Energy recovery from municipal waste in Spain and Andorra: carbon footprint and comparison with landfill

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sg-advisory
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CONSULTANCY Technical - economic - strategic

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1. INTRODUCTION

1.1 Background

AEVERSU (hereinafter also referred to as the Customer) is the Association of MW Energy Recovery Companies. It brings together 12 companies, 11 in Spain and one in Andorra, whose activity is recovering energy from Municipal Waste (MW), which involves producing electricity and heat by using the calorific value of the waste.

The basic aim of AEVERSU is to enhance and encourage the development of energy recovery from the non-recyclable fraction of MW, and to do so in compliance with the hierarchical scale established by the European Union (EU) in its Directive 2008/98/EC, subsequently modified by Directive 2018/851, which returns to the production cycle, the energy value contained in the waste; this process is essentially better than dumping the waste at a landfill site.

In 2015, and with the twofold aim of publicising its objectives and contributing to overcoming the problem of suitably managing MW, AEVERSU commissioned *G-advisory Consultoría Técnica, Económica y Estratégica, S.L.P.* (hereinafter, G-advisory) to conduct research into the socioeconomic and environmental impacts of energy recovery from MW in Spain and Andorra.The study provided an updated view of energy recovery from MW and the opportunities for the sector from that perspective.

AEVERSU commissioned G-advisory to carry out a detailed analysis of the contribution made by the MW Energy Recovery Sector in Spain and Andorra not only to mitigating climate change but also to the transition towards a low-carbon economy, asking the firm to do this placing the emphasis on greenhouse gas emissions. To do this, the study analyses the carbon footprint and the net balance (carbon footprint minus emissions prevented) for energy recovery from MW and compares them with the carbon footprint and the net balance associated with disposing of MW at a landfill site.

1.2 Aims

The threefold aims of this work are as follows:

- To explain and highlight the role of energy recovery from MW as part of the environmental solution, after reduction, reuse and recycling.
- To analyse the carbon footprint in the MW Energy Recovery Sector.
- To compare that carbon footprint with the footprint left by MW landfill.

1.3 Sources of information

We analysed the information provided by the different members of AEVERSU when carrying out this work. It includes updated data from every processing plant regarding the mass and energy balances (amounts of MW received every year, quantities of slag and ash produced, fuel and electricity consumptions, electricity produced, etc.), together with information regarding waste transport. We also received occasional specific information about MW landfill.

That information was emailed to G-advisory in different communications as from March2020.

Moreover, we referred to public sources of information regarding the management of MW in their energy recovery. Such sources included the report drawn up by the German Federal Environment Agency in 2015 concerning the Waste Sector's potential for mitigating climate change, the article written by Møller & Fruergaard in 2009 about accounting for greenhouse gases in the waste sector or the United Nations Environment Program Report (hereinafter UNEP) from 2019 regarding the considerations about energy recovery for decision-making, amongst others.

We consulted such sources of information as the *National Greenhouse Gas Inventory* (Edition 2020, Series 1990-2018) to obtain information about greenhouse gas emissions; it was published by the Spanish Ministry for Ecological Transition & Demographic Challenge (MITECO) in March 2020.

The Annex to this report contains a list of the main documents reviewed when conducting our study.

1.4 Limitations and responsibility

This Report was prepared with the sources of information quoted in Section 1.3.

We have considered the following hypotheses with respect to the information sent by

AEVERSU:

- The documents and information furnished and examined contain only correct and complete data that were valid on the date this Report was published. They do not contain any false information. Neither have they been modified or superseded by any documents other than those provided by the sources consulted, and no important information or documentation has been withheld or concealed that might modify or otherwise alter in any way the documents and information that have been the subject of examination.

- The documents have been signed by persons who are sufficiently well qualified to make their contents binding where the organisations they represent are concerned.

- The scanned and electronic documents are complete and are a true copy of the original documents.

- There are no annexes or modifications to the documents examined that have not been made available to us.

- The signatures that appear on the documents furnished are those of the people that, as stated in the documents analysed, actually took part in preparing those documents. Moreover, the dates that appear on the documentation are the same as the dates when they were actually created, issued, signed, executed or produced.

- Other than the documents provided, there are none that modify, contradict or alter the ones that were analysed.

When assessing the work, the following limitations and reservations with which it was carried out have to be taken into account:

- The only documents or information that were analysed were those referenced in Section 1.3 of this Report and any generated after the latter's emission date are excluded.
- The documents and information assessed exclude the following aspects: (i) business opportunities involved in signing them; (ii) compliance with them and actual effectiveness, in practice.
- Technical standards and the "state of the art" applicable to these types of MW processing facilities.

Where this Report is concerned, G-advisory is liable and answerable only to AEVERSU and such responsibility will not exceed the fees received by G-advisory for the part of the services that gives rise to liability. Under no circumstances will such liability include indirect damage, loss of income & consequential damage or opportunity cost.

2. EXECUTIVE SUMMARY

The European Union has established commitments for Spain that are particularly challenging where municipal waste management is concerned: as from 2030 recoverable MW will no longer be admitted at landfill sites, and before 2035 the amount of MW disposed of as landfill will have to be reduced by 10% in weight.

Faced with these challenges, an increase in reuse and recycling, plus energy recovery for reject fractions, is positioned as a key scheme if Spain is to comply with its European commitments in matters involving MW management. All of the above is in keeping with the hierarchy established by the EU regarding waste management and is consistent with what the main EU Member States are doing.

However, in Spain, the main MW management system is still direct disposal at landfill sites, which receive 56.3% (12.7 million tonnes) of the MW generated, followed by recycling (33.8%) and energy recovery (9.9%). In terms of GHG emissions, the Waste Sector accounts for 4% in Spain and could make a considerable contribution to mitigating climate change.

The carbon footprint calculations summarised in this Report are based on the internationally recognised guidelines contained in the GHG Protocol, EpE Protocol and the IPCC Guidelines (2006). They focus on Scopes 1 and 2, whose methodological details are shown in Section 4.2 of this Report.

As the starting point, we have used the information supplied by the energy recovery plants that form part of AEVERSU. We compared the data and rejected any that was either incomplete or showed signs of inconsistency. One particularly important parameter was the data coming from actual measurements of the biogenic carbon content in MW from 6 facilities, which amounted to 83% of the MW processed by AEVERSU.

When it came to calculating the carbon footprint from MW disposal, we decided to rely mainly on the National Greenhouse Effect Gases Inventory (Edition 2020,Series 1990-2018) as our source of information; it was issued by the Ministry for Ecological Transition & Demographic Challenge (MITECO) anddated March 2020.

In the study we used the very latest emission factors to be published by official sources and, whenever it was possible to do so, we selected the most specific factors and the ones that were most comparable to the real situation affecting our study, in Spain and Andorra.

We can conclude as a Report finding, that the energy recovery carbon footprint is clearly lower than the landfill carbon footprint:

- Energy recovery plants generate GHG emissions amounting to 377 Kg CO_2e/ t MW and show a net balance of 224 Kg CO_2e / t MW.
- Landfill sites generate GHG emissions of 781 Kg CO_2e / t MW, 107% more than energy recovery, and show a net balance of 772 Kg CO_2e / t MW,245% more than energy recovery.

According to the target scenario for the Comprehensive National Energy & Climate Plan (hereinafter PNIEC, 2021), the percentage of renewable generation in the electricity sector would undergo an increase of 34 per cent, rising from 39.7% in 2020 to 73.6% in 2030. Taking the PNIEC's target scenario as the point of reference and assessing only the variation in the electricity mix in the footprint calculations analysed (without including any potential variation affecting other parameters in time, very difficult to evaluate), the difference between carbon footprints from landfill disposal and energy recovery would be reduced, and by 2030 the net balance for GHGs per tonne from MW as landfill would be 133% higher than for energy recovery.

The lower carbon footprint for energy recovery when compared to landfill disposal is a factor that not only endorses the hierarchy established for waste management in Europe but also validates the role that can be played by energy recovery in Spain and Andorra, as a supplement to recycling, in order to achieve the goals set by the circular economy strategies and to combat climate change.

3. THE ROLE OF ENERGY RECOVERY FROM MUNICIPAL WASTE

3.1 Introduction

Humans generate over 2,000 million tonnes of waste every year. According to UN calculations, this figure is expected to rise to 3,400 million[1] over the next 30 years. A large proportion of this waste ends up as landfill, which has a major negative environmental and social impact and is a solution that is unsustainable in time. All of this generates emissions into the atmosphere that exceed 1,600 million tonnes of greenhouse gases (GHGs) coming from the solid waste generated. It is estimated that this accounts for 5% of all global emissions.

Concern over the depletion of the natural resources available and the need to reduce the amount of waste generated have made it essential to change the traditional economic model and replace it with a model that optimises the utilisation of the resources, materials and products. All of this has to be done at the same time as guaranteeing economic growth, achieving greater welfare for society in general and boosting nature conservancy. The new model has come to be known as the circular economy.

The aim of the circular economy is to keep the value of products, materials and resources stable for as long as possible, reincorporating them into the production cycle once they have completed their working life, while at the same time minimising the generation of waste and the associated GHG emissions.

Figure 3-1. Diagram of the circular economy. Source: European Commission.

According to the statement issued by the European Commission on 26th January 2017 regarding the role of energy recovery from waste in the circular economy, this type of waste management is one of the vital processes in the circular economy production cycle, as long as it is used following the EU waste management hierarchy.

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[1] UNEP, 2016 (United Nations Environment Programme) and the World Bank, 2018 (What a waste 2.0: a global snapshot of solid waste management to 2050, 2018).

This hierarchical pyramid (See Section 3.2) is based upon the following order of priority regarding waste management: waste prevention, preparation for reuse, recycling, energy recovery and, finally, waste disposal in landfill sites. To quote the European Commission, energy recovery from waste can help to decarbonise key sectors (such as central heating, air-conditioning or transportation), as well as helping to cut down on GHG emissions in the Waste Sector.

As far as considerations about energy recovery for decision making are concerned, the UNEP agrees the importance of energy recovery, which could not only make it possible to reduce by 90%, the volume of waste that ends up as landfill, but also cut down on GHG emissions into the atmosphere.

Energy recovery involves converting into energy any waste that cannot be recycled, whether that energy is in the form of electricity, steam or hot water for domestic or industrial purposes. This process is recommended for waste that cannot yet be reused or recycled and is vital for other purposes, such as medical and healthcare products, which have few viable management alternatives.

Recovering energy from waste, using its value to generate electricity and heat, means that it does not have to be disposed of as landfill and prevents the associated negative environmental and social impacts.

3.2 Regulatory and strategic framework

This section summarises the analysis made of the regulations that apply to MW material in Spain.

3.2.1 European regulatory and strategic framework

Since 2008, waste management in the EU has been governed by Directive 2008/98/EC of the European Parliament and the Council, dated 19th November 2008, concerning waste, also known as the Waste Framework Directive (hereinafter WFD), transposed into the Spanish legal system through Act 22/2011, of 28th July on Waste and Contaminated Soil.

One of the new aspects introduced by the WFD is a clear definition of the terms prevention, reuse, preparation for reuse, treatment and recycling, and these have been defined with a view to clarifying the scope of application of those concepts. The WFD also modified the definitions of recovery and disposal to make sure there was a clear-cut distinction between the two concepts based on the differences between the impacts of the two options, recognition being given to the benefits of waste recovery to the environment and human health when that waste is used as a resource.

The WFD also introduced a 5-level hierarchy to govern all the legislation and the waste management policy; this hierarchy was to be interpreted as an order of priorities to be followed when adopting waste management measures. Exactly the same hierarchy has been transposed in Spain as both a state regulation and on a regional level. It can be seen in the following figure.

