explained.

2.2.1. History of the Ternary Diagram method

The development and application of Ternary Diagram method can be traced back to the middle of 18th century. At that time, it was applied by the astronaut, mathematician and cartographer Tobias Mayer, who’s investigation was based on Isaac Newton’s colour experiments on mixing three colours. Mayer used the Newton’s experiments and plotted graphically three colours in one equilateral triangle. Then, Georg Christoph Lichtenberg for the first time provided mathematical definition of one point in the triangle. At the end of the 19th century, for the first time Ternary Diagram was applied in physical chemistry. Finally, under the name of “Gibbs Triangle” Ternary Diagram is applied for graphical presentation of ternary-mixtures up to today. Nowadays, Ternary Diagram method is widely used in chemistry, geology, mineralogy, process engineering, etc. (Howarth, 1996). For the visualisation of waste management data, Ternary Diagram method was applied in few selected cases by Cossu and Piovesan (2007), Cossu (2009) and Bartl (2014). The first idea for application of Ternary Diagram in waste management sector at international level came from prof. Raffaello Cossu and therefore Bartl (2015) referred to as “Cos-su’s Diagramme” in his editorial text in Waste Management.

In the paper, extensive description of the method with its limits and possibilities for municipal waste management sector is given for the first time.

2.2.2. Mathematical basics, computer-aided modelling and visualisation

The mathematical basis for the equilateral triangle is the well-known Viviani’s theorem, named after Italian mathematician Vincenzo Viviani. The theorem states that the sum of the distances from any interior point to the sides of an equilateral triangle equals the length of the triangle’s altitude, see Eq. (5).

\[ a + b + c = h = 3r \]  

(5)

In the meantime, there are various computer-aided possibilities for modelling and visualisation of Ternary Diagrams depending on the field of application (e.g. Graham and Midgley, 2000; Graham,
In present case, i.e. for the development of Ternary Diagram method for visualisation of the European municipal waste management performance, conventional Microsoft Excel-Programme was applied. Although, the Ternary Diagram is not available in Excel-Programme, by application of XY scatter diagram in combination with equilateral triangle used as image file, modelling and visualisation of results is possible. Therefore, based on the data and instructions of Graham and Midgley (2000) and Graham (2006) and own calculations and modelling, a Ternary Diagram ready for use in municipal waste management was further developed in detail.

Hence, the data for all three components (A, B and C) have to be converted in XY-coordinates. First, the start point of the XY-coordinates is set in the “corner A”, the length of the x-axis corresponds to the line AB and the length of the y-axis to the line BC, cf. Fig. 4 – left. According to this approach, the point “Pxy” is defined by x = B and y = C. However, the point “Pxy” can be located outside of the equilateral triangle (i.e. image file only), as shown in Fig. 4 – left.

Therefore, in the second step the coordinates of the point “Pxy” have to be transferred to the point “Pxy0”, see Fig. 4 – right. Hence, for the calculation of x' and y' following Eqs. (6) and (7) have been applied.

\[ y' = h = C \times \cos(30') \]  

(6)

If the scaling of the Y-axis is reduced by the factor \( \cos(30') = \sqrt{3}/4 = 0.86 \) on the height of the triangle, then the following fact \( y' = h = C \) applies. Implementing this approach makes the modelling easier as the Y-value directly represents the value for component C.

For the graphical visualisation in Excel, component B has to be mathematically changed (cf. Eq. (7)) only. Component C remains unchanged and the component A is not required in the two-dimensional XY scatter diagram. The position of the component A within the ternary system is automatically calculated as the difference of the total system sum, i.e. A = 100 – B – C.

\[ x' = B + C \times \cos(60') = B + C/2 \]  

(7)

2.2.3. Reading of the diagram

When reading the diagram, it must once again be noted that every single point within the triangle points out a different composition of all three components. Every corner represents one component, namely A, B and C in its pure form (i.e. 100%). One point located directly on the line of the triangle represents a two-components-system without the component located in the opposite corner. One point located within the triangle consists of all three components. The closer the point to the corner is, the more component located in this corner is contained in the mixture. There are different methods on how to read the Ternary Diagram. For waste management, the most practicable method is by using grid lines (with distance representing 10%) within the triangle, see Fig. 5.

2.2.4. Application of computer-aided Ternary Diagram method in waste management

The Ternary Diagram consists of three sides that can be used for three treatment categories in municipal waste management (cf. Figs. 2 and 3), namely:

- “A” for “Landfilled”,
- “B” for “Incinerated” and
- “C” for “Recycled & Composted”.

The scaling of main grids in the diagram represents 10%. In total, for every treatment option 9 main grids are used which represent 10–90% performance. Additionally, triangle lines themselves represent 0% as well as 100% performance.

