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Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe

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ABSTRACT

This paper proposes an overarching review of national municipal waste management systems and waste-to-energy as an important part of it in the context of circular economy in the selected countries in Europe. The growth of population and rising standards of living means that the consumption of goods and energy is increasing. On the one hand, consumption leads to an increase in the generation of waste. On the other hand, the correlation between increased wealth and increased energy consumption is very strong as well. Given that the average heating value of municipal solid waste (MSW) is approximately 10 MJ/kg, it seems logical to use waste as a source of energy. Traditionally, waste-to-energy (WtE) has been associated with incineration. Yet, the term is much broader, embracing various waste treatment processes generating energy (for instance, in the form of electricity and/or heat or producing a waste-derived fuel). Turning waste into energy can be one key to a circular economy enabling the value of products, materials, and resources to be maintained on the market for as long as possible, minimising waste and resource use. As the circular economy is at the top of the EU agenda, all Member States of the EU (including the EEA countries) should move away from the old-fashioned disposal of waste to a more intelligent waste treatment encompassing the circular economy approach in their waste policies. Therefore, the article examines how these EU policies are implemented in practice. Given that WtE traditionally is attached to the MSW management and organisation, the focus of this article is twofold. Firstly, it aims to identify the different practices of municipal waste management employed in selected countries and their approaches in embracing the circular economy and, secondly, the extent to which WtE technologies play any role in this context. The following countries, Estonia, Greece, Italy, Latvia, Lithuania, Norway, Poland, Slovenia, Spain, and the UK were chosen to depict a broad European context.

1. Introduction

As European society has grown wealthier, it can afford to buy more products and therefore more waste is produced than ever before. Consumption has also changed dramatically, as consumers

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Abbreviations

AD	Anaerobic Digestion
BMW	Biodegradable Municipal Waste
EEA	European Economic Area
EFTA	European Free Trade Association
EPR	Extended Producer Responsibility
GDP	Gross Domestic Product
GHG	Greenhouse Gas
MBT	Mechanical Biological Treatment
MSW	Municipal Solid Waste
NWMP	National Waste Management Plan
RDF	Refuse Derived Fuel
SRF	Solid Recovered Fuel
WFD	Waste Framework Directive
WtE	Waste-to-Energy

have much more choice and products are designed to have shorter lifespans with many single-use and disposable products. Advances in technology mean that consumers own and use many more personal devices, and update them more often [1]. With the growth of population and rising standards of living over the world the consumption of goods and energy is increasing. On the one hand, consumption leads to an increase in the generation of waste. For instance, the average amount of municipal solid waste (thereafter MSW) generated by each of about 512 million inhabitants of the European Union was accounted as 477 kg per year in 2015 [2,3]. Taking into consideration an estimated density of MSW (about 200–400 kg/m^3), after one year of generation the EU municipal solid waste would cover Malta (316 km^2) with a layer almost 2 m high! That sounds alarming. On the other hand, the correlation between increased wealth and increased energy consumption is very strong [4]. Specifically, about 1530 million TOE of primary energy was consumed by the EU countries in 2015. Knowing that the average heating value of MSW is approximately 10 MJ/kg [5], it seems logical to use waste as a source of energy. Traditionally, waste-to-energy (thereafter WtE) has been associated with incineration. Yet, the term is much broader, embracing various waste treatment processes generating energy (for instance, in the form of electricity and/or heat or producing a waste-derived fuel) [6]. Turning waste into energy can be one key to a circular economy, which is part of the EU's broader picture of an action plan for the circular economy adopted in 2015 aiming at, *inter alia*, fostering sustainable consumption and production patterns; this is also in line with EU commitments under the 2030 Agenda for Sustainable Development. In contrast to a linear economy summarised as 'take, produce, consume and dispose of', a circular economy is defined as one in which the value of products, materials and resources is maintained for as long as possible, minimising waste and resource use (i.e. what used to be considered as 'waste' can be turned into a valuable resource) [7]. In this context, the EU calls for waste management to be transformed into sustainable material management which embeds the principles of the circular economy, enhances the diffusion of renewable energy, increases energy efficiency, reduces the dependence of the Union on imported resources and provides economic opportunities and long-term competitiveness [8]. As part of its Action Plan is the European Commission's proposals to revise the key EU waste acquis: the Waste Framework Directive (thereafter WFD) [9], the Landfill Directive [10], the Packaging Directive [11], and the Directives on end-of-life vehicles [12], batteries and accumulators [13], and waste electrical and electronic equipment (WEEE) [14]. Given that there is a clear focus from the main legislative piece, WFD (currently under review), on municipal waste, including food waste, this paper will focus solely on MSW. Even though municipal waste represents only approximately 7%–10% of the total waste generated in the Union (measured by weight), this waste stream is amongst the most complex ones to manage. The EU considers that countries which have developed efficient municipal waste management systems generally perform better in overall waste management [15].