Figure 3-2. European waste management hierarchy. Source: European Commission and own illustration.

However, the WFD does allow for a degree of flexibility when applying the hierarchy, in the sense that the best environmental options must be analysed in each particular case, the characteristics of the different waste flows to be treated have to be considered and the potential alternatives should also be borne in mind. In all the aforementioned circumstances the general principles of precaution, sustainability, technical feasibility, economic viability and resource protection must invariably be taken into account.

The WFD was recently modified by EU Directive 2018/851. Although this Directive introduces some modifications, energy recovery still takes precedence over waste disposal.

A series of targets are established in the WFD designed to encourage preparation for reuse, recycling and recovery. These targets are as follows:

- For Municipal Waste, the amounts earmarked to be prepared for reuse and recycling must, as a whole, reach a minimum of:
    - 50% in weight before 2020.
    - 55% in weight before 2025.
    - 60% in weight before 2030.
    - 65% in weight before 2035.
- In order to facilitate or improve preparation for reuse, recycling and other recovery operations, the waste must be collected separately and not mixed with other waste materials that have different properties.

It must also be pointed out that the final versions of a series of Directives were published in June 2018, which meant the completion of a long process that commenced in December

2015, when the European Commission presented an updated package of measures concerning the circular economy, which included what came to be known as the «package of waste measures»,consisting of four legislative proposals.

This updated legislation attempts to tackle environmental problems that have transnational effects, including the impact of unsuitable management of waste in GHG emissions, atmospheric pollution and uncontrolled waste dumping, especially in the sea. One of its aims is to guarantee that the materials of value contained in the waste are actually reused, recycled and reinserted into the European economy, paving the way for a circular economy and reducing the EU's dependence on raw material imports, encouraging the careful, efficient and rational use of natural resources.

The four Directives passed are as follows:

- Directive (EU) 2018/851 of the European Parliament and the Council, of 30th May 2018, amending Directive 2008/98/EC on waste.

- Directive (EU) 2018/850 of the European Parliament and the Council, of 30th May 2018, amending Directive 1999/31/EC on waste disposal.

- Directive (EU) 2018/852 of the European Parliament and the Council, of 30 May 2018, amending Directive 94/62/EC on packaging and packaging waste.

- Directive (EU) 2018/849 of the European Parliament and the Council, of 30th May 2018, amending Directive 2000/53/CE on end-of-life vehicles, Directive 2006/66/CE on batteries and accumulators and waste batteries and accumulators and Directive 2012/19/EU on waste electrical and electronic equipment.

The following are among the goals set by this new legislative package: (i) guaranteeing a gradual reduction in disposing of waste as landfill, especially waste that is suitable for recycling or other kinds of recovery, such as energy recovery, and (ii) applying strict technical and operational requirements in matters involving waste and its disposal, establishing measures, procedures and guidance to prevent or reduce as much as possible the negative effects on the environment of dumping waste, particularly when it pollutes surface water, groundwater, the ground, the air and, generally, the planet's environment, including the greenhouse effect, as well as causing any other risk to human health, throughout the entire life cycle of the landfill site.

To achieve the above goals, EU Directive 2018/850 has made the following compulsory:

- As from 2030, no waste that is suitable for recycling or other kinds of recovery, especially municipal waste, must be accepted as landfill, except for waste whose disposal in a landfill site is the best option from an environmental perspective.

- By 2035, the maximum amount of municipal waste that can be disposed of as landfill has to be reduced to a maximum of 10% in weight of the total quantity of municipal waste generated.

Finally, according to the statement issued by the European Commission on 11th March 2020 regarding a new plan of action for the circular economy conducive to a cleaner and more competitive Europe, a proposal is made to review Directive 2008/98/CE, a series of goals being set concerning waste reduction for specific flows. One of the new targets will involve reducing by half (50%) the quantity of residual MW (not recycled) by 2030, when compared to the 2020 level.

3.2.2 Spanish regulatory and strategic framework

As the aforementioned latest four Directives were only published recently, their content has not yet been transposed into the national and regional regulations. Nevertheless, G-advisory is showing below the different regulatory frameworks currently in force.

As we have already explained, the WFD was transposed into Spanish legislation through Act 22/2011, of 28th July on Waste and Contaminated Soil, which replaced the previous Waste Act 10/1998, of 21st April. This Act contains all the goals included in the WFD.

Under Act 22/2011, energy-efficient incineration (fulfilling certain minimum performance criteria stipulated in the Act itself) is a management option that must take precedence over the disposal option. However, it has to comply with the established prevention and recycling goals, aimed at waste prevention and at maximising the material use of waste.

Act 22/2011 establishes that the Ministry with powers in environmental matters shall draw up the State regulatory framework for matters concerning waste. In this respect, the State Waste Framework Plan (PEMAR) 2016-2022 is currently in force, passed by the Spanish Cabinet on 6th November 2015, whereas the State Waste Prevention Programme 2014-2020, passed in November 2012, ceased to be valid this very year, 2021.

- The PEMAR sets out the strategic lines for waste management from 2016 to 2022 and the measures needed to comply with the European Community targets in this area. The ultimate aim of the Plan is to replace a linear economy with a circular economy. The PEMAR applies the hierarchy principle established in the European Community waste regulations, especially with regard to reducing waste disposed of as landfill, by increasing preparation for reuse, recycling and other ways of recovery, including energy recovery. This Plan introduces, amongst others, the following objectives regarding waste management and disposal:
    - Not disposing of untreated municipal waste as landfill, in compliance with what is established in Royal Decree 1481/2001, of 27th December, which regulates the disposal of waste in landfill sites.
    - Before 2020, the amount of domestic and commercial waste given over to preparation for reuse and recycling for fractions of paper, metals, glass, plastic, bio-waste and other recyclable fractions, should reach a minimum of 50% in weight.

- In 2020, limit to 35% the total amount of municipal waste disposed of at landfill sites.

In June 2020, approval was given to the Spanish Circular Economy Strategy (EEEC). It establishes actions to be taken in this decade that, amongst other things, will permit a 30% reduction in the consumption of materials nationwide, a 10% improvement in the efficient use of water and a 15% decrease in waste generation when compared to 2010, all of which will make it possible to put GHG emissions in the Waste Sector below 10 million tonnes in 2030.

Royal Decree 646/2020, of 7th July, regulates the disposal of waste at landfill sites, in order to adapt such disposal to the circular economy. The Decree specified what waste is allowable in such sites, together with the objective for the landfill of MW, which is consistent with what is established by the EU: a maximum of 10% in weight of MW to end up as landfill by 2035. It sets the partial targets of a maximum of 40% by 2025 and 20% by 2030.

Finally, it must be pointed out that on 2nd June 2020, the Spanish Cabinet gave the go ahead for a new Waste and Contaminated Soil Bill, at the request of the Ministry for Ecological Transition & Demographic Challenge. It was subjected to the required public information formality between 3rd June and 3rd July 2020, and is currently being processed. The Cabinet is expected to pass the Bill between March and April, before *Las Cortes* (the two Spanish Parliamentary Chambers) finally makes it Law. The aims of this Draft Bill are to boost the circular economy, limit certain plastic products, enhance the waste management hierarchy and incorporate targets for reducing generation: the goals of a 13% reduction by 2025 and a 15% reduction by 2030, are added to the aim of achieving a 10% reduction in 2020, in all cases when compared to the percentages in 2010.

3.2.3 How emission reduction targets have evolved in the European Union and Spain

The EU has been defining and updating European GHG emission reduction targets, in which energy recovery can play a major role, due to the fact that its emissions are lower than for landfill disposal, as we shall see in this study.

In 2008, a commitment was established to reduce emissions via the European Energy & Climate Change Package. It set a target of a 20% reduction in emissions by 2020, when compared to the levels in 1990, as well as a minimum of 20% renewable energies where energy consumption was concerned. In order to attain the European emissions target at a State level, Spain had to achieve a 10% reduction in GHG emissions by 2020, when compared to the country’s 2005 figure.

During the period ranging from 2021 to 2030, the European Council’s Energy & Climate Change Policies, of October 2014, set targets binding for 2030 to reduce emissions by 40% when compared to 1990, plus at least 27% renewable energies in energy consumption.

The recent European Green Deal, passed in December 2019, is even more ambitious. It is a plan that contains 50 specific actions to combat climate change, and aims to make Europe the first climate neutral continent by 2050. It intends to do this through lowering emissions by 50% or 55% by 2030 using such instruments as (i) the Emissions Trading System, possibly applying this to new sectors, (ii) the aims of the Member States to reduce emissions in sectors not included in that system, (iii) regulating land use, changing land use and forestry and (iv) the Commission's current proposal for a first European Climate Act to regulate the goals established in the European Green Deal.

In Spain, the Comprehensive National Energy & Climate Plan 2021-2030 (PNIEC), of January 2020, contains a set of actions to try and achieve a reduction in GHG emissions of 23% by 2030, when compared to the 1990 figure. The diffuse sectors, which include waste management, would make a 39% contribution to reducing the 2005 emissions. The PNIEC contains a set of measures for reducing emissions when dealing with selective collection, managing the biogas that has leaked from landfill sites and providing incentives for energy recovery from forestry waste and other crop-related remains.

In May 2020, the Government sent the first Climate Change & Energy Transition Bill *Las Cortes* (the two Spanish Parliamentary Chambers). Its purpose is to achieve emissions neutrality by 2050 at the latest. Spain intends to establish by Law, a GHG emissions reduction target of 20% by 2030, when compared to the 1990 levels, bringing the country in line with the EU's new and more ambitious goals.

3.2.4 Summary of aims and commitments

The following goals and commitments can be deduced from an analysis of the Community and State Framework:

Waste Commitments	Deadline	Regulatory / strategic link
Precedence of energy recovery over waste disposal.	As from 2008	Directive 2008/98
50% in weight of MW to be prepared for reuse and recycling.	2020	Directive 2008/98, Act 22/2011 and PEMAR
55% of MW to be prepared for reuse and recycling.	2025	Directive 2018/851
60% of MW to be prepared for reuse and recycling.	2030	
65% of MW to be prepared for reuse and recycling.	2035	
No recoverable waste (especially MW) will be permitted in landfill sites.	As from 2030	Directive 2018/850
Reduce to 10% in weight the amount of MW deposited in landfill sites.	2035	
Reduce by half the amount of residual MW (not recycled) when compared to 2020.	2030	European Commission Statement (11/03/2020)
Reduce the waste generated by 10% in weight when compared to the waste generated in 2010.	2020	Act 22/2011 and State Waste Programme
Maximum of 40% in weight of MW that ends up as landfill.	2025	Royal Decree 646/2020
Maximum of 20% in weight of MW that ends up as landfill.	2030	
Maximum of 10% in weight of MW that ends up as landfill.	2035	
Limit to 35% total disposal as landfill of the MW generated.	2020	PEMAR
Reduce the waste generated by 10% in 2020, 13% in 2025 and 15% in 2030, in all cases when compared to what was generated in 2010.	2025 and 2030	Waste and Contaminated Soil Bill

Waste Commitment	Deadline	Regulatory / strategic link
Increase in preparation for MW reuse and recycling up to a minimum of 55% in weight by 2025, 60% by 2030 and 65% by 2035.	2025, 2030 and 2035	
Emissions	**Deadline**	**Regulatory / strategic link**
EU: 20% reduction in emissions when compared to the levels in 1990. Spain: 10% reduction when compared to 2005.	2020	Europe Energy & Climate Change Package
EU: 40% reduction in emissions when compared to the levels in 1990.	2030	Energy & Climate Change Policies Framework 2021-2030
EU: 50%-55% reduction in emissions by 50%-55% when compared to the levels in 1990.	2030	European Green Deal
EU: climate neutrality (net zero balance of emissions).	2050	
Spain: reduction of at least 20% when compared to 1990 (reviewable).	2030	Climate Change & Energy Transition Bill (May 2020)
Spain: climate neutrality.	2050	

Table 3-1. Commitments and targets for waste management and atmospheric emissions.

