Development of indicators to monitor environmental impacts of transitioning to PAYT tariffs

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Project LIFE PAYT – Tool to reduce waste in South Europe (**LIFE 15 ENV/PT/000609**)

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1. Introduction

This study aims to define a consistent set of relevant indicators to assess the environmental benefits of implementing pay-as-you-throw waste tariffs at the 5 demonstration sites involved in the project LIFEPAYT, namely in Aveiro, Condeixa-a-Nova and Lisbon (in Portugal), Larnaka (Cyprus) and Vrilissia (Greece).

Performance indicators are the basic tool to measure and communicate the results and degree of success of a given initiative (Euroconsultants, 2010). Indicators allow to assess to which extent the project is reaching its intended objectives, and how fast is the project progressing towards meeting its ultimate goals. Moreover, indicators should be the result of "compacting" a large amount of information to communicate it in a simplified form. Particularly in the field of municipal waste management, research has recently taken place about suitability and best practices regarding performance indicators (Sanjeevi & Shahabudeen, 2015; Rigamonti, Sterpi, & Grosso, 2016). As exposed by researchers (Ristić, 2005), performance indicators used with solid waste management should comply with five essential quality criteria:

- Analytical soundness (correlation between changes in the indicator and changes in environmental pressure and/or use of resources)
- Responsiveness (capacity to reflect and respond to policy actions)
- Comparability of the used data
- Consistency with other related indicators
- Clarity (easily understandable)

Therefore, indicators are primarily chosen regarding their ability to reflect the expected effects derived from the progress of the project. It is intended that the selected indicators provide an integrated view on all the features which are representative of the situation of municipal solid waste generation and management in a given place, thus linking personal behaviours such as the amount of waste generation or the extent of home separation of recyclable materials to its consequences for the waste management process

– such as the energy required for collection – and its associated main environmental impacts, like carbon footprint. At the same time, there is an intention of building a set of indicators simple in its appearance, quick and easy to be understood, so that it could be presented to the general public – that is, not limited to academic partners or institutional stakeholders –, regardless of technical background.

2. Methodology

To achieve its best effectiveness and thus obtain a representative picture of the environmental state of each demonstration site within the project, before and after PAYT implementation, indicators should be based upon a sound set of primary data with good quality. Frequently, this is not the case in waste management studies, where the availability of raw data is scarce due to difficulties for effective measurement of parameters such as weight, volume or composition, particularly at a local, small-scale level, forcing then to make assumptions and extrapolations from larger scales. Whenever possible, the indicators for the LIFE PAYT project will rely on locally gathered data from the waste characterisation campaigns to be held in the involved areas. These campaigns will in fact be designed accordingly to the measurement of the defined indicators, thus ensuring its validity.

Regarding the frequency of measurement, in order to perform a proper monitoring of the evolution of PAYT implementation during the project, it is advised that measurements for the indicators should take place at least in three different moments, namely:

- Just before the beginning of the project, with the goal of obtaining a complete picture of the previous situation ("baseline"), which is expected to change as a consequence of the project implementation.
- During the implementation of the project (at a middle point, where an intermediate target may be established).
- After the end of the project, aiming at evaluating the fulfilment of the final objectives of the project.

This timing procedure will be followed in project LIFEPAYT, so that three characterisation campaigns will be scheduled in every location: the first before the project starts, the second during its development and the third after its completion. Nevertheless, once the IT platform which will give support to the project is active, a continuous register of waste amounts entering the system will be generated.

The defined set of indicators should be limited to an acceptable number of indicators, for the sake of simplicity. Therefore, the choice should be focused on those key indicators which are likely to be most affected by changes in municipal waste policy, i.e. the scope of action of PAYT.

The set of selected indicators will be applied to all of the demonstration sites of the project, in five different municipalities of three countries (Cyprus, Greece and Portugal). Therefore, although the environmental indicators will be basically the same for all the sites, the methodology must account for the differences occurring in each of the pilot experiences (e.g. a specific indicator evaluating level of home composting is not needed for all cases, since home composting will not be introduced in all of the five locations).

The set of environmental indicators is organised in three parts. A first group includes the indicators related to the amounts of municipal solid waste generated in each of the five target zones. The second group of indicators is derived from the first one and refers to assessment of the various degrees of recovering of valuable materials contained in municipal solid waste. Finally, a third group of indicators covers the performance of the waste management focusing on the environmental impacts – both positive and negative – generated by these activities. This approach seems adequate to better understand the relationship between the amounts of municipal waste generated and its subsequent impact on the environment, thus enhancing the awareness of the waste producers – i.e. the local population – on this issue.