The solutions of MSW management should not only be environmentally sustainable but also cost-efficient and socially acceptable. There are several factors that influence this complex process (see Table 1), which are largely intertwined. First of all, there is a need for political will, a willingness to pursue changes. While the EU sets a direction (i.e. a shift towards the circular economy), waste management is implemented at national level. Waste management contains a multi-level governance system, embracing central governments for setting strategies, creating national plans, then regional and in most cases local authorities for designing and implementing policies and organising tools for waste collection, treatment, and disposal. Government regulations, taxes and support schemes play an important part in the development of this sector and encouragement of new technologies, which would struggle to survive without governmental support. Even though 'Advances in Technology' are essential tools to facilitate change, there should be a platform for innovation and technology demand. Sometimes regulatory barriers may prevent the commercialisation of new beneficial technologies. Equally, there has to be a vivid business case for the industry to get involved. Private investment played an essential role in the development of the Estonian waste management system. Markets for 'secondary' waste-derived raw materials need to be created. From an economic point of view, new technologies typically face an uphill struggle when first introduced due to a lack of economies of scale and learning economies, not yet established supply chains and market structures [4]. Depending on the technologies involved, they may not fit neatly with the existing infrastructure. While the WtE sector presents an immense business potential with financial value in new circular business models: enabling companies to make substantial economic gains and become more competitive, the obstacles defined above must be overcome. The challenges of municipal waste management also stem from the direct proximity of the generated waste to citizens, a very high public visibility, and an active involvement of citizens and businesses (i.e. willingness to recycle etc.). Different countries have different societal structures that interject in part to different 'societal preferences' [16]. For instance, a WtE installation may face effective local protest (known as a NIMBY (Not In My Backyard) syndrome) especially if a sufficient case for nuisance through noise or odours can be made. Ren et al. [17] in their study analysed risk perception and public acceptance over protested WtE facilities. According to their findings, WtE processes should be promoted through highlighting their benefits as renewable energy sources and the conservation of land to weaken strong protests from local

Table 1
Factors that influence waste management.

Factors of waste management
Political: political will, multi-level governance, government regulations (taxes, subsidies), data collection and monitoring;
Economic: business model, cost-benefit analysis, availability of finance, collaboration, and transparency along the value chain;
Environmental: sustainability policy, human health impact;
Social: community perception;
Technological advances: innovation, infrastructure;
Educational: research centres, cooperation projects.

communities against incineration plants, especially in areas with high population densities. The most significant factors influencing the choice of protest were: risk perception, income, opinion about the benefits of WtE, gender and previous experience of odour pollution. Additionally, a significant statistical relationship between knowledge and risk perception was identified. Thus, the need for risk communication, as well as involving the public in the whole management process, is highly recommended. New technologies also quite often require significant changes in user practices, habits, and aspirations. A new term of 'prosumer' has emerged attributing to the role of active consumers with the potential to be energy producers, particularly through self-generation of renewable energy, storage, energy conservation and participation in demand response [18]. Waste management and its impact on the environment and human health is self-evident: poor choices, such as landfills may, depending on the way they are built, contaminate soil and water with chemicals contained in waste and also lead to a climate change.