It can be seen that on both a State and European level there are numerous aims associated with reducing waste disposal at landfill sites. So recoverable waste will not be allowed (especially municipal waste) at landfill sites as from 2030, and the amount of waste that is disposed of as landfill must be gradually reduced to 40% by 2025, to 20% by 2030 and to 10% by 2035.

3.3 Prospects of compliance with European commitments

Directive 2008/98 established that, before 2020, 50% of MW should be prepared for reuse or recycling. However, the recycling data for 2018 of 33.8% of the waste –the most recent year with data available-, according to the 2020 data from MITECO, suggest that it would be difficult to achieve those figures in Spain. This commitment is increased 5% every 5 years, until it reaches 65% of the waste reused or recycled by 2035; the latter goals are also included in the Waste and Contaminated Soil Draft Bill. In this sense, progress is gradually being made in recycling, and complying with some of the aforementioned commitments in 2025, 2030 or 2035 is a distinct possibility.

Directive 2018/850 included the requirement not to permit any type of recyclable or recoverable waste to enter landfill sites as from 2030. Furthermore, this should lead 5 years later, to a reduction in the amount of MW sent to a landfill site to a maximum of 10% in weight before 2035. Despite the fact that energy recovery and, particularly, recycling, have been evolving positively, it still seems rather optimistic to think that Spain could progress from over 50% of waste disposal at landfill sites in 2017 to less than 10% by 2035.

From a European perspective, and according to the estimates of the CEWEP (Confederation of European Waste-To-Energy Plants) in 2019, waste energy recovery plants would need to increase their capacity by 40 million tonnes/year, which would enable them to reach a capacity of 142 million tonnes/year of waste, which is the figure estimated as being necessary to achieve the targets set for 2035.

The emissions reduction commitments for 2020 as established in the European Energy & Climate Change Package amounts to a 20% decrease when compared to 1990. The EU cut its emissions down by 22% between 1990 and 2017, so the SOER Report 2020[2] issued a positive prediction when it came to attaining that goal. Yet the European Environment Agency admits that a further major effort is required to achieve the targets set for 2030 and 2050.

On a national level, Spain is on course to fulfil its own particular commitment, because emissions in 2017, according to Spain's Fourth Biennial Report on the UN Framework Convention on Climate Change (MITECO, December 2019), had decreased by 23% when compared to 2005. However, it must be remembered that in 2005 it presented emissions well above average, and that when compared to 1990, the 2017 emissions had risen by 17.9%, although that is not a comparison year for Spain in this case. The Waste Sector accounted for 4% of emissions in 2017.

The commitments to 2030 and 2050 established in the new Climate Change & Energy Transition Bill set a target for reducing GHG emissions by 20% by 2030 when compared to the 1990 levels, bringing the goals into line with the EU's ambitious aims. According to the PNIEC's trend scenario, i.e., the one where the current trend is perpetuated with no further measures, an emissions increase of 8% is projected for 2030, when compared to 1990. Therefore, Spain must opt for making considerable investments in emissions reductions if it is to achieve the targets set by the EU. The reduction of emissions in the Waste Sector (4% out of the total in 2017, as we have stated) would help to achieve those goals.

3.4 Municipal waste in Europe

The EU Member States generated an average of 489 Kg of MW per capita in 2018[3], although the amounts varied greatly from one to another. Spain was slightly below average, with 475 Kg/per capita. The countries that generated most included Denmark (766 Kg/per capita), Malta (640 Kg/per capita) and Germany (615 Kg/per capita), whereas Czechia (351), Poland (329) and Rumania(272) were among those that generated the least.

[2]The environment in Europe. Status and Prospects 2020. SOER Report, 2019. European Environment Agency, 2019.

[3] Municipal Waste Statistics, Eurostat, 2019.

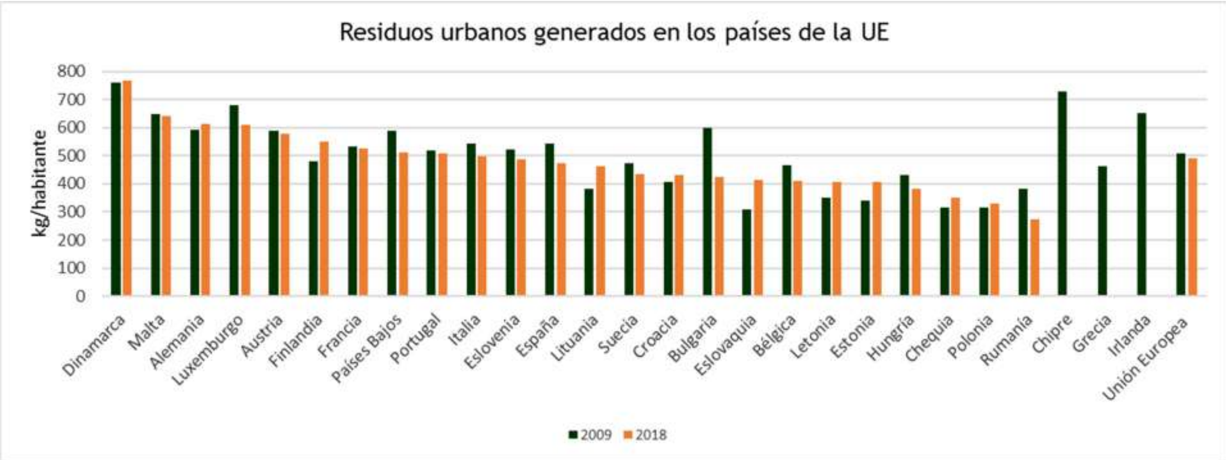


Figure 3-3. Municipal waste generated in the EU countries in 2009 and 2018 (in Kg per capita).
Source: own sources based on Eurostat data (2019).

According to Eurostat, the European average for MW treatment in 2018 (considering the 27 EU Members as from 31st January 2020), showed that 49% was given over to recycling or composting, 27% to energy recovery and 24% went to landfill sites.

As can be seen in Figure 2-4, the extent to which the different EU countries manage their waste varies greatly. In countries like Malta, Greece or Cyprus over 80% of municipal waste ends up as landfill and hardly any is recovered as energy. This is in marked contrast to such countries as Germany, Denmark, Sweden or Finland, where waste disposal at landfill sites is minimal (less than 1%), and around half the waste is recycled and the other half is recovered as energy (except in the case of Germany, where almost 70% of waste is recycled). Therefore, a correlation can be observed between the countries that dispose of least waste as landfill and those that recover the most waste, and it can be confirmed that energy recovery replaces mainly waste disposal at landfill sites and not recycling.

Waste treatment evolved greatly between 1995 and 2018 (See Figure 2-5). Landfill waste fell by more than 60%. Both recycling and incineration (with and without recovering the heat generated) grew during the same period. The biggest growth rate affected recycling and composting, rising from 17% to 47% in that period. Incineration[4] rose by 117% between 1995 and 2018, until it accounted for the treatment of 28% of all MW.

[4] Incineration of waste involves thermal treatment to eliminate waste, with or without recovering the heat generated, whereas energy recovery involves the incineration of waste while making use of the energy generated, i.e., energy recovery uses waste firstly as a fuel for producing heat and secondly to produce electricity.

According to Directive 2008/98/EC and Act 22/2011, before the incineration of MW can be regarded as a recovery operation within the MW management hierarchy framework, it has to reach or exceed an energy efficiency of 0.65. If it fails to attain this value, the process will be considered as incineration without energy recovery.

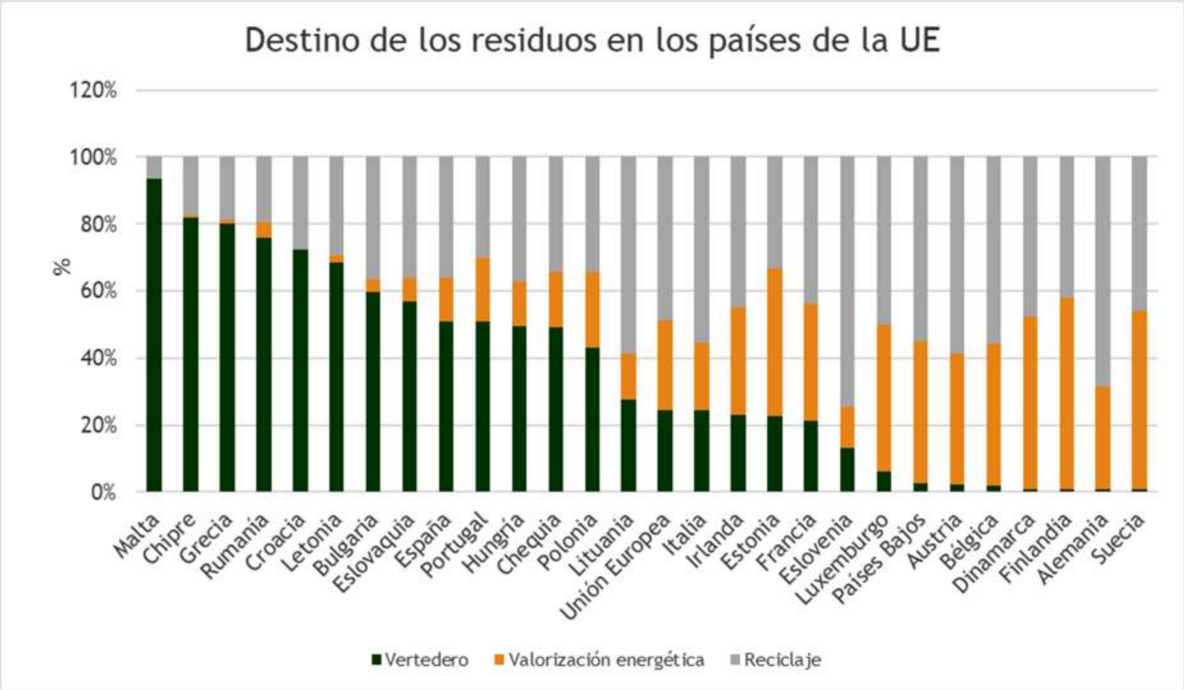


Figure 3-4. Destination of waste in EU countries in percentages (data from 2018 except for Greece, Ireland and Cyprus, which are from 2017). Source: own sources based on data from Eurostat (2020).