3. Results and discussion

A set of 11 environmental indicators has been chosen – each indicator is identified by an assigned code, ranging from E1 to E11. This proposed set of indicators is summarised in Table 1, including its measurement units and calculation formula.

Table 1. Set of environmental indicators

INDICATOR		UNITS	CALCULATION FORMULA
E1	**Annual production of mixed MSW**	kg mixed MSW · year^{-1}	$\frac{\text{mixed MSW (kg)}}{\text{year}}$
E2	**Annual production of source separated MSW**	kg source separated MSW · year^{-1}	$\sum_i \left[\frac{\text{waste fraction i (kg)}}{\text{year}}\right]$ (i = plastics & metals; paper & cardboard; glass)
E3	**Annual production of MSW**	kg MSW · year^{-1}	$\frac{\text{total MSW (kg)}}{\text{year}}$
E4	**Source separation**	%	$\frac{\text{source separated MSW (kg)} \cdot 100}{\text{total MSW (kg)}}$
E5	**Recyclable materials in mixed MSW**	%	$\frac{\sum_i (\text{mixed waste fraction i (kg)}) \cdot 100}{\text{mixed MSW (kg)}}$
E6	**Separation percentage of single recyclable materials**	%	$\frac{\text{source separated waste fraction i (kg)} \cdot 100}{\text{(source separated + mixed waste fraction i) (kg)}}$ (i = plastics & metals, paper & cardboard; glass)
E7	**Organic waste home composted**	%	$\frac{\text{home composted organic MSW (kg)} \cdot 100}{\text{total organic MSW (kg)}}$
E8	**Substituted raw materials due to recycling**	kg/year	$\frac{\text{recycled waste i (kg)}}{\text{year}} \cdot (\text{Market factor i}) \cdot (\text{Quality factor i})$ (i = plastics & metals, paper & cardboard; glass)
E9	**Reduction of MSW sent to landfill**	%	$\frac{\text{prevented MSW to landfill (kg)} \cdot 100}{\text{produced MSW (kg)}}$
E10	**Energy consumption associated to MSW management**	toe/year	$\frac{\text{collected MSW (t)} \cdot \frac{\text{toe consumed}}{\text{1t MSW}}}{\text{year}}$
E11	**Greenhouse effect emissions related to waste management**	kg CO_2 eq. / year	$\frac{\text{collected MSW (t)} \cdot \frac{\text{kg } CO_2\text{eq. emitted}}{\text{1t MSW}}}{\text{year}}$

In the next part, an explanation of the relevance of each indicator for the LIFEPAYT project and methodology of calculation is given. Registered statistical data (mainly for Portugal) are also provided as a benchmark, with an orientation purpose. The data concerning total waste generation in Portugal for indicators E1, E2 and E3 are extracted from the annual report about the environment, released by the Portuguese Environmental Agency (APA, 2016b).

- **Annual production of mixed MSW (Indicator E1)**

In 2015 the *per capita* production of mixed municipal solid waste (MSW) in Portugal reached 458 kg per year, of which 84.7% was mixed MSW (APA, 2016b). The main goal of PAYT tariff systems is actually to achieve a reduction of the mixed municipal waste through the introduction of an economic incentive.

As total mass of MSW, this indicator is expressed as: *kg of mixed MSW / year*

The waste characterisation campaigns will allow to calculate this amount. Every sample will be weighted and when necessary, the weight of sample is extrapolated to obtain the total amount generated in the target area. This extrapolation is necessary at least in the case of Lisbon and Condeixa, as the number of commercial producers involved is too large to sample all of them, but in the other sites it is expected the sample to be formed by the total amount generated. Historical recordings of MSW collected in the municipality will be consulted to account for seasonal variations, in order to determine an average value.

Even if the indicator is expressed with mass units, since this is the usual practice and thus easier to understand, it is also of practical interest to determine as a second parameter the volume of mixed waste produced (as m^3/year). Although is not usually possible to measure volume with the same accuracy as mass, it is actually less complicated to implement, since weighing devices are typically more complex equipment. In the LIFE PAYT project it has been decided that monitoring will be based on the volume of waste delivered to the collection containers, so that the waste tariff will be accordingly based on volume. Furthermore, this choice possesses a particular advantage: since a large part of the waste volume typically consists of packaging materials (with low specific weight), the pricing based on volume will enhance the source separation of these materials and delivery to the recyclables collection system, thus contributing to the reduction of mixed municipal waste.