Finally, education, public awareness and advocacy on the organisation of waste management and the potential of MSW to be used as an energy resource should be not forgotten. The cooperation of the institutions (research centres and Ministries, such as Environment and Energy) within and among Member States should be encouraged. For instance, a regional project "RECO Baltic 21-Tech" (partly funded by Baltic Sea Region Programme 2007–2013) serves as an inspiring example of mutual benefits: it encompassed universities, research centres and companies, which work hand in hand in search of solutions for the problems associated with waste management in Baltic Sea region countries, such as Germany, Poland, Lithuania, Estonia, Latvia and Sweden, contributing to sustainable waste management in the region, at the same time gaining interesting topics for research, possibilities for capacity building and curriculum enrichment for students [19]. Along similar lines, there is another three-year European project COOLSWEEP (funded by the EU 7th Framework programme), involving six different European regions. The COOLSWEEP project seeks to identify possible synergies and partnerships between public and private stakeholders and knowledge institutions within the field of WtE and to support the development of new businesses based on utilising waste as the feed material for efficient sustainable energy production and more effective use of the by-products from the energy generation. COOLSWEEP also has an additional mentoring task to establish a new cluster based in Riga, Latvia, with strong competencies within the field of WtE [20]. This is an essential element for the WtE development in Latvia given its current underdeveloped WtE infrastructure as will be discussed in Section 7.1.4.

As the circular economy is at the top of the EU agenda, the EU Member States (including the EEA countries) by addressing all the factors discussed above should move away from the old-fashioned disposal of waste to more intelligent waste treatment encompassing the circular economy approach in their waste policies. Therefore, the article examines how these EU policies are implemented in practice. Given that WtE traditionally is attached to the MSW management and organisation, the focus of this article is twofold. Firstly, it aims to identify different practices of municipal waste management employed in selected countries, their approaches in embracing the circular economy, and any challenged faced, and, secondly, the extent to which WtE technologies plays any role in this context. The following countries, Estonia, Greece, Italy, Latvia, Lithuania, Norway, Poland, Slovenia, Spain and the UK were chosen to depict a broad European context.

The paper is organised in two main parts: i) generic – embracing the EU MSW policies and its approach to WtE; and ii) specific – with an overview of MSW management in the selected countries and their policies on WtE. Apart from the introduction (Section 1) and methodology (Section 2), Sections 3 and 4 are devoted to the EU domain respectively, the EU definition of 'MSW' and related concepts, and EU waste management requirements. While Section 5 will explore the role of WtE in the context of the circular economy, Section 6 (with its Subsection 6.1) will analyse existing technologies, including WtE technologies and their position in the waste hierarchy defined by the WFD. The final Sections 7–10 are devoted to specific countries and their management policies, including WtE. The concluding remarks are distilled in Section 11.

2. Methodology and the state of the art

The preparation and organisation of MSW management with its recent trend centred on the circular economy needs inputs from a range of disciplines, therefore, this paper embraces an interdisciplinary perspective (legal, scientific, and to a lesser extent economic). Previous studies on waste management either had a scientific focus [21], or economic justifications [22], socio-legal aspects [23,24], or technology advancements and related issues [25], including WtE plants in some European countries [26]. There is also a profound literature on the future of renewable energy and sustainability compiled by Professor Olabi [27–29] with an emphasis being placed on energy security.

There have been some studies with a specific emphasis on WtE, for instance, under the influence of market and EU legislation [30]. The most recent broadest (in scope) study was conducted by the European Environment Agency "Assessment of waste incineration capacity and waste shipments in Europe" in 2017 [31], with the previous study on incineration overcapacity and waste shipping in Europe commissioned by the Global Alliance for Incinerator Alternatives in 2013 [32]. These studies observed an uneven distribution of WtE capacity across Europe with the six countries – Germany, France, the Netherlands, Italy, the United Kingdom, and Sweden - accounting for almost three-quarters of Europe's incineration capacity and with the other countries heavily relying on landfill for MSW disposal. These reports also noted a lack of consistent data across Europe.

Further studies focused on different aspects of waste management in specific countries [33]. For instance, Guziana et al. [34] focused on the EU waste management and energy policy in the context of Sweden. They pointed out, that nowadays the priority of waste prevention and concern for food losses has significantly influenced the WtE sector in the EU: the amount of waste delivered to incineration plants will gradually decrease since the recycling rate and waste prevention will grow. They concluded that there is a need to redesign waste management systems in order to meet the waste hierarchy.