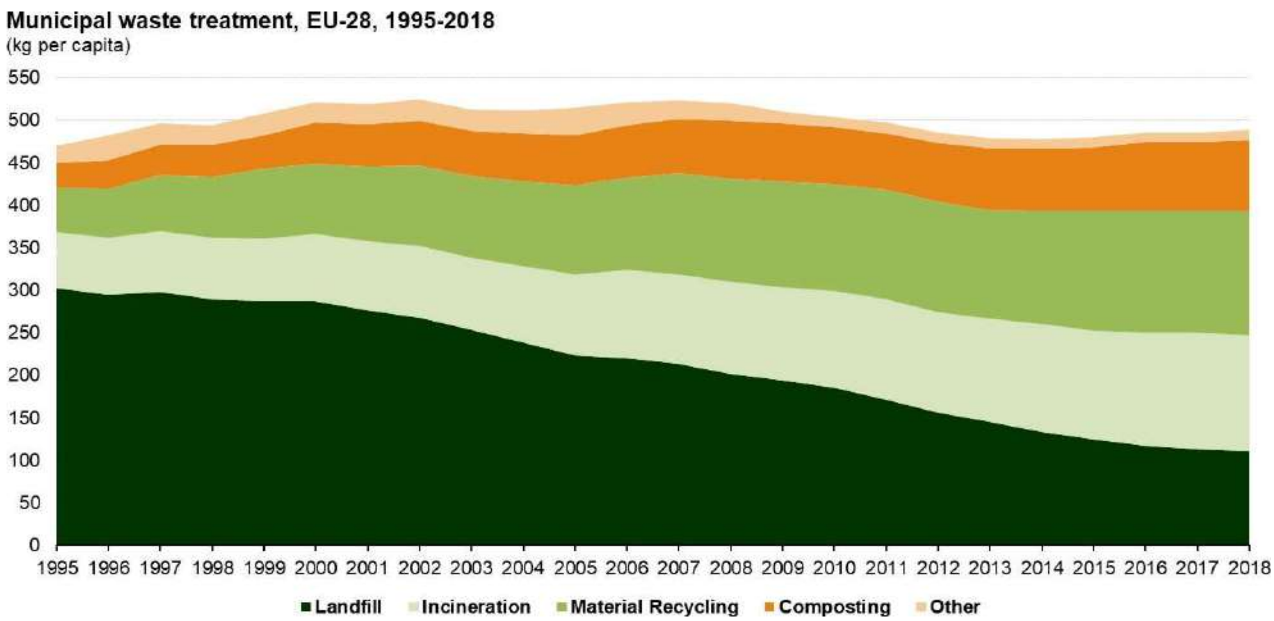


Figure 3-5. Treatment of municipal waste generated in the EU countries between 1995 and 2018(in Kg. per capita). The 28 Member States in 2018 are shown (including the United Kingdom). Source: Eurostat (2019).

3.5 Municipal waste in Spain

In 2017, 483.9 Kg of MW were produced per person in Spain, which amounted to a total of 22.5 million tonnes of MW. MW treatment in Spain basically involved landfill, recycling and energy recovery. The percentage distribution in 2018 can be seen in Figure 2-6.

The main MW management system in Spain is still direct disposal as landfill, where 56.3% (12.7 million tonnes) of MW generated is sent, followed by recycling, which amounts to 33.8% (7.6 million tonnes) and energy recovery, with 9.9% (2.2 million tonnes). It can be seen that an increase in recycling will not, by itself, be sufficient *a priori* to comply with the European and domestic landfill reduction targets, which culminate with the goal of a maximum of 10% in weight of the landfill waste by 2035. What will also be needed is an increase in waste given over to energy recovery.

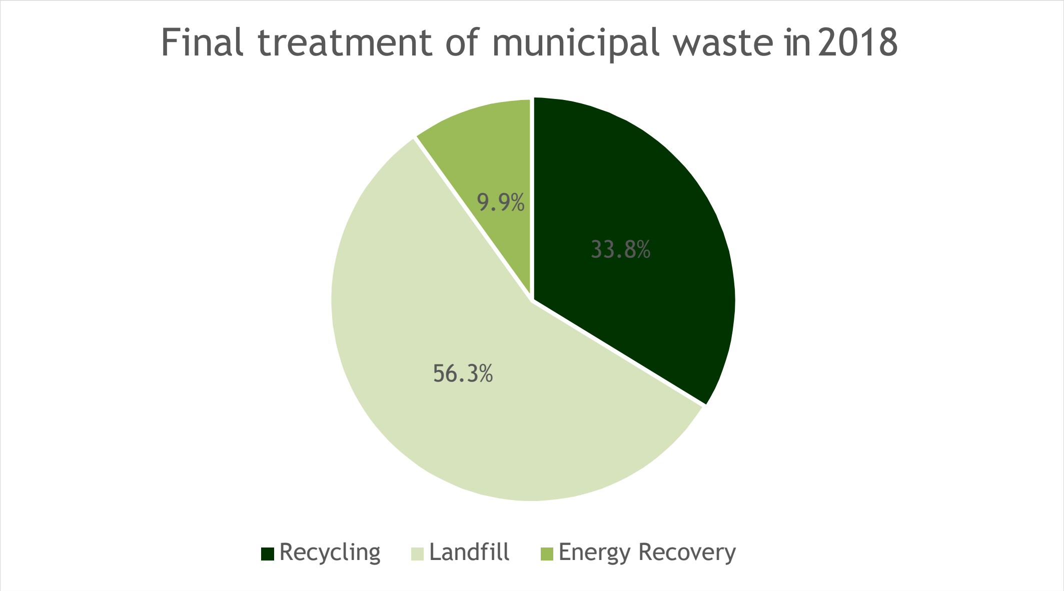


Figure 3-6. Percentages of final treatment of MW in 2018. Source: own sources based on data from the MITECO (2020).

In recent years, there has been a management trend towards a decrease in waste for landfill (more than 4% less in 9 years) and an increase in recycling (1.6% more in 9 years) and in energy recovery (2.6% more in 9 years). However, the trends are slight rather than sharp.

	Recycling	Landfill	Energy Recovery
2010	32.2%	60.5%	7.3%
2011	31.3%	60.3%	8.4%
2012	34.9%	56.8%	8.3%
2013	35.3%	55.9%	8.8%
2014	31.8%	58.8%	9.4%
2015	32.5%	57.8%	9.6%

2016	32.6%	56.9%	10.5%
2017	33.8%	56.2%	10.0%
2018	33.8%	56.3%	9.9%

Table 3-2. Percentage given over to recycling, landfill and energy recovery in Spain between 2010 and 2018. Source: own sources based on data from the MITECO (2020).

The figure below shows the aforementioned evolution of the amounts processed in the same period 2010-2018, plus the total MW. Since 2010 there was a reduction in MW generation, falling from 26 million tonnes in 2010 to less than 22 million in 2014, all of which was associated with the economic crisis that commenced in 2008. The waste reduction dynamics were reversed again as from 2014, coinciding with the upturn in the growth of the Spanish economy. As from that year, waste increased from year to year until it reached over 22.5 million tonnes in 2017, still below the 26 million tonnes generated in 2010.

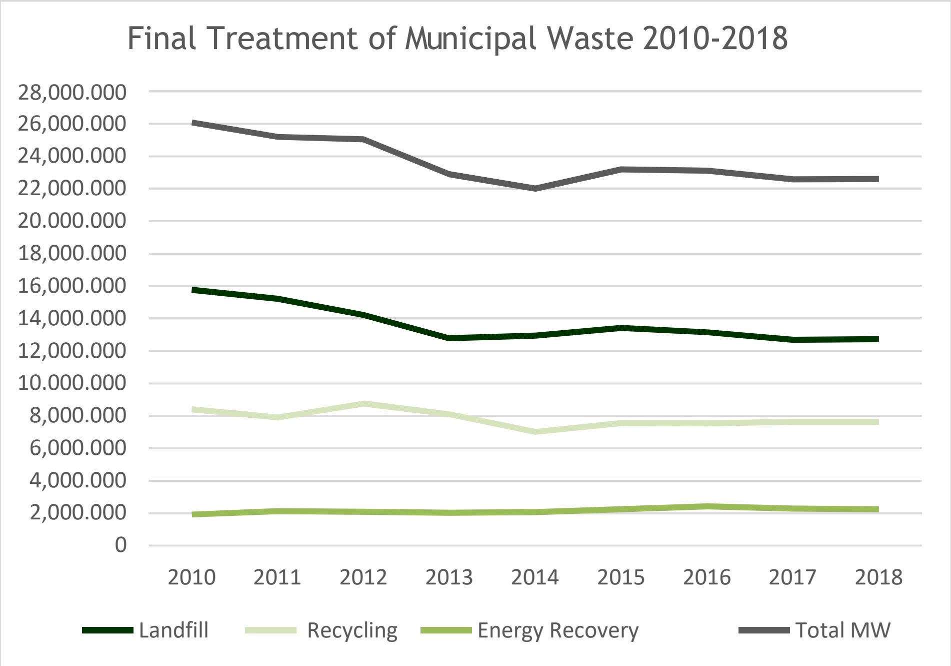


Figure 3-7. How tonnes of waste destined for landfill, recycling and energy recovery have evolved, and how the total MW in Spain evolved between 2010 and 2018. Source: own sources based on data from the MITECO (2020).

3.6 Energy recovery in Europe and Spain

The average for the EU is 26% of energy recovery from the total MW generated, whereas Spain, with only 12.7%, lies far from this value.

As from 2009, an increase in energy recovery has been detected in nearly all European countries. All of this shows the steady inroads being made by this use for MW, which is gradually replacing landfill as an option. A few European countries are proving to be exceptions to this trend as they are still not using waste for energy recovery (namely Ireland, Malta, Greece and Cyprus) plus Portugal, where it has decreased.

The list is headed by Finland and Sweden, with 57% and 53%, respectively, in 2018. One outstanding statistic is the large number of countries whose percentage devoted to energy recovery has increased between 2009 and 2018.

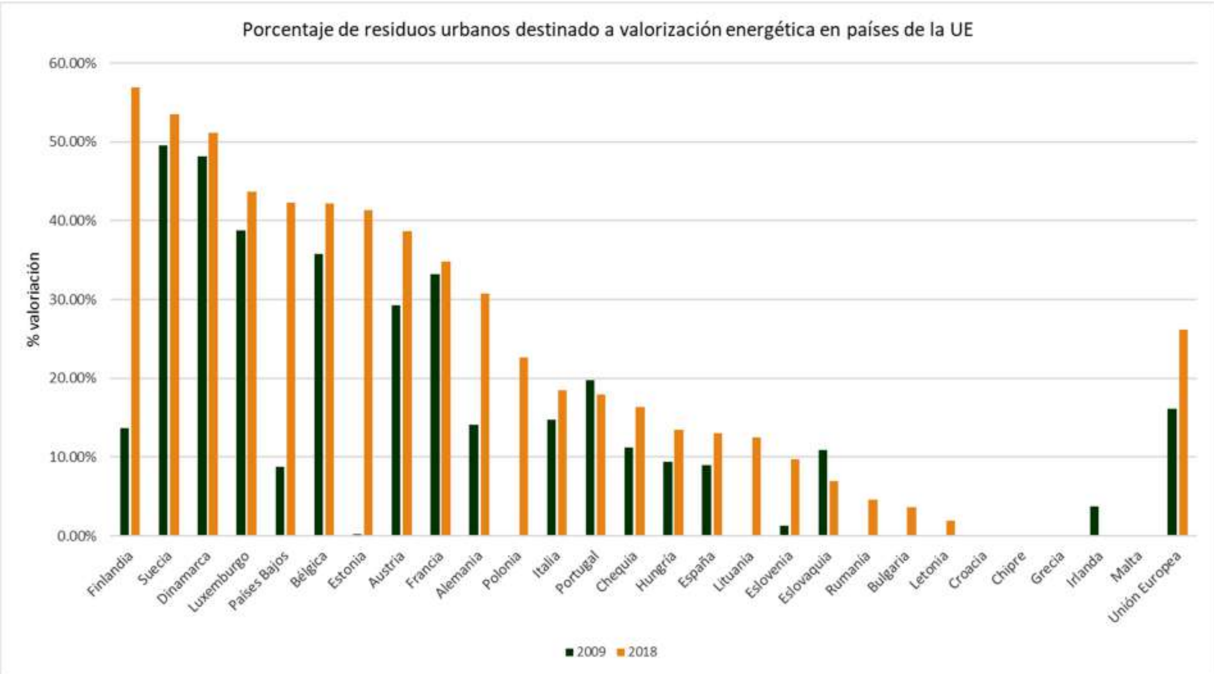


Figure 3-8. Percentage of MW given over to energy recovery in EU countries in 2009 and 2018. Source: own sources based on data from Eurostat (2019).