Another important question arises when discussing this indicator. As reported in several works (Bilitewski, Werner, & Reichenbach, 2005; Dunne, Convery, & Gallagher, 2008; Simão Pires, 2013), it is not unusual that the implementation of PAYT systems might lead to the emergence of undesired behaviours, such as dumping of waste in an improper manner. If it is detected during the project that a significant amount of waste is diverted in this way, it will be taken into account in the indicator.

- **Annual production of source separated MSW (Indicator E2)**

As explained before, it is expected that the recyclable materials which are covered by the separate collection schemes (typically packaging materials of plastics, metals, paper, cardboard and glass) will be diverted out of the mixed municipal waste through source separation towards these collection routes. In Portugal the amount of municipal waste which was source separated and separately collected reached 61 kg per inhabitant in 2015 (APA, 2016b), which represents a 13.5% of all municipal waste. This is considered a low rate, when compared to the numbers exposed in other works (BiPRO, 2015). From previous experiences with PAYT systems, it can be concluded that with application of such a variable pricing policy, the amount of source separated materials may significantly increase (Reichenbach, 2008; Puig Ventosa, Calaf Forn, & Mestre Montserrat, 2010; Simão Pires, 2013; Morlok, Schoenberger, & Styles, 2017.

As for the mixed waste, the amount of source separated waste will be known from a specific characterisation campaign. In this case the determination will consist in a measurement of volume of waste delivered to waste containers of each separate collection stream – typically paper and cardboard, plastics and metals and glass –. This measurement can be performed by estimating the filling degree of containers just before its emptying for collection. Since the composition of these waste streams is less complex than that of mixed waste, previously published values of specific weight for the mentioned waste materials can be applied to obtain the amount as mass. In the particular case of Lisbon, this procedure will be easier, since the collection (of both mixed and source separated waste) to the commercial producers involved takes place through a door-to-door system, so it is possible to know how many full containers are emptied every time. During the project this will be tracked with sensors installed on the containers.

Therefore, the indicator is expressed as the total mass of source separated municipal waste – i.e. the addition of every waste stream in separate collection: *kg of source separated MSW / year*

The characterisation campaign should be also aimed at verifying that the source separation is correctly done and no other strange materials are present than those to which the container is assigned. If not so, that would be considered another form of undesired behaviour.

- **Annual production of MSW (Indicator E3)**

After the decline from 2010 onwards mainly due to the difficult economic situation, it has been observed since 2014 a slight increase in municipal waste generation. The last registered data corresponding to year 2015 presents an annual per capita generation of 458 kg (APA, 2016b). The same indicator for Cyprus corresponds to 638 kg (2015) and for Greece is 506 kg (in 2012, last year available). For comparison, the EU average as of 2015 amounted 476 kg (Eurostat, 2017).

This indicator will be calculated for the target zones as the addition of the quantities of waste delivered both to the undifferentiated and separate collection schemes. Therefore, its units will be: *kg of MSW / year*

The relevance behind this choice responds to the interest of evaluating if the adoption of a variable tariff system produces any effect on the consuming pattern of the population, thus leading to a reduction on the overall waste production – i.e. prevention of waste generation. Even though environmental concern is not the only motivation influencing consumer behaviour, this still may play a significant role. It is thought that at least some consumers would care about making use of less packaging materials – e.g. buying items of larger size (such as larger drink bottles), thus carrying more product per packaging unit –, or even trying to reduce consumption at all. For this project it is proposed to achieve a slight decrease of 2% – thus inverting the increasing trend observed in the last two years. On previous PAYT experiences, it was not always possible to achieve a global reduction of municipal waste – while in other cases the reduction was larger than 10% – (Reichenbach, 2008; Puig-Ventosa, 2008; Šauer, Pařízková, & Hadrabová, 2008; Puig Ventosa, Calaf Forn, & Mestre Montserrat, 2010; Morlok, Schoenberger, & Styles, 2017). The strategic plan on municipal waste adopted by Portuguese authorities establishes a reduction goal of 10% for 2020 respect of 2012 (Ministério do Ambiente, Ordenamento do Território e Energia, 2014). Nevertheless, given these variations, the mentioned value of 2% in reduction was chosen as a conservative goal for this indicator.