Given the limited interdisciplinary studies on waste management (and WtE as an important part of it) as well as a narrow scope of jurisdictional coverage, this paper aims to fill this gap in the literature. Building on the previous studies, this article selected ten countries (i.e. Estonia, Greece, Italy, Latvia, Lithuania, Norway, Poland, Slovenia, Spain, and UK) to better represent a European context. These ten countries were chosen because they offer a range of perspectives in terms of their different stages of economic development (e.g. the UK and Norway with a GDP per capita above the EU average (EA-106), and the rest of the countries being below this level, as shown in Table 2 [35,36]); different sizes of their economies (small, for example, Estonia, Latvia, Lithuania and Slovenia and large - the UK); different Accession waves (EU and EEA (European Economic Area) countries): Italy as one of the co-founding states of the EU; Estonia, Latvia, Lithuania, Poland, and Slovenia (i.e. the newer Member States which joined the EU in

Table 2
Profile of the selected countries.

GEO	Population (mil)	Size/Km^2	Density	GDP per capita [35]	Administrative units
Estonia	1.315	45,227	28.8	74	213 municipalities: 183 rural municipalities and 30 cities
Greece	10.784	131,957	86.4	67	13 regions
Italy	62.808	302,073	201.32	96	8040 municipalities
Latvia	1.95	64,573	30,19	65	10 waste management regions/110 municipalities and 9 independent cities
Lithuania	2.88	65,286	44.1	75	10 counties/counties are subdivided into 60 municipalities
Norway	5.267	304,282	14	149	19 administrative regions/426 municipalities
Poland	38.42	312,679	123	69	2479 municipalities
Slovenia	2.06	20,273	102	83	212 municipalities/8 regional MSW management centres
Spain	46.446	505,944	92	92	17 autonomous communities, 2 cities with statutes of autonomy, and 8125 local institutions
UK	65.6	248,528	250	108	England: 353 local authorities; Wales: 22 and Scotland: 32 county councils; Northern Ireland: 11 district councils [36]

2004), the UK – a potential leaver of the EU, and Norway as a representation of an EEA country; and, finally, geographical positioning: Northern (Norway), Southern (Greece, Italy, Spain), Eastern and Central European states (Estonia, Latvia, Lithuania, Poland, and Slovenia) and Western (UK). The last groupings will be followed in this paper, as they represent not only geographical regions, but also similarities in the countries' GDP (with the exception of Greece due to the State's debts); and duration of the EU membership – the Southern region countries classified as 'old' Member States, the Central European region – falling to the 'newer' Member States classification, the Northern region – representing the EEA rather than being a Member State of the EU and finally, the Western region – referring to the Member State, whose fate is not clear due to the Brexit negotiations.

The duration of EU membership does not seem to correlate with the states' waste management performance, as it depends on different visions, strategies, and priorities of waste management. Yet, historical data of some Member States (for instance, the Baltic states) are not available due to different classifications of waste streams before joining the EU. Therefore, the data for this article aim to cover the 2004–2015 period (and 2016 where possible) with the template provided for each national rapporteur. While national rapporteurs collected the data mainly drawn from the NWMPs and other governmental reports, statistical data from Eurostat and the EU reports prepared for the EEA (European Environment Agency), and for the European Commission (BiPRO) were also consulted. Information and the availability of data in this field is rather limited. It has been noted that the Member States have difficulties in collecting and calculating the necessary information on MSW for the EU reporting. For instance, the three Baltic countries have producer responsibility schemes for packaging waste. Given that there is no established reporting system, private operators of these schemes do not always provide data on the sources of the packaging waste, and therefore packaging waste is not always included in Eurostat as MSW in the Baltic countries. Similar situation exists in other countries, such as Greece. There is also no uniformity with regard to MSW sent to Mechanical Biological Treatment (MBT); in some countries the whole amount received at the MBT plant is allocated to recycling, whereas in other countries – only the actual amount recycled after the MBT.