As we have seen, energy recovery in Spain underwent a slight increase as a destination for MW between 2010 and 2016, after which the percentage began to fall until 2018. However, the differences are slight, and it could be said that there has not been much progress made as regards energy recovery. The figure below shows that it grew from 1.9 million tonnes of MW in 2010 to 2.2 million in 2018. There is a slightly upward average trend.

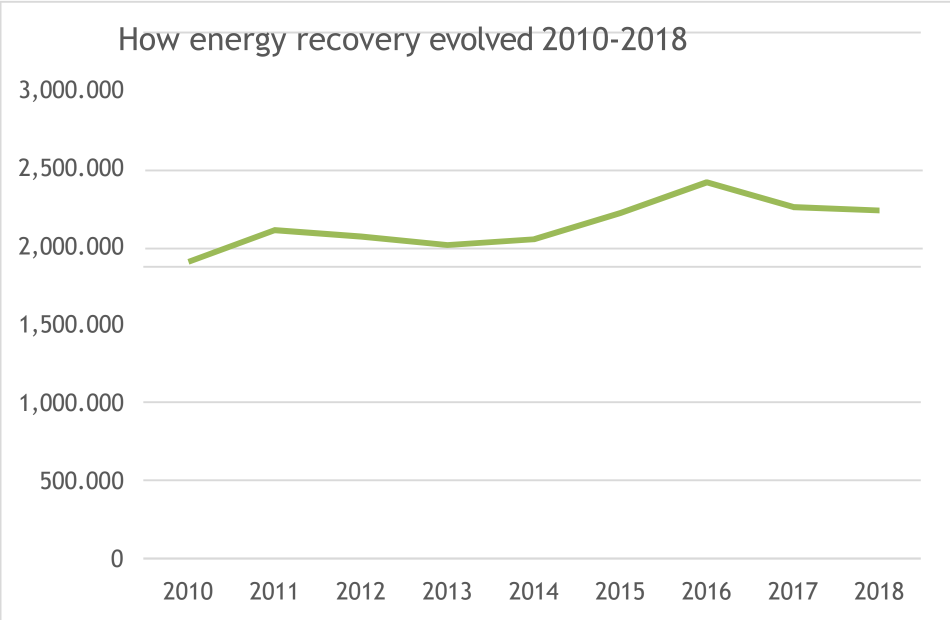


Figure 3-9. How energy recovery from MW has evolved in Spain between 2010 and 2018 (tonnes). Source: Own sources based on data from Eurostat (2019).

A diagram is shown below comparing the evolution of energy recovery and landfill, not only in Spain but also in the European Union:

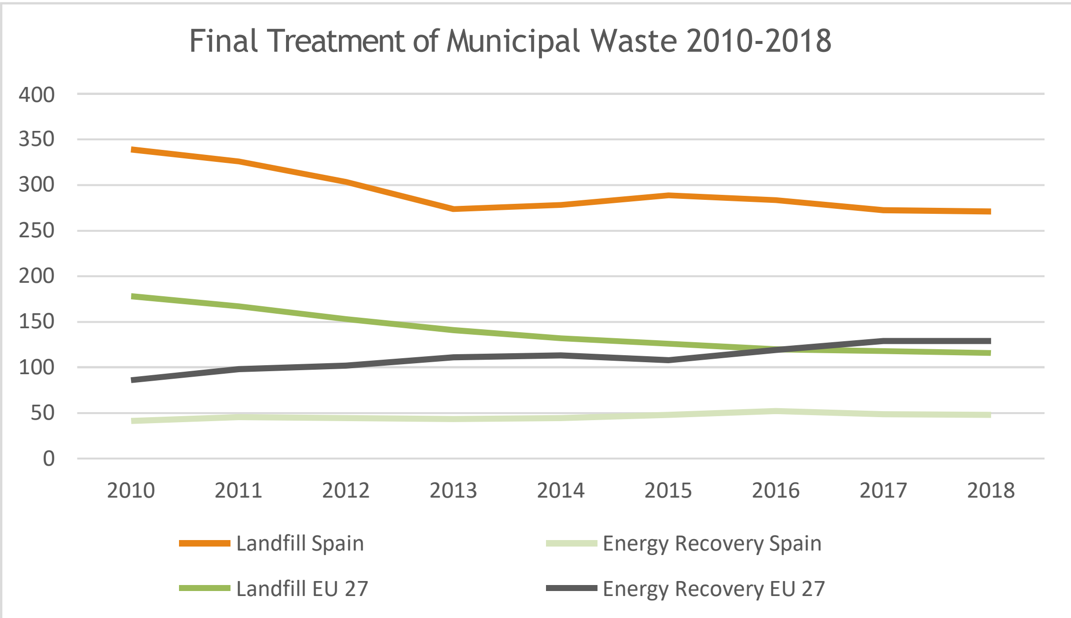


Figure 3-10. How energy recovery and landfill have evolved in Spain and in the European Union (with the 27 member countries since 31st January 2020), in kg per capita and year. Source: own sources based on data from the MITECO (2020) and Eurostat (2019).

The above figure shows a decrease in the number of kgs of MW per capita destined for landfill not only in Europe but also in Spain, in the period 2010-2018. However, the waste destined for landfill in Spain is much higher than the average for Europe. Growth in energy recovery in Europe was considerable in that same period (2010-2018), whereas this trend was much less marked in Spain.

3.7 Conclusions concerning the role of energy recovery from municipal waste

The following are among the main legal and strategic commitments regarding MW management in Europe:

- The waste management hierarchy must be included in the policies and measures adopted by the Member States in order to comply with the European commitments: preparation for reusing or recycling everything possible and ensuring that it is not disposed of as landfill.

- According to what is established in Directive 2018/850, recoverable MW shall not be used as landfill as from 2030 and the quantity of MW used as landfill must be reduced to 10% in weight before 2035. These commitments are particularly challenging for Spain, which sent more than 50% of its MW as landfill in 2017.

In this sense, energy recovery has undergone a slight increase in Spain in the past decade, rising from 1.9 million tonnes/year of MW in 2010 to 2.2 million tonnes/year in 2018. Despite that progress, at present, 56.3% of MW is sent to landfill sites in Spain, compared to 9.9% that is destined for energy recovery.

In both Europe and Spain, the increase in energy recovery has been accompanied by an even bigger increase in recycling, to the detriment of landfill.

The current European trend towards an increase in reuse and recycling, together with greater energy recovery, appears as an essential part of fulfilment of Europe’s commitments in municipal waste management, while at the same time abiding by the hierarchy defined for waste management. At present, *a priori*, an increase in recycling is not sufficient to comply with waste targets, and it must necessarily be accompanied by an increase in energy recovery from waste. This will contribute to achieving the GHG emissions reduction goals.

4. CARBON FOOTPRINT

4.1 Introduction

The carbon footprint measures the total amount of GHGs emitted through the direct or indirect effect of an individual, organisation, event or product. Its purpose is to establish their contribution to climate change and is expressed in tonnes of CO_2 equivalent (tCO_2e). The basic GHGs, as determined by the IPCC[5], are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), oxides of nitrogen (NOx), hydrofluorocarbon compounds (HFC), chlorofluorocarbon compounds (CFC) and sulphur hexafluoride (SF_6).

GHG emissions in energy recovery from municipal waste

Energy recovery from municipal waste, consisting of the complete oxidation of the waste with excess of air and at temperatures higher than 850ºC, produces a series of GHG emissions. These are firstly due to the combustion of the waste that occurs and, secondly, to other associated processes, such as the transport or consumption of energy from external sources. These emissions may be classified as direct and indirect.

The direct emissions are from the CO_2 emitted by the combustion of the waste, the CO_2 emitted by the auxiliary fuel used, the CO_2 emitted by the vehicles owned by the recovery plant and the emissions of N_2O. We subtract from the emissions, the CO_2 that comes from the biogenic carbon, i.e., the CO_2 contained in the biomass in recoverable municipal waste, because that CO_2 had been absorbed earlier through the natural process of photosynthesis, so it is not taken into account when calculating emissions.

The indirect emissions are those that come from the purchase of electricity from external sources, if this electricity is not provided by renewable sources, plus the emissions from transport provided by vehicles that are not owned by or controlled by the recovery plant, i.e., vehicles that have not been classified as producing direct emissions.

Moreover, as the recovery process generates energy, emissions that would have been produced when generating the same amount of energy by means of other methods are prevented, so they decrease the net balance. In the case of electricity, in Spain and according to the Spanish Electricity Grid (hereinafter REE), in 2019 the energy mix on mainland Spain emitted an average of 170 Kg of CO_2e per MWh produced. There is also a certain reduction in emissions as a result of recycling the slag generated during the recovery process.

[5] Intergovernmental Panel on Climate Change or IPCC (http://www.ipcc.ch/).

GHG emissions in municipal waste used as landfill

Disposing of municipal waste as landfill basically involves sending it to a landfill site, which is a basin sealed in an attempt to reduce land contamination to a minimum.

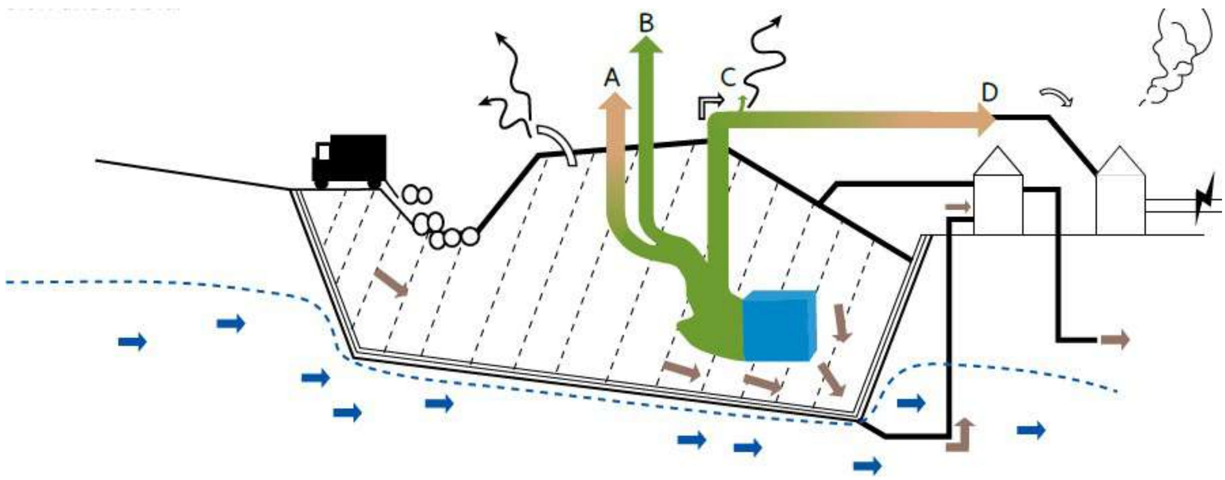
Landfill sites are one of the main sources of GHG emission in the Waste Management Sector. Disposal of MW on a landfill site generates biogas when the waste ferments. Biogas is composed of methane -coming from the anaerobic decomposition of the organic components in the waste-, CO_2 –coming from the anaerobic decomposition- and, to a lesser extent of N_2, O_2, H_2S, CO, NH_3, H_2 and COVs.