- **Percentage of source separation (Indicator E4)**

This indicator represents the ratio between the quantity of municipal waste which is source separated and delivered to the separate collection system and the total generation of municipal waste (both source separated and mixed), expressed as percentage (weight/weight). Therefore, this particular indicator should be regarded as a measurement of the yield achieved by the separate collection. This indicator is calculated by simply dividing the value of indicator E2 between the value of indicator E3.

As explained before, the value of this yield in Portugal is around 13.5% of the total generation of municipal waste. This is a low value, considering that the amount of materials suitable to be diverted to the separate collection scheme – i.e. glass, metals, plastics, paper and cardboard – accounts for roughly 30% of the total municipal waste (APA, 2016a). Moreover, this value has remained stable for the last years, even though significant efforts have been made to extend the implementation of separate collection (APA, 2016b). Thus, a further enhancement of source separation of waste is needed in order to reach the objectives fixed by national and EU waste policies. From the previous experiences already mentioned for indicator E2, it is concluded that the 30–40% of separation could be achieved within the project.

- **Dry recyclable materials in mixed MSW (Indicator E5)**

Along with the previous indicators referred to quantities of waste, the indicators E5 and E6 are specifically related to the physical composition of the municipal waste generated in the target areas. This composition will be determined through the planned waste characterisation campaigns, parallel to the assessment of the waste quantity produced. In every campaign samples will be collected assuring representativeness of every target area involved. Each of the collected samples will be classified distinguishing the main waste fractions present. A guideline to this procedure is provided by the legal instruction 851/2009, issued by Portuguese Ministry of Environment for technical regulation of municipal waste characterisation (Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, 2009). The physical composition will be given as a percentage (%, weight/weight). Thence the percentages of every waste fraction can be likewise also known and namely those of the dry recyclable materials: glass, metals, plastics, paper and cardboard. For the indicator the addition of all dry recyclable materials in one single percentage value will be calculated.

The assessment of dry recyclable materials still present on the mixed municipal waste, – i.e. not diverted to the specific collection containers – will be a relevant conclusion of this analysis. As exposed for indicator E4, a large part of dry recyclable materials is still not source separated and left within the mixed waste. As a consequence, this deficient source separation has even led to a paradoxical situation where some waste treatment facilities obtain amounts of valuable materials – namely plastics – from the pre-treatment of mixed municipal waste larger than those plastic amounts recovered in the sorting facilities for municipal waste from separate collection circuits. This result will serve as basis to further calculate the indicator E6 and at the same time it will provide information regarding the maximum potential improvement which will be possible to achieve by further encouraging the source separation of these materials.

- **Separation percentage of single recyclable materials (Indicator E6)**

While the indicator E4 refers to an overall performance of the source separation as a whole, it is of importance to assess separately the results concerning each specific dry recyclable waste stream, which is also known as *capture rate*. The calculation procedure is based on the quantities and composition of the different waste streams which were analysed in the characterisation campaigns. Once the amount of a given material – either glass, metals, plastics or paper and cardboard – in both the mixed municipal waste and in the respective separate collection stream is known, the indicator value corresponds to the ratio between the amount delivered to separate collection and the total amount of the material within the separate collection and the mixed municipal waste, expressed as percentage (weight/weight).

The relevance comes from the fact that not all the recyclable materials are source separated in the same extent, due to differences in the behaviour of population. Typically, glass and paper present the highest separation rates – since they are the most intuitive materials to be separated –, while that of plastics tends to be poorer. In a report assessing the separate collection systems of the 28 EU capital cities (BiPRO, 2015), the average capture rate for glass was 49% and that of paper 36%, while the result for plastics dropped to 11%. When plastics recovery is considered in combination with metals and composites (*comingled fraction*) the indicator reaches 22%. However, in the case of metals alone source separation is not as essential as with the other materials, since metals can be easily recovered by electromagnetic devices during pre-treatment. In the particular case of Lisbon – which presents a better behaviour regarding source separation than Portuguese average –, the numbers were 59.8% for glass, 38.0% for paper and 25.9% for the comingled fraction of plastics and metals. Nevertheless, in the best cases the rates for glass and paper were more than 80% and that of the comingled fraction was higher than 60%, thus showing that there is still a great margin for improvement. Moreover, it is noteworthy that all of the best cases take place in cities which apply some kind of PAYT pricing.