3. The notion of 'MSW' – more clarity from the EU

Given that the application of the waste legislation in its entirety depends on the notion of 'waste', it is essential to define its scope. The WFD encompasses a broad notion of waste defining it as "any substance or object which the holder discards or intends or is required to discard" [9], which has barely changed since the first WFD issued in 1975. The European Commission has been criticised for the lack of clarity on the definitions of 'waste', 'municipal waste', 'by-product', 'end-of-waste' ever since. The introduction of the new concepts of 'by-product' and 'end-of-waste' in the 2008 WFD aimed to tighten the scope of 'waste'. For instance, the WFD now regulates the possibility of removing substances from the legal classification of waste (reclassify them as by-products) at EU and national levels [24]. Article 6(1) of WFD states that certain specified waste would cease to be waste when it has undergone a recovery operation, including recycling, and complies with the generic requirements prescribed by the Directive (see Table 3) and the specific criteria defined for each waste stream either at EU or national level.

When no end-of-waste criteria are set at EU level, 'Member States may decide case by case whether certain waste has ceased to be waste considering the applicable case law' [9]. This means that some materials in certain Member States can be regarded as 'waste' but in others they can escape the waste regulatory requirements due to attribution to 'end-of-waste' status. For example, Solid Recovered Fuel (SRF) has been eliminated from the classification of waste in certain EU Member States (i.e. Italy and UK) regarding them in legal terms as fuel products. Other Member States do not have this reclassification. Given that the application of the current end-of-waste legislation has been circumscribed by inconsistencies in different Member States, this may lead to fragmentation of the internal market. To ensure the smooth functioning of the internal market and a high level of protection of human health and the environment, the Commission should establish harmonised provisions concerning the criteria for granting an end-of-waste status for specific waste streams. Indeed, the Parliament recommends the Commission should, as a rule of thumb, be empowered to adopt delegated acts establishing specific harmonised provisions related to the end-of-waste status to certain types of waste, at least for aggregates, paper, glass, metal, tyres and textiles [8].

The other definition that is currently lacking clarity is MSW, which only appears in the Landfill directive [10]. Undoubtedly, the concept of municipal waste varies across the Member States, as municipal waste reflects different waste management operations in the Member States. To address any uncertainties, the European Commission in its newest proposal to WFD aims to harmonise the

Table 3
The cumulative generic conditions of 'end-of-waste'.

The cumulative generic conditions defined by the WFD are:
(a) the substance or object is commonly used for specific purposes;
(b) a market or demand exists for such a substance or object;
(c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and
(d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.

definition of municipal waste across the Member States, referring to 'municipal waste' as:

> "(a) mixed waste and separately collected waste from households including: paper and cardboard, glass, metals, plastics, bio-waste, wood, textiles, waste electrical and electronic equipment, waste batteries and accumulators; bulky waste, including mattresses and furniture; garden waste, including leaves, grass clipping; (b)mixed waste and separately collected waste from other sources that is comparable to household waste in nature, composition and quantity; (c) market cleansing waste and waste from street cleaning services, including street sweepings, the content of litter containers, waste from park and garden maintenance." [15].

The definition, however, excludes waste from sewage networks and treatment, including sewage sludge and construction and demolition waste. It is also neutral regarding the public or private status of the operator managing waste [15]. The Commission is consistent in its approach as this notion of MSW is in line with the current definition used for statistical purposes by Eurostat and the OCSE. Yet, this newly proposed definition is more explicit precluding the Member States from different interpretations. Even though this is only a proposal and is subject to the approval from the Council of the European Union and the European Parliament, nevertheless, it seems that the Parliament is welcoming this definition (subject to some minor changes) [8]. Additionally, the Parliament notes that the notion of 'food waste' should be added defining it as "food intended for human consumption, either in edible or inedible status, removed from the production or supply chain to be discarded, including primary production, processing, manufacturing, transportation, storage, retail and consumer levels, with the exception of primary production losses" [8].