The application of the computer-aided Ternary Diagram method in waste management is possible in three ways:

1. “Performance positioning”: positioning of one or more waste management unit(s) (i.e. company, city, association (i.e. combination of different companies, municipalities, cities, states, etc.) province, country, or even the EU including all 28 countries, etc.) regarding its/their waste management performance at a specific date,
2. “Performance dynamics”: dynamical visualisation of the waste management development of one or more waste management units over a time period by using filming (motion pictures) of single graphics (e.g. few figures per second in e.g. Microsoft PowerPoint).

3. “Performance development”: presentation of the performance development of one or more waste management units over a time period expressed as track(s) or line(s).

Additionally, if required, the waste quantities generated/treated per waste management unit can be considered in two forms:

a. the dot-size can be introduced for showing the total amount of waste generated/treated per time unit (by using selected settings in Microsoft Excel) and
b. the dot-size can be introduced for showing the inhabitants specific unit “kilograms per capita and time unit” (by using selected settings in Microsoft Excel too).

3. Results and discussions

Here, selected results for various waste management units (WMU) are presented. WMU displayed here are single countries/member states of the EU 28 as well as the superior association EU 28 (i.e. data for all 28 member states expressed as average values for all three treatment categories).

3.1. Performance positioning

As mentioned before, Eurostat (2016a, 2016b) provides data for European municipal waste management performance from 1995 to 2014. In Fig. 6, evaluation of municipal waste management performance of single member states and EU 27 at a specific date, i.e. for year 1995 is given.

As shown in Fig. 6, in 1995 not three (cf. Fig. 3, Tables 1 and 2) but two characteristic groups of countries only, as far as their municipal waste treatment performance is concerned, can be identified. On one hand, “Transition Countries” with incineration rates between 10 and 60% (higher value: the more the point is located to the right) and recycling & composting rates between 15 and 50% (higher values: the more the point is located upwards) and on the other hand “Landfilling Countries” with landfilling rates between 80 and 100% (higher value: the more the point is located to the left) are positioned.

As before presented in Fig. 3, already three groups of countries regarding their municipal waste treatment performance can be identified in 2014, cf. Fig. 7.

As shown in Fig. 7, nine countries of the EU 28 (i.e. “Landfilling countries”) still landfill 79% of municipal waste on an average (cf. Table 2). Progressing countries like GB, IT, PL, ES, etc. have moved from mainly landfilling in 1995 (cf. Fig. 6) towards recycling & composting and incineration in 2014 (cf. Fig. 7) and have become part of the “Transition Countries”. During the period 1995–2014, France had almost constant incineration rate but landfilling rate was partly reduced by increasing recycling & composting rate. Despite this positive development, France still belonged to the “Transition Countries” in 2014. Austria, Germany, Denmark, Netherlands, Sweden, Belgium and Luxembourg have developed from “Transition Countries” in 1995 to “Recovery Countries” in 2014. The most interesting development is shown by the remaining “Recovery Countries”, Finland and Estonia. Finland has strongly developed in waste incineration and therefore the incineration rate increased from 0% (1995) to ca. 50% (2014). The recycling rate in Finland for 2014 is comparable with the one from 1995. Estonia has successfully developed from >80% landfilling, <10% incineration and <10% recycling & composting in 1995 towards less landfilling but more recovery, i.e. 8% landfilling and 55% incineration and 37% recycling & composting in 2014 (cf. Figs. 3 and 7).

Finally, comparing the development of municipal waste treatment performance within the EU 28 in the period 1995 (i.e. Fig. 6) to 2014 (i.e. Fig. 7) it becomes evident that between recycling & composting rate and incineration rate is a clear “60–65:40–35”-correlation. This confirms that the development of both treatment categories in the EU 28 went hand in hand.

As explained in detail in Section 1.2, the new proposed European strategy “Circular Economy Package” (EC, 2015a) contains, among others, ambitious recycling rates for municipal waste for 2025 (60%) and 2030 (65%). New rates should be calculated by applying the new method that considers waste amount entering the final recycling process and not as noted in the currently valid WFD 2008 (EU, 2008), where the input in a pre-treatment sorting plant is considered as recycled, cf. equations 1–4. Hence, it can be expected that the present “60–65:40–35”-correlation has to be changed when this fact is taken into consideration.

In Figs. 8 and 9, the evaluation of municipal waste management performance in 1995 and 2014 is shown, considering total municipal waste treatment in kg per capita.