At present, most landfill sites in Spain are equipped with systems for capturing the biogas produced in the landfill cells. Their efficiency can range from 10% to over 90% in some cases. The gases captured can be eliminated by being burnt in a flare or used to produce electricity or heat, usually with cogeneration engines. In a similar way to energy recovery, the biogas captured and destined for engines, generates electricity that is sent to the grid and helps to displace the electricity mix and, so, this counts as emissions prevented that decrease the net balance.

However, a proportion of the gases produced are not captured and become diffuse emissions, which reach the atmosphere for a variety of reasons (before the landfill cells are closed, crossing the cell roofs, open-air landfill, etc.), and after undergoing a partial oxidation process. The emissions generated vary in time and also on the basis of the nature of the waste. They increase rapidly in the first years after disposal before gradually decreasing for many years. The methane captured is converted into CO_2 through biogas combustion, whose potential for global warming is 25 times less.

Landfill sites are also a source of indirect emissions coming from the purchase of electricity from external sources and from vehicles that are not owned by the site or are not controlled by the facilities themselves, and thus have not been included as direct emissions.

The diagram below shows the different sources of emission:



A: The gas is oxidised inside the cover layer and escapes to the atmosphere: only CO2.
B: Diffusion of landfill gas into the atmosphere: CO2 and CH4.
C: Leak affecting the landfill gas collection system: CO_2 and CH_4.
D: Gas disposal or recovery (flares, engine or turbine): CO_2.

Figure 4-1. Sources of landfill site gas emissions. Source: European Environment Agency -EEA-(2005).

4.2 Calculation methodology

The carbon footprint calculations summarised in this report follow the guidelines indicated by the GHG Protocol (Greenhouse Gas Protocol), an organisation that provides the GHG accounting standards most extensively used and recognised on an international level.

Furthermore, we have used as a specific reference for the sector, the GHG emissions calculation protocol in the waste management activities -EpE Protocol[6]-, constructed from the GHG Protocol and consistent with it.

The carbon footprint calculations were developed on a spreadsheet, using the calculation tool developed by the Association of Waste Management & Special Resources Companies (hereinafter ASEGRE), which in 2006 made available to Spanish waste management firms a GHG calculation tool and the "Protocol for the quantification of greenhouse gas emissions from waste management activities". ASEGRE's tool is also a result of the one developed by the French association EpE (*Entreprises pour l'Environnement*) and its associated calculation protocol.

G-advisory has adapted ASEGRE's calculation tool to the requirements of this study, following the IPCC Guidelines (2006) and updating the emission factors to the most recent publications and those that can be best compared to the reality of our study (See the following sections).

[6] Protocol for the quantification of greenhouse gas emissions from waste management activities. Version 5.0. October, 2013.

When estimating the carbon footprint for landfill sites, we took into account all the data available in the National GHG Inventory belonging to the MITECO (March, 2020).

4.2.1 Main sources of information

The main source of information regarding data from energy recovery plants in Spain and Andorra was AEVERSU, which centralised the information from every one of the facilities that form part of the Association. The study was prepared with the basic information from the following facilities belonging to AEVERSU: CTRASA, SIRUSA, SOGAMA, TERSA, TIRCANTABRIA, TIRMADRID, TIRME and UTETEM. Each firm is the owner of one energy recovery facility, so in this Report we refer to companies or to facilities as being synonymous.

Figure 4-2. Map of AEVERSU's facilities that took part in the study. Source:own sources.

The values furnished by the different facilities to calculate the carbon footprint for 2019, are shown below. In overall terms, the energy recovery plants in the study process 2.2 million tonnes of MW per year and sell 1 TWh/year of electricity.

Information about MW recovery plants belonging to AEVERSU	Value	Unit
Waste		
Amount of MW recovered as energy	2,248,495	t
Amount of slag generated	347,588	t
Amount of ash generated	152,946	t
Consumptions		
Gas oil consumption	1,332,591	l
Natural gas consumption	7,470,420	Nm^3
Consumption of electricity from external sources	267,799	MWh
Consumption of heat from external sources	0	MWht
Production		
Amount of electricity produced	1,289,776	MWh
Amount of electricity sold	1,031,095	MWh
Amount of heat produced and sold	100,227	MWht

Table 4-1. Initial information from AEVERSU's plants. Annual data.

As the information provided by AEVERSU was very limited, it came from only two landfill sites, when calculating the carbon footprint from disposal at landfill sites, we decided to use the value from the National GHG Inventory (Edition 2020, Series 1990-2018), issued by the Ministry for Ecological Transition & Demographic Challenge (MITECO),March 2020.

4.2.2 Emission factors

The reference methodology recommends considering the average national emissions factors in the calculations and also recommends using the most specific ones as long as they are available and the data come from an official source.

The following table contains a summary of the emissions factors that we have used:

Recovery	Factor	Units	Source
Combustion	332.46	Kg CO_2 / t. waste	MITECO and AEVERSU
	0.05	Kg N_20 / t. waste	MITECO
Fuel consumption	2.68	Kg CO_2 / l of gas oil	MITECO
	2.38	Kg CO_2 / Nm^3 of natural gas	MITECO and Resolution of 21st June 2019, issued by the Energy & Mines Directorate General
Electricity consumption	170	Kg CO_2 / MWh	Spanish Electricity Grid (REE)
	154	Kg CO_2 / MWh	Sustainability Report, Trading company Andorra
	778	Kg CO_2 / MWh	Balearic Islands Government
Emissions prevented	170	Kg CO_2 / MWh	Spanish Electricity Grid (REE)
	778	Kg CO_2 / MWh	Balearic Islands Government
	154	Kg CO_2 / MWh	Sustainability Report, Trading company Andorra
	279	Kg CO_2 / MWht of heat	AEA Technology, waste management options and climate change
Landfill	**Factor**	**Units**	**Source**
Emissions prevented	190	Kg CO_2 / MWh	Spanish Electricity Grid (REE)

Table 4-2. Emission factors used to calculate the carbon footprint and the net balance for both energy recovery from municipal waste and landfill. Own sources based on a variety of sources.

All the emission factors included in the above table were used to calculate the carbon footprint, not only for energy recovery but also for landfill.

The most important data, the emission factor considered for the emissions from the MW combustion process was 332.46 Kg fossil CO_2 per tonne of MW. We took into account the following references and measurements when estimating this factor:

- Ministry for Ecological Transition & Demographic Challenge (MITECO) in 2020, in its Statement to the European Commission in compliance with EU Regulation 525/2013 concerning the National Greenhouse Gas Emissions Inventory between 1990 and 2018: this Statement considers a global emissions factor in MW recovery of 900 Kg CO_2 / t. waste, which G-advisory was able to compare with different IPCC and EPA publications, as well as other reference studies (See Annex).

- The aforementioned Statement issued by MITECO also proposes an emissions factor of 297 Kg fossil CO_2 per tonne of MW and uses it by default whenever there are no specific data for each facility. The National Inventory work team considers this factor to be the one that best reflects the characteristics and composition of the MW that enters Spanish energy recovery facilities. This emission factor indicated by the MITECO is based on a 67% biogenic carbon content of 67%.

- Compared to the 67% of biogenicity in MW considered in the National Inventory, this study has fixed this factor at 63.06%, using its own measurements from 6 AEVERSU plants. Their percentage of biogenic carbon was measured in the laboratory at these plants, between January and February 2021, and the following results were obtained:

Plant	Laboratory	% Biogenic carbon	% Waste from AEVERSU
SOGAMA	Dekra	67%	23.38%
TIRME	Beta Analytic - Dekra	69%	21.78%
TERSA	Tüv Rheinland	56%	13.87%
UTETEM		56%	6.14%
SIRUSA	Beta Analytic - Bureau Veritas	60%	5.08%
TIRMADRID	Beta Analytic	58%	12.73%
Weighted average / Total	-	63.06%	82.98%

Table 4-3. Percentage of biogenic carbon in the AEVERSU plants where measurements were taken. Source: AEVERSU (2021).

The plants where measurements were taken accounted for 82.98% of AEVERSU's MW, a very high percentage.

- A global emission factor of 900 Kg CO_2 / t. waste and 63.06% of biogenic carbon in the waste composition yields an emission factor of 332,46 Kg fossil CO_2 per tonne of MW recovered.

We considered two options for the indirect emissions coming from the consumption of electricity generated by external sources, depending on the availability of information:

- Using the emission factor published by the electricity marketing company at the plant in question, as is the case with the Andorra plant, in 2019, as long as that information is available.

- If information is lacking about the particular marketing company, we used the value of 170 Kg CO_2/MWh from REE for 2019 in the case of mainland facilities, and the one for its location for the Balearic Islands Plant. Note that at present there are no MW energy recovery plants on the Canary Isles.

These emission factors associated with electricity consumption were also used to calculate the emissions prevented.

We used the value of 190 Kg CO_2 / MWh for the emissions prevented at landfill sites thanks to the biogas captured and used for engines, this value being provided by REE for 2019 for the whole of Spain (including not only mainland landfill sites but also those on the Balearic Islands and the Canary Islands).

4.2.3 The carbon footprint scope

In compliance with the methodologies used in this Report (IPCC Guidelines 2006, GHG Protocol and EpE Protocol), we calculated the carbon footprint using the following differentiation of scopes.

Carbon footprint for energy recovery

- Direct GHG emissions or Scope 1: these are the emissions coming from processes or items of equipment owned by or under the control of the organisation concerned. In the case of energy recovery, we considered the main sources of emissions from the combustion facilities: emissions of CO_2 and N_2O arising from the MW combustion process, as well as the consumption of auxiliary fuels.

- Indirect emissions, which are split into two parts:
  - Scope 2. GHG emissions arising from the production of electricity consumed by the organisation, but produced by a third party.
  - Scope 3. GHG emissions caused by transport in vehicles not owned by the organisation or over which the latter has no control. It has been excluded from the scope of the study, as we will explain later.

Energy recovery emissions prevented

Exports to the grid generated by MW energy recovery prevents the GHG emissions that would have been produced when generating the same amount of electricity by means of other technologies. Such prevented emissions reduce the emissions being generated that were described in the three aforementioned scopes, in what is known as net balance.

Carbon footprint of landfill sites

- Direct GHG emissions or Scope 1: the National Inventory considers diffuse emissions of methane (CH4) coming from the anaerobic decomposition of waste from landfill (flows A, B and C in Figure 3-1) as the only pollutant. Following the instructions in the IPCC Guidelines (2006), the National Inventory ignores the emissions coming from the burning of biogas in flares, engines and turbines (Flow D in Figure 3-1). G-advisory calculated these with the data available, making sure that their contribution to the carbon footprint is minimal.

  The estimate for CH_4 emitted from Flows A, B and C is calculated by deducting the amount of CH_4 recovered (Flow D) from the total quantity produced. In this respect, the National Inventory considered the following assumptions:

  - When the value of biogas captured in a landfill site is declared to be greater than 70% of what is produced, the National Inventory has considered 70%. This estimate is based upon the fact that most of the landfill sites with biogas recovery have modern facilities and their biogas capture is, on average, 70%.
  - In cases where there is known to be biogas capture but the exact value is not known, the National Inventory has considered a 20% capture.

  These assumptions are based upon the studies quoted in the IPCC Guidelines (2006) in its section of biogas recovery (Section 3.2.3, Chapter 3, Volume 5). G-advisory thinks they are reasonable, considering the uncertainties surrounding the amount of biogas produced on a landfill site or that leaks out or is captured there.