- **<u>Organic waste home composted (Indicator E7)</u>**

This indicator will be measured as percentage of reduction (through home composting) of the total amount of organic waste produced. The total amount of organic waste is known from the characterisation of quantity and composition performed for previous indicators. Data for estimating the amount of organic waste being home composted will be obtained from the participants in the home composting program, and the percentage between home composted and total organic waste can be determined.

Home composting will be offered to the households as an alternative to effectively divert organic waste from the mixed waste stream, with environmental benefits already studied (Martínez-Blanco et al., 2010). Organic waste that is home composted can be considered in practice as prevented waste, since it never enters the waste management system. Therefore, home composting contributes to the global reduction of municipal waste. However, the success of such an alternative relies mostly on factors which are external to the project, namely the suitability of households to support this activity – i.e. enough space at home, appropriate waste, sufficient training – and, on the other hand the existence of a potential demand for making use of the produced compost, mainly as soil amendment. With regard to these aspects, it is considered that those households consisting in detached houses with gardens will be the most feasible – and hence the most interested – for this purpose, although large apartment buildings are not excluded if they possess a collective container for biowaste. The established objective for the project is to encourage at least 25% of people living in detached houses to join the home composting initiative.

- **Substituted raw materials due to recycling (Indicator E8)**

The most relevant of the environmental effects derived from the adoption of a PAYT scheme consists on the increase of the quantities of materials suitable for recycling which are delivered to the separate collection systems. Recycling processes have a net positive impact on the environment, as they contribute to prevent the extraction of primary raw materials from nature. It is assumed that a given amount of a certain recycled material will therefore substitute an equivalent amount of the correspondent primary raw substances required to produce the same material. In terms of life cycle assessment, this is considered an *environmental credit*.

These substitutions of raw materials are deduced from the amounts of materials diverted to recycling processes, which are known from the characterisation procedures of quantity and composition performed for indicators E1, E2 and E5 and also from the data supplied by the waste management operations about quantities of waste recovered for recycling during the treatment of municipal waste. After calculating the substituted amounts, these are expressed in form of quantities (mass) of prevented primary raw materials: *kg prevented raw materials / year*

Therefore, to properly determine this indicator, care should be taken on how to calculate the mentioned substitution between the amounts of materials delivered to the recycling processes – that is, after waste collection and sorting operations, with its subsequent material losses –. Although this substitution of raw materials has been traditionally done on a 1:1 basis (Laurent *et al*., 2014; Bala Gala, 2015), it is recommended to take into account some considerations which discourage the simple 1:1 assumption:

- A lower quality of the recycled material respect of virgin material.
- Significant ratio of recycling already achieved for a particular material, so that the substitution of 100% virgin material no longer applies as such, rather being a substitution of a mix of virgin and recycled material.

Hence, following a previous approach on this issue (Bala Gala, 2015), the substitution method is given by:

$$\textbf{Environmental credit} = x \cdot REC + (1\text{-}x) \cdot Q \cdot VIR$$

where *x* is the ratio of material currently already recycled (i.e. composition of market mix for a given material), *REC* is the environmental impact of producing a given amount of recycled material, *VIR* is the correspondent impact of producing the same amount of virgin material and *Q* is a factor between 0 and 1 accounting for the loss of quality. The credit is equivalent to the impact of producing the mix of virgin and recycled material, and so, the amount of virgin material which is really substituted is that affected by factors *x* and *Q*.

The key issue is to find adequate values for the two factors Q and x. Values for the quality factor *Q* can be assumed as 1 for glass and metals, since no significant loss of quality occurs during the re-melting process. For paper a value of 0.8 was reported by the European Environmental Agency (EEA, 2006), while for plastics it is difficult to obtain a single value. For instance, a value for HDPE of 0.75 was reported from a laboratory research (Bala Gala, 2015). However, it has been suggested on a study regarding the market situation in Italy (Rigamonti, Grosso, & Sunseri, 2009) a generic value of 0.8 for plastics based on economic considerations (comparison of prices of virgin and recycled material), as an alternative to overcome the lack of technical research. On the other hand, with regard to factor *x*, the following market mixes compositions for several materials are reported (Bala Gala, 2015) in Table 2:

Table 2. Market mixes distributions of recyclable materials (Bala Gala, 2015)

Material	% virgin	% recycled
Aluminium[1]	63	37
Steel	50	50
Glass	55	45
Cardboard	16	84
Paper	71	29
Beverage cardboard	57	43
Plastics[2]	**	**

As explained in the table, the distribution between virgin and recycled plastics is difficult to assess in a simple manner given the heterogeneity of this material. While some plastics like PET or HDPE have high recycling rates, the overall EU[3] production of recycled plastic reached only a 15.6% of the total EU plastic consumption in 2015 (PlasticsEurope, 2016), which can be used as a reasonable approach.