3.2. Performance dynamics

For better visualisation of waste management performance development of different waste management units, single diagrams can be animated in a short film data set. Therefore, graphical data over a certain time period is required. By using e.g. Microsoft PowerPoint and showing few diagrams per second, this can successfully be carried out. Here, as it is not possible to show a short film, selected data (10 diagrams from 1996 to 2013; another data for 1995 is shown in Fig. 6 and data for 2014 in Fig. 7) required for dynamical visualisation of the European municipal waste management performance is provided, cf. Fig. 10.

3.3. Performance development

As described in Sections 3.1 and 3.2, the waste management performance development of various units (e.g. country or EU 28) can be presented for a specific period or year. Using this single data for one or more waste management units in the same Ternary
Diagram allows the presentation of the development plotted as a “unit track” or “unit line”. For better readability of the single data inserted in the same diagram, it is recommended not to consider the waste quantities generated/treated (i.e. by different dot-sizes). Here, the waste management performance development for the “Recovery Countries” Austria and Germany (cf. Fig. 11), the “Transition Country” United Kingdom (cf. Fig. 12), the “Landfilling Country” Slovakia (cf. Fig. 12), and the EU 28 (cf. Fig. 13) is shown.

As shown in Figs. 11 and 12, the countries presented have a completely different developments track/line. “Recovery Countries” like Austria and Germany had a quite good starting position in 1995 and have successfully developed in a sustainable way and their waste management has become an important supplier for...
secondary resources and energy as well. Despite quite similar waste management strategies in Austria and Germany, Austrian track/line is showing a different course. The reason for this is mainly the size of the country. The smaller the country is and the stricter regulations (e.g. landfilling ban for untreated municipal waste that was introduced in 2004 in Austria and 2005 in Germany (Lorber et al., 2011)) or the more specific measures (e.g. extension of separate collection (e.g. 1995 in Austria)) are implemented or operations of large waste treatment plants (e.g. MBT and/or incineration plants in Austria in 2004 or in Germany in 2005) have started, the greater is the development leap, cf. Fig. 11. A comparison of the recycling & composting rates only shows that in Austria the recycling and composting rate in 2014 was more or less on the same level as it was during the period 1996/1998, while in Germany it has continuously increased from ca. 40% (1995) to more than 60% (2014).
The development track/line for the United Kingdom (cf. Fig. 12) mainly shows an increase of recycling & composting rate for the period 1995–2010, while in the period 2010–2014 this increase becomes slower on one hand – on the other hand, the incineration rate becomes higher. This change is primarily due to three reasons: extension of separate collection for “recyclables”, introduction and annual increase of the landfill tax (i.e. Tax >80 British pounds per tonne of waste from April 2014 to at least 2020 (UK, 2016)) and
Fig. 10 (continued)

Fig. 11. Presentation of Austrian (left) and German (right) waste management performance development, data for 1995–2014 period, expressed as a track.
a recent increase of (pre-treated) municipal waste exports from the UK to other EU 28 countries for incineration, etc. (Eurostat, 2016a).

The development track/line for the Slovakia clearly shows the reason why Slovakia still belongs to the "Landfilling Countries". Next to the introduction of separate collection for selected fractions but evidently not in sufficient extent, Slovakia still has to push the implementation of the European waste management measures (e.g. extension of separate collection of recyclables, building up of sorting, MBT, waste to energy plants, etc.) for sustainable development of its Circular Economy.

In Fig. 13, the European municipal waste management performance development, given in an usual chart form as displayed in Fig. 2, is depicted by applying Ternary Diagram method.

As clearly shown in Fig. 13, the European (EU 28) municipal waste management is steady developing towards sustainable resources utilization (optimal recycling and composting rate) and energy (appropriate incineration rate) management. Landfilling of untreated municipal waste is obsolete and must be further reduced (from scientific point of view actually stopped) in Europe and the trend is showing that EU 28 is developing in right direction.

In Fig. 14, the statistical prognosis of further treatment performance of the EU 28 based on the available data (1995–2014) is given. Additionally, the change in development compared to the statistical prognosis required by the proposed “Circular Economy Package” (EC, 2015a, 2015b) is displayed. At this point, for the sake of fairness, it must be noted that the ambitious recycling targets set for 2025 and 2030 (EC, 2015a) have to be calculated by considering waste sent into a final recycling process (EC, 2015b) and therefore the existing rates valid for 2020 (EU, 2008) cannot directly be compared with the new ones. First investigations considering available data for Germany and 2013 (Eurostat, 2016b) but applying the new calculation method (EC, 2015b) have been carried out by Obermeier et al. (2016).