- Indirect emissions, Scopes 2 and 3: the National Inventory's calculation method does not include indirect emissions such as those due to transport and electricity consumption, so they have not been taken into account in this study either.

Emissions prevented from landfill sites

The exports to the electricity grid generated at landfill sites as a result of biogas captured and given over to engines prevent GHG emissions that would otherwise have been produced on generating the same amount of electricity from other technologies. These prevented emissions reduce the generated emissions described above, in what is known as net balance.

4.2.4 Exclusions and assumptions

We have made certain assumptions and exclusions in the calculations. They are listed below:

- When making the calculations, we have excluded any data provided by AEVERSU that diverges greatly from the rest of the facilities or that are inconsistent.

- We have not included the data from the TRARGISA Plant, because it is not currently operational, and neither have we included any data from the REMESA Plant, because we have not received any. The same applies to the data from the ZABALGARBI Plant, given that it is not possible to easily distinguish between the emissions coming from energy recovery from MW and those coming from natural gas combustion.

- MW being transported by vehicles has been excluded from the study scope, owing to the lack of data and the disparity of the data that is available. As we have already pointed out, the National Inventory also excludes this information for landfill sites.

- When estimating the direct emissions due to energy recovery, we have considered that the methane emissions are not significant: 0.1 g of CH_4 per tonne of MW, according to the MITECO, in 2018.

- The MITECO's National GHG Inventory (March, 2020) contains the landfill emissions data for 2018, but does not furnish data for 2019. For our study, we have considered that the proportion of MW emissions per tonne remains constant for those two years, and so, in relative terms, the energy recovery emissions for both 2018 and 2019 are comparable. However, we have not compared the total emissions, but the relative ones (Kg CO2e / t of MW), so the findings will not be distorted because the results are for different years and, thus, with tonnes of MW that are slightly different.

- The National Inventory offers the landfill emissions data for 2018, including only the Spanish landfill sites, so the study has not used information from sites in Andorra.

- Calculating the emissions prevented:

- We have considered the emissions prevented as coming from electricity sold, it being understood that the difference between the electricity produced by the energy recovery facility and the electricity sold corresponds to the electricity to be consumed by the plant itself. This value was used when calculating the net balance.

- In the cases where we do not have self-consumption electricity data, we have considered that 80% of the energy produced by the plant is sold and 20% consumed at the plant itself, this being the average self-consumption value at the plants for which we have data available.

- We have considered the electricity production at the recovery plants prevents emissions corresponding to the electricity mix where the recovery plant is located: Mainland Mix (170 Kg CO_2 per MWh), Balearic Mix (778 Kg CO_2 per MWh) and Andorran Mix (154 Kg CO_2 per MWh). Please note that there are no MW energy recovery plants on the Canary Islands at present.

- Slag recycling has not been included in the calculations, because it is considered that (i) the emissions prevented factor is only slight – approximately 0.5 Kg CO2 per tonne of MW is prevented (source: Christensen et al, 2015. Waste to energy: the carbon perspective) and (ii) there is uncertainty regarding the amount of slag recycled at each plant.

- We have not included in the emissions prevented calculations, the CO_2 absorbed by slag carbonation, owing to the high variability in slag management at the different facilities involved in the study. Carbonation is a natural process that takes place between the carbon dioxide in the air and the calcium contained in the slag, causing the CO2 to be fixed, in ratios that can range from 12 to 251 Kg per tonne of slag (source: Johansson and Lönebo, 2016).

4.3 Carbon footprint and net balance for energy recovery from municipal waste

The results from calculating the carbon footprint for energy recovery from MW are shown below.

The GHG emissions from the energy recovery process per tonne of MW treated, calculated following the guidelines recognised internationally in the GHG Protocol, EpE Protocol and the IPCC Guidelines (2006), are estimated at 357 Kg CO_2e / t MW. These emissions come from the process of MW combustion (347 Kg CO_2e / t MW) and the consumption of auxiliary fuels (10 Kg CO_2e / t MW). 20 Kg CO_2e/t MW must be added to this value to take into account the consumption of electricity from external sources.

The aforementioned combustion process emissions come from fossil carbon emissions. The emissions from biogenic carbon, 567.5 Kg CO2e / t MW, are deducted in the methodology used.

The emissions prevented arising from the sale of electricity and heat (estimated at 153 Kg CO2e / t MW), give rise to a net balance of 224 Kg CO2e / t MW.

Scope	Emission source	Emissions ($t\ CO_2e$)	Emissions per tonne of waste ($Kg\ CO2e$ / t MW)
Scope 1	MW Combustion	781.037	347.4
	Consumption of auxiliary fuels	21,315	9.5
	Total Scope 1	*802,352*	*356.9*
Scope 2	Consumption of electricity from external sources	45,473	20.2
	Total Scope 2	*45,473*	*20.2*
CARBON FOOTPRINT	**Scope 1 + Scope 2**	**847,825**	**377.1**
Emissions prevented	Emissions prevented through sale of electricity	316,459	140.7
	Emissions prevented through sale of heat	27,963	12.4
	Total Prevented	*344,423*	*153.1*
NET BALANCE	**Scope 1 + Scope 2 - Prevented**	**503,402**	**224.0**

Table 4-4. Overall balance for calculating the carbon footprint from energy recovery.

We explain below the breakdown of the emissions calculated for each one of the scopes summarised in the table above.

Scope 1: Direct emissions

Direct emissions are the ones coming from the MW combustion process, in which CO_2 and N_2O are emitted, and from the consumption of auxiliary fuels.

- CO_2 emissions from MW combustion:

Scope	Emission source	Quantity recovered (t MW)	Emission factor (Kg CO_2 / t MW)	Emissions (t CO_2)
Scope 1	MW combustion	2,248,495	332.46	**747,535**

Table 4-5. CO_2 emissions from MW combustion.

- N_2O emissions from MW combustion:

Scope	Emission source	Quantity recovered (t MW)	Emission factor (Kg N2O / t MW)	Emissions (t N_2O)	Emissions (t CO_2e)
Scope 1	MW Combustion	2,248,495	0.050	112	**33,503**

Table 4-6. N_2O emissions from MW combustion.

Thus, direct emissions (Scope 1) arising from the MW combustion process are as follows:

Scope 1: direct emissions	Emissions (t CO_2)	Emissions (t N_2O)	Emissions (t CO_2e)
Combustion from MW	747,535	-	747,535
	-	112	33,503
TOTAL			**781.037**

Table 4-7. CO_2e emissions from MW combustion.

- Emissions due to the consumption of auxiliary fuels:

Scope 1: direct emissions	Quantity consumed	Emission factor (Kg CO2 / l and Kg CO2 / Nm3)	Emissions (t CO_2e)
Gas Oil (l)	1,332,591	2.681	**3,572**
Natural Gas (Nm^3)	7,470,420	2.375	**17,743**
TOTAL	-	-	**21,315**

Table 4-8. Emissions due to the consumption of auxiliary fuels.

Scope	Source	Emissions (t CO_2e)	Emissions per tonne of waste (Kg CO_2e / t MW)
Scope 1: direct emissions	Combustion from MW	781,037	347.4
	Consumption of auxiliary fuels	21,315	9.5
	TOTAL	**802,352**	**356.9**

Table 4-9. Total emissions for Scope 1: direct emissions.

Scope 2: Indirect emissions

Indirect emissions are the ones due to the consumption of electricity generated by external sources. As we have already explained, we have taken the specific emission factors for each region and divided their calculation into Mainland Facilities, the facilities located in Andorra and those located on the Balearic Islands, as shown below.

Scope	Source of the electricity	Electricity consumed (MWh)	Emission factor (Kg CO_2 / MWh)	Emissions (t CO_2e)	Emissions per tonne of waste (Kg CO_2e / t MW)
Scope 2: indirect emissions	Mainland	262,461	170	44,618	19.8
	Andorra	5,287	154	814	0.4
	Balearic Islands	52	778	40	0.0
	TOTAL	267,799	-	**45,473**	**20.2**

Table 4-10. Emissions due to the consumption of electricity generated by external sources (Scope 2).

Emissions prevented

The sale of energy –heat and electricity- from MW energy recovery prevents the GHG emissions that would have been released if that energy had been generated by other technologies. The plants that form part of AEVERSU have been designed to maximise electricity production, rather than heat production. Although the amount of heat produced and sold is low, when compared to other plants that recover energy from MW in other European countries, the emissions prevented by selling this heat are significant. We will see below what emissions are prevented by the sale of electricity and heat, which contribute to decreasing the net balance (carbon footprint minus emissions prevented).

- Emissions prevented by the production and sale of electricity.

Scope	Source of the electricity	Quantity sold (MWh)	Emission factor (Kg CO_2 / MWh)	Emissions prevented (t CO2e)
Emissions prevented	Mainland	781,019	170	132,773
	Andorra	17,238	154	2,655
	Balearic Islands	232,838	778	181,031
	TOTAL	1,031,095	-	**316,459**

Table 4-11. Emissions prevented through the sale of electricity.

- Emissions prevented through the production and sale of heat.

Scope	Source	Quantity sold (MWh)	Emission factor (Kg CO_2 / MWht)	Emissions prevented (t CO2e)
Emissions prevented	**Heat**	100,227	279	**27,963**

Table 4-12. Emissions prevented by the sale of heat.

- Total emissions prevented through the production and sale of electricity and heat.

Scope	Source	Quantity sold (MWh)	Emissions prevented (t CO_2e)	Emissions per tonne of waste (Kg CO_2e / t MW)
Emissions prevented	Electricity	1,031,095	316,459	140.7
	Heat	100,227	27,963	12.4
	TOTAL	1,131,323	**344,423**	**153.1**

Table 4-13. Emissions prevented through the sale of electricity and heat.

Energy recovery from MW prevents emissions amounting to a total of 344,423 t CO2e, which would have been released if the same amount of heat and electricity had been obtained by using other resources. One case in point is the Balearic Islands which, with only one facility, TIRME, and due to the fact that they are islands and depend on unrenewable sources, have an electricity mix with a high emission factor that makes it possible to count as prevented, almost the same tonnage of CO2e as all the mainland facilities as a whole.

4.4 Carbon footprint and net balance for disposing of MW at landfill sites

We will show below the calculations for the landfill carbon footprint from MW, starting with the data from the National GHG Inventory owned by MITECO (March 2020), in which the data broken down into individual landfill sites is not featured, so we have revised only the total values.

Considering that in 2018 Spanish landfill sites managed 12,716,275 t of MW, the National GHG Inventory estimates the following emissions released as a result of MW management on a landfill site:

- Emissions from MW at landfill site.

Scope	Emission source	Emissions (t)	GWP* of the gas emitted	Emissions (t CO_2e)	Emissions per tonne of waste (Kg CO_2e / t MW)
Scope 1	Diffuse emission of CH_4	397,237	25	9,930,929	781.0
	Emission from burning in flare	0	0	0	0.0
	Emissions of CH_4 due to energy recovery from biogas	4.67	25	117	0.0
	Emissions of N_2O due to energy recovery from biogas	0.47	298	140	0.0
	Total Scope 1	*397,242*	-	*9,931,186*	*781.0*
Scope 2	Electricity consumption	-	-	0	0.0
CARBON FOOTPRINT	**Scope 1 + Scope 2**	**394,242**	**-**	**9,931,186**	**781.0**
Emissions prevented	Emissions prevented through sale of electricity	-	-	*116,465*	9.2
NET BALANCE	**Scope 1 + Scope 2 - Prevented**	**397,242**	**-**	**9,814,720**	**771.8**

*Global Warming Potential.