- **<u>Reduction of MSW sent to landfill (Indicator E9)</u>**

An estimated 34% of municipal waste generated in Portugal (continental) in 2015 was sent to landfill without further treatment (APA, 2016b). Although this ratio has remarkably decreased in the previous years – in 2010 it was 62% –, the EU environmental policy on landfills is pressing for a further reduction, in accordance with the waste hierarchy which places landfills as the last option for municipal waste treatment. Particularly, in the case of organic municipal waste, the Portuguese strategic plan on municipal waste establishes a reduction goal of 35% of organic municipal waste to be achieved in 2020

[1] For the packaging sector these percentages move to 25% virgin / 75% recycled
[2] The percentage of plastics is difficult to quantify
[3] EU28 (with UK) + 2 (CH,NO)

with respect to the amount generated in 1995 (Ministério do Ambiente, Ordenamento do Território e Energia, 2014).

Since the application of PAYT variable pricing will expectedly reduce the generation of mixed municipal waste, in the end this results in a lower amount of waste arriving to the landfill after the previous treatment operations. In Portugal, information about the distribution of final destinations of municipal waste must be annually reported by every waste operator to the national environmental authority, which makes them publicly available (APA, 2016a). The data concerning the quantities of waste classified by final destination originated by the waste management companies responsible for the target areas of the project will be taken as a starting point to extrapolate them from the total amount managed by the operator (i.e. at a regional scale) down to the local scale of the target areas, assuming that the distribution of final destinations (and thus the composition of the waste) remains similar. In this way it will be estimated the amount of waste sent to landfill from the target areas, expressed as the percentage of total municipal waste generated which is prevented of being sent to landfill.

Moreover, although it will be difficult to observe in a local pilot experience – too small scale as to produce appreciable effects on the entire waste management system –, there exists a second positive effect of PAYT related to less landfilling: one of the main problems affecting the performance of the waste treatment facilities is the low quality of the recovered materials which might difficult or even make not possible the recycling or valorisation processes. The reason behind this poor quality is the cross-contamination caused mainly by a wrong source separation of waste (or no separation at all). For instance, the absence of cross-contamination is crucial for the feasibility of paper recycling, and also a critical issue in biological processes, since the presence of materials other than organic matter can severely harm the yield of biogas production or the quality of compost. Classification of different plastics is also more difficult when performed on a mixed waste flux, and separation of glass is actually inexistent.

All this troubles will finally result in a considerable amount of rejected materials – it can account for 50% or more of the total incoming waste flux – which will be either incinerated or – more likely – landfilled. It is therefore of great interest to rise the quality of recyclable materials (through enhanced source separation) in order to improve the performance of treatment processes and minimise this secondary landfilling. This requirement is mentioned on the EU Waste Framework Directive (European Parliament and Council, 2008) and is expected to be an increasing trend for waste operators and recyclers (BiPRO, 2015).

- **Energy consumption associated to MSW management (Indicator E10)**

Besides the negative consequences derived from landfills, another major contribution from waste management processes to environmental impacts is that caused by the energy consumption of management operations. Consumption of energy takes place mainly during the waste collection stage, due to the fuel needed by the collection vehicles. Actually, consumption of energy – in form of electricity – during the waste treatment operations may be fully overcome by the facility operator if some kind of waste-to-energy process is performed (e.g. through biogas production), thus creating energetically self-sufficient treatment sites, which in addition could act as suppliers of electricity based on renewable sources of energy. In contrast to this scenario, waste collection remains as the main energy consuming component of the waste management scheme. This has also a strong economical implication: fuel consumption along with the labour costs also involved make the waste collection and transportation stages account for the major part of waste management costs, reportedly up to a 70% (Tavares, Zsigraiova, Semiao, & Carvalho, 2009).