Obermeier et al. (2016) report that the German municipal waste recycling rate was 64% of the mass (weight) of the whole municipal waste in 2013. This performance may nominally exceed the EU’s requirements given by its WFD (EU, 2008) that provides for a recycling rate of 50 percent by weight for at least paper, metal, plastic and glass from households and any other sources as far as the concerning waste flows resemble household waste, but in reality, the fact is that much less secondary raw materials enter the economic circle. For this, the Statistical Federal Office of Germany subsumes actually applied recovery processes that are numbered R2 to R13 under the umbrella term “Treatment and Material Recovery”. The sum of the input into these plants and processes is compared with the whole municipal waste to result in a stated recycling rate of 64% in 2013. If the new calculation method is applied according to the Circular Economy Package 2015 (EC, 2015b), the finding is that Germany reached a distinctly lower rate of recycling for total municipal waste in 2013, amounting to 40% only (Version 1 without biological waste treatment processes) or 50% (Version 2 with biological waste treatment processes) vs. those 64% that have been calculated with help of the input in R2-R13 processes by the German Statistical Federal Office. Hence, even the already high quality level of municipal waste management in Germany (i.e. “Recovery Country”) will have to be improved in order to reach new recycling targets.

Nevertheless, obviously all “Recovery Countries” will have to improve their municipal waste management performance in the (near) future. The development of “Transition Countries” and the
EU 28 (average) will be quite similar as they have been in a comparable position in 2014. Particular considerations in reaching the targets shall be given to the “Landfilling countries” as their development paths will be the most challenging ones in the EU 28, cf. Fig. 14.

Finally, it has to be mentioned that in municipal waste management, the economic aspects, i.e. especially costs, can in most cases not be fully covered by the (international) market value of secondary raw materials only. Therefore, a gap between an economic optimum and ecological optimum (required by recycling targets, among others) is existing that has to be financed by someone (Bunge, 2016).

4. Conclusions

The actual framework for sustainable development of the European municipal waste management up to year 2020 is set by the Waste Framework Directive 2008/98/EC. In the EU 28, ca. 240 million tonnes of municipal waste are generated per year. While in 1995, 17% were recycled and composted, 14% incinerated and 64% landfilled, in 2014 ca. 71% were recovered but 28% landfilled only. As shown, development of European municipal waste management was and is still dynamical. Looking at the performance development of the individual countries, actually there is a so-called “multi-speed Europe”. This “multi-speed” Europe can be divided in three country groups, regarding their municipal waste management performance, namely: “Recovery Countries”, “Transition Countries” and “Landfilling Countries”. Data on this three groups analysed show that the further municipal waste development will be strongly influenced by the “larger countries” that are a part of “Transition Countries” and not by the smaller ones from the third “Landfilling” group. Considering calculated rates only, “Landfilling Countries” have the poorest performance, but taking into account the waste amount generated, “Transition Countries” still landfill (without pre-treatment!) more than 50 million tonnes annually. The proposed new development of municipal waste management in the EU 28 towards “Circular Economy”, containing higher recycling targets for 2025 (80%) and 2030 (65%) can be described as “engine for development”, but it has to be mentioned critically that it is strongly connected with new technical, economical and ecological challenges too. Especially the proposed new and unique calculation of recycling targets and its influence on currently calculated and reported quotas require additional investigations. First application examples show a respectable influence, e.g. reduction of calculated recycling rate from 64% to 40–50% for Germany in year 2013. Additionally, a gap between economic and ecological optimum has to be considered and at the end of the day has to be payed by someone.

The Ternary Diagram method applied and extensively described in this paper enables three types of visualization for municipal waste management performance: 1. “Performance Positioning” of waste management unit(s) at a specific date; 2. “Performance dynamics” over a certain time period and; 3. “Performance development” expressed as a track(s). Additionally, the statistical prognosis enables the possibility for better understanding of existing coherences and potential future developments. One of the main coherences shown by the method is the linked development of recycling & composting (60–65%) with incineration (40–35%) performance over the last 20 years in the EU 28. Such, 1000 kg municipal waste landfilled was/is replaced by the combination of 600–650 kg recycled & composted and 350–400 kg incinerated.

Further application of the Ternary Diagram method (dynamic visualization of all 28 EU countries, European cities and regions as well as the impact of waste management measures (e.g. extension of separate collection, landfill tax, landfill ban, etc.) on the municipal waste management performance development) is currently in preparation. Dynamic visualisations using Ternary Diagram method enables better understanding and monitoring of development paths. Additionally, in case of deviations between actual and planned developments/results actions and measures can be set timely by decision-makers.

Finally, authors propose following acrynom “RIL-Ternary Diagram” (according to the treatment categories: Recycling & Composting, Incineration and Landfilling) to be used for the reported application of the Ternary Diagram method and dynamic visualization of waste management performance described.

Conflict of interest

The authors declare no conflict of interest and confirm that the investigation work has not been funded by any organisation.
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