Table 4-14. Emissions from MW at landfill site (2018). Source: Report issued by the National GHG Inventory (Edition 2020, Series 1990-2018), Ministry for Ecological Transition & Demographic Challenge.

As we have described in previous chapters, biogas capture in Spanish landfill sites ends up by being burnt in flares or used as fuel for engines. In the latter case, the MW landfill site has to be particularly large if the investment is to be feasible.

According to the estimates from the MITECO's National GHG Inventory, the emissions from burning biogas in flares is considered to be insignificant, given that the CO_2 emissions are from a biogenic source and the emissions of CH_4 and N_2O are only slight, as can be seen in the table above.

The National Inventory calculation method does not include the Scope 2 emissions, so neither have they been considered in this calculation.

The biogas captured and destined for engines leads to a production of electricity that can be injected into the grid. In such cases, it is considered to be helping to move the electricity mix and, so, it becomes emissions prevented. Although the National Inventory does not calculate the emissions prevented, it does estimate that in 2018 92,965 t of CH_4 were given over to motor-generators. On the basis of this information, G-advisory has estimated 116,465 t of CO_2 emissions prevented, considering an efficiency of a standard motor-generator to be 40%, and a lower heat power (PCI) of 10.83 kWh / Nm^3. Moreover, this energy recovery obtained from landfill biogas produces N_2O emissions and, if the combustion is incomplete, CH_4 emissions, also considered in this study, although this makes a negligible contribution to the carbon footprint, as can be seen in the above table.

All in all, the net balance of disposal of MW in Spain is almost 10 million tonnes CO_2e, which is equivalent to 772 Kg CO_2e / t MW. These data take into account not only the diffuse emissions from the landfill site but also exporting to the grid the electricity generated from the biogas captured.

4.5 Carbon footprint comparison: energy recovery vs. landfill

It can be seen from the results shown in the preceding sections that there is a major difference between the GHG emissions coming from energy recovery and from landfill sites per tonne of MW.

Considering only the treatment phase in the MW management life cycle, the following table shows the carbon footprint difference between waste used in energy recovery and waste sent to a landfill site.

Scope	Emissions per tonne of waste (Kg CO_2e / t RU)		Difference Landfill-Recovery	
	Waste at landfill sites	Energy recovery	Difference (Kg CO_2e / t MW)	Difference (%)
Scope 1 (Direct emissions)	781.0	356.9	+424.1	+119%
Scope 2 (Indirect emissions)	-	20.2	-20.2	-100%
Carbon footprint (total emissions)	781.0	377.1	403.9	+107%
Emissions prevented	9.2	153.1	-143.9	-94%
Total net balance	**771.8**	**224.0**	**547.8**	**+245%**

Table 4-15. Comparison between the carbon footprint at a landfill site and energy recovery from MW.

As can be seen, the landfill option amounts to an emission increase of 404 Kg CO_2e / t MW, i.e., 107% more emissions.

If we deduct the emission reductions obtained as a result of generating and exporting electricity to the grid, this difference increases to 548 Kg CO_2e/ t MW, which amounts to 245% more emissions in the net balance.

Therefore, it can be concluded that MW disposal at a landfill site generates about twice as many GHG emissions as energy recovery, per tonne of waste treated, and the net balance is 3.5 times as great.

4.6 Scenarios and interpreting the findings

This section analyses the carbon footprint from MW energy recovery in two future scenarios with variation in the domestic electricity mix and we compare it with its current carbon footprint and with the carbon footprint from disposal at landfill sites.

The scenarios selected for this study are the ones proposed by the Comprehensive National Energy & Climate Plan (PNIEC) 2021-2030, which defines two projections for the contribution that the production of renewable energy makes to total electricity generation.

The scenarios considered by the PNIEC and transferred to this study are as follows:

- Trend scenario: no new policies are implemented to encourage renewable energy production. This scenario considers that in 2025, 47% of the electricity generated will be from renewable sources. This projection for 2030 is 52%.

- Target scenario: the measures indicated in the PNIEC are implemented, so in 2025, 60% of the total electricity generated will be from renewable sources. This percentage rises to 74% in 2030.

Therefore, the scenarios considered for this study are based on a potential variation in the domestic electricity mix in 2025 and 2030. The rest of the variables have been considered constant, as a reasonable approximation, especially the quantity and the composition of MW in Spain and Andorra.

The increase in the proportion of renewable electricity generation when compared to the total means cleaner electricity generation, with less GHG emissions, and thus a lowering of the emission factor. As the PNIEC estimates in its scenarios, we have considered one single emission factor for electricity generation for the whole of Spain, without making any distinction between Mainland Spain, the islands and the autonomous cities.

The trend and target scenarios considered for this section are as follows:

	Trend scenario		Target scenario	
Year	2025	2030	2025	2030
Renewable energies (% out of the total electricity generation)	47%	52%	60%	74%
Emission factor (Kg CO_2e/MWh)	146	141	86	59

Table 4-16. Trend and target scenarios. Source: PNIEC (January 2020).

Scenarios for the carbon footprint and the net balance for energy recovery from MW

The next table summarises the emissions from MW energy recovery in both scenarios, trend and target. Not only the emissions calculated for 2019 are included (See calculations in Section 4.3) but also the estimates made for 2025 and 2030 on the basis of the emission factors proposed by the PNIEC for each scenario.

Emissions per tonne of waste (Kg CO_2e / t MW)					
Scope	**Basic case**	**Trend scenario**		**Target scenario**	
	2019	**2025**	**2030**	**2025**	**2030**
Scope 1 (Direct emissions)	356.9	356.9	356.9	356.9	356.9
Scope 2 (Indirect emissions)	20.2	17.4	16.8	10.2	7.0
Carbon footprint	**377.1**	**374.3**	**373.7**	**367.1**	**363.9**
Emissions prevented	153.1	73.5	70.9	43.3	29.7
Net balance	**224.0**	**300.8**	**302.8**	**323.8**	**334.2**

Table 4-17. GHG emissions (Kg CO_2e / t MW) of energy recovery from MW calculated in different scenarios.

As can be seen in the preceding table, direct emissions remain constant in all the scenarios, because the electricity mix variation has no effect in Scope 1. However, an emission reduction for the same electricity consumption can be observed in Scope 2. This is explained by the reduction of the emission factor for electricity consumption and this also leads to a reduction in emissions prevented by the sale of electricity. The result is an increase in the net balance associated with recovery, especially due to the reduction in emissions prevented.

Scenarios for the carbon footprint and the net balance for disposing of MW at landfill sites

As we have already shown, the emissions from landfill mainly come from diffuse methane emissions (Scope 1), which we have considered constant in these scenarios, so the only variation that affects the net balance is due to the emissions prevented. The reality is that, bearing in mind the future reduction in MW that is sent to landfill sites, their emissions will build up with the emissions from MW disposed of earlier, given that the waste deposited emits methane for several decades. So, the ratio of Kg CO_2e / t MW disposed of will increase. Yet it is not possible to assess this increase with an objective numeric value, so we have considered this ratio to be constant in the future.

Furthermore, the movement of the electricity mix leads to a reduction in the electricity generation emission factor, and thus to a reduction in the emissions prevented because the energy from biogas at landfill sites is harnessed. The following table summarises the estimates made for 2025 and 2030, in both the trend and target scenarios.

Emissions per tonne of waste (Kg CO_2e / t MW)					
Scope	**Basic case**	**Trend scenario**		**Target scenario**	
	2019	**2025**	**2030**	**2025**	**2030**
Scope 1 (Direct emissions)	781.0	781.0	781.0	781.0	781.0
Scope 2 (Indirect emissions)	0	0	0	0	0

Carbon footprint	781.0	781.0	781.0	781.0	781.0
Emissions prevented	9.2	7.0	6.8	4.1	2.8
Net balance	**771.8**	**774.0**	**774.2**	**776.9**	**778.2**

Table 4-18. GHG emissions (Kg CO_2e / t MW) from dumping MW at landfill sites calculated for different scenarios.

It can be observed that the progressive reduction in emissions prevented leads to a slight increase in the net balance for landfill, due to the fact that the emissions prevented hardly contribute to the whole in any of the scenarios.

Comparison between scenarios: energy recovery and waste sent to landfill sites

Emissions per tonne of waste (Kg CO_2e / t MW)					
Scope	**Basic case**	**Trend scenario**		**Target scenario**	
	2019	**2025**	**2030**	**2025**	**2030**
Energy recovery	224.0	300.8	302.8	323.8	334.2
Landfill	771.8	774.0	774.2	776.9	778.2
Difference net balance: landfill - energy recovery	547.8	473.2	471.4	453.1	444.0
Difference net balance (%)	**245%**	**157%**	**156%**	**140%**	**133%**

Table 4-19. Comparison between trend and target scenarios.

The electricity mix development scenario towards an increase in the proportion of renewable energies will lead to a reduction in the emissions prevented through energy recovery and, thus, to an increase in their net balance. The same occurs with the emissions associated with landfill. However, as the emissions prevented in landfill sites are much lower, they are less affected by the reduction of the emission factor in the electricity sector, and the increase in the net balance in future scenarios would be more moderate.

If a comparison is made between the differences in net balance (landfill - energy recovery) between the basic case and the different scenarios, substantial reductions can be seen in detriment to recovery. However, even in the PNIEC's target scenario, the net balance from landfill is more than twice the net balance from energy recovery.

This variation is not only due to the aforementioned unequal decrease of emissions prevented when comparing the two treatments, but also because of the geographical standardisation of the emissions factor carried out by the PNIEC, considering one single average factor for the whole of Spain.

The following can be deduced from the above analysis:

- Emissions from landfill sites in 2030 and, according to the PNIEC's target scenario will still be 115% higher than those from MW energy recovery.

- The net balance for waste disposal at landfill sites in 2030 and according to the PNIEC's target scenario will still be 133% higher than MW energy recovery.

This exercise has enabled us to analyse the future of one of the major parameters that affect the net balance of both kinds of MW treatment. However, it must be stressed that there are other parameters that will have a bearing on the future scenario and whose assessment is highly complex. The most important factor is how the composition of landfill waste or energy recovery waste will vary in the future (especially with respect to the biogenic carbon content) in both Spain and Andorra and how this will affect the GHG emissions generated.

ANNEX. DOCUMENTATION REVIEWED

- ✓ Excel spreadsheet with the results of the biogenic carbon measurements carried out at SOGAMA, TIRME, TERSA, UTETEM and SIRUSA.
- ✓ Biogenic carbon emissions measurement report from the TIRMADRID Plant, prepared by SGS TECNOS, S.A.U. on 10th February 2021.
- ✓ Council Directive 75/442/EEC, of 15th July 1975 on waste.
- ✓ Council Directive 91/156/EEC, of 18th March 1991, modifying Directive 75/442/EEC on waste.
- ✓ Act 10/1998, of 21st April on waste.
- ✓ Directive 2006/12/EC of the European Parliament and the Council, of 5th April 2006 on waste.
- ✓ Directive 2008/98/EC of the European Parliament and the Council, of 19th November 2008 on waste and repealing certain Directives.
- ✓ Act 22/2011, of 28th July, on Waste and Contaminated Soil.
- ✓ Directive (EU) 2018/851 of the European Parliament and the Council, of 30th May 2018, amending Directive 2008/98/CE on waste.
- ✓ Directive (EU) 2018/850 of the European Parliament and the Council, of 30th May 2018, modifying Directive 1999/31/CE on waste disposal.
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