For the cases of study in this project, the values of energy consumption will be obtained from the waste management companies responsible for treatment and collection, expressed as tonnes of oil equivalent per year: *toe/year*

If a significant reduction of the mixed municipal waste generation is achieved, it could be possible to reduce the collection frequency and thence reduce the energy consumption. On the other hand, it would be argued that the increased amount of recyclable materials sent to separate collection may lead to higher collection costs, but previous experiences with PAYT systems show that this increased cost is compensated by the larger recovery of valuable materials and higher quality of collected materials (Bilitewski, Werner, & Reichenbach, 2005; Morlok, Schoenberger & Styles, 2017). Moreover, waste collection frequencies in Southern European countries like Portugal and Spain, collection frequencies of mixed municipal waste are usually higher than in Central and Northern

Europe – i.e. daily vs. weekly or even monthly collection –. This difference is typically attributed to the warmer temperatures which favour a faster biodegradation of organic matter with uncomfortable consequences, like bad smell. However, these negative features are thought to be at some extent over-perceived, thus not justifying such a high frequency of collection. The introduction of PAYT might therefore serve as an opportunity to test better optimised collection routines.

- **Greenhouse effect emissions related to waste management (Indicator E11)**

Among the environmental impacts derived from the waste management, the greenhouse effect emissions were selected as the most representative. Actually, the assessment of carbon footprint is a widely extended methodology of communicating the environmental impacts in a quick and simple manner. Carbon footprint is usually reported through the value of equivalence in emissions of carbon dioxide (CO_2 eq.).

The waste treatment sector is the fourth largest contributor to greenhouse effect emissions within EU, responsible for a 3.4% of the total greenhouse gas (GHG) emissions from EU in 2014 (EEA, 2016). The main source of emissions corresponds to the waste disposal in landfills, where the anaerobic biodegradation of organic matter produces carbon dioxide – with no accountable global warming potential since its origin is biogenic – but also methane – with global warming potential estimated as 25 times that of CO_2 in a 100-year time horizon –.

These methane emissions from landfills occur in a diffuse manner and are thus difficult to measure, but for Portugal were estimated as 3806 kt CO_2 eq. in 2014. Despite a continued increasing in last years, it is expected that these emissions will be lower in the future, due to the improved recovery of landfill gas and the progressive diversion of organic waste to alternative forms of treatment.

Similarly to the situation regarding indicator E10, waste collection and transport is also another major contribution to GHG emissions caused by waste management. Once again, the adoption of PAYT can help in reducing these emissions by reducing the collection frequency and diverting waste from landfill. Another relevant aspect is that fostering recycling activities can result in the prevention of GHG emissions which would be otherwise originated by the production based on primary raw materials, following the approach of *environmental credit* explained for indicator E8. A ton of recovered paper can save up to 0.35 t of CO_2 emitted, that of glass up to 0.20 t of CO_2 and that of plastics up to 1.71 t of CO_2 (Eunomia, 2015).

GHG emissions due to management of waste from the target zones will be obtained from responsible entities – those methane emissions originated by landfilling are publicly available from European Pollutant Release and Transfer Register (E-PRTR), those from waste collection can be calculated from the fuel consumption and those originated by the treatment facilities can be estimated from process data –. Carbon savings due to recycling of materials will be subtracted from the emissions value to obtain a final result in form of: *kg* CO_2 *eq. / year.*

4. Conclusions

The indicators for evaluating the environmental performance of waste management at 5 demonstration sites involved in the LIFE PAYT project, before and after PAYT implementation, have been presented and discussed. The indicators were selected according to the relevance for the environmental assessment of the project and clarity of explanation. Some of the indicators include minimum objectives of performance to be expectedly fulfilled by the project. Previous experiences with PAYT systems have shown to be able to affect these indicators significantly and in an environmentally positive way. The indicators are mainly focused in the changes in quantity and composition of the municipal waste fluxes which are expected to occur due to the adoption of a PAYT variable pricing policy: less mixed municipal waste, and more recyclable materials recovered through source separation and separate collection, along with reduced waste generation reinforced by the introduction of home composting. These changes in the waste streams will induce some effects upon performance of the waste management systems – namely on energy consumption – and on the environmental impacts derived from these activities – namely on carbon footprint and prevention of primary raw materials consumption –.

The indicators will be determined whenever possible from local data gathered in the target locations of the project, since this will assure representativeness of the analysed case. The results of the indicators will be regularly updated in order to perform a tracking of the progress achieved by the project. Particularly, the indicators will be measured before the beginning of the project, during the project development and after the project completion, aiming to establish a comparison of the different scenarios.

5. References

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