Equally, for this paper, the final notion needs to be clarified. Given that 'waste' can be regarded as a resource, the energy regulatory framework comes into play, in particular, the European Renewable Energy Directive (known as RED, which is currently under review) embraces "biomass" as one of its 'renewable sources'. Biomass is further defined as "biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste". The biodegradable or organic fraction of municipal solid waste includes food waste from restaurants, households, farmers' markets, gardens, textiles, clothing, paper, and other materials of organic origin.

It seems that there has been a slow progress in defining the main concept in waste legislation. Clear and unambiguous definitions set by the EU are essential to ensure that the reporting and monitoring system works effectively and the results (in achieving the set target) reported by Member States are *bona fide* and comparable, and the scope and credibility of future waste legislative targets are justified. Therefore, further harmonisation at EU level is required, especially in the context of setting well-defined criteria for the 'end-of-waste' status and the calculation rules. While this paper attempts to employ these definitions discussed above, there is no certainty that the same concepts were applied across the chosen jurisdictions. Equally, there is no single homogenous method how to calculate what is recycled, composted, or landfilled. Therefore, some deviations in the statistical data should be acknowledged.

4. MSW management: EU requirements

As discussed in Section 1, waste management is a complex field which goes beyond prevention, collection, treatment, and disposal of waste, embracing a larger ambit of socioeconomic development, government regulations, policy choices, and resource management. It is about protecting, preserving, and improving the quality of the environment, human health, ensuring prudent and rational utilisation of natural resources, promoting a more circular economy, through improving resource use and the efficiency of such use and by ensuring waste is valued as a resource [8]. The European Commission expressed that the EU's economy currently loses a significant amount of potential secondary raw materials which are found in waste streams, with only a limited share (43%) of the municipal waste generated in the Union being recycled, with the rest being landfilled (31%) or incinerated (26%) (see Fig. 1 [37]) [15]. Given that the EU misses out significant opportunities to reclaim as many resources as possible and to improve resource efficiency and to enhance the transition towards a circular economy, it sets the targets for the Member States and for the Union itself. The European Parliament, which urged the Commission to put forward ambitious proposals to revise waste legislation, plays an essential role in the EU's transition towards a circular economy. In March 2017, the European Parliament adopted its position on the review of the four key waste directives with more ambitious targets and provisions compared to the Commission's proposals issued in 2016. For example, in some of its 234 proposed amendments to the WFD and to accelerate the switch to a circular economy, the Parliament tightened the Commission's proposed targets for the preparation for reuse and recycling of municipal solid waste to at least 60% by 2025 (including a minimum of 3% of total municipal waste prepared for re-use) and at least 70% by 2030 (including a minimum of

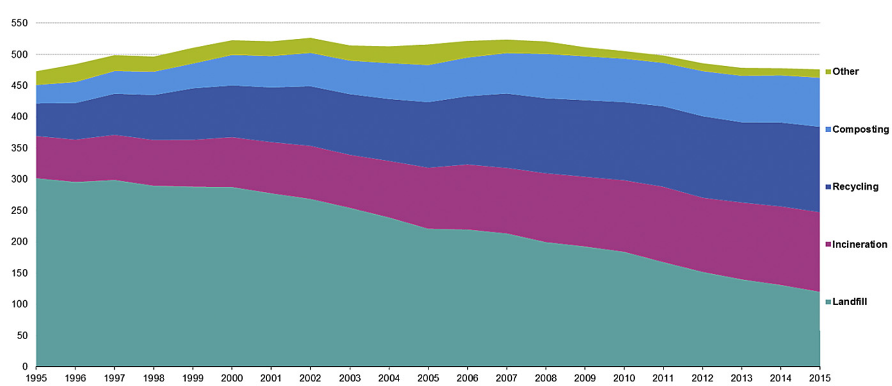

Fig. 1. Municipal waste treatment in EU-27 by type of treatment, (kg per capita), 1995–2015 [37].

5% of total municipal waste prepared for re-use), and also called on the Commission to examine the opportunity to set EU waste prevention targets. Furthermore, these amendments set stricter obligations for separate collection, removing Commission text that this should be carried out where ‘technically, environmentally and economically practicable’. The Parliament also urged the Commission to introduce a food waste hierarchy as well as to set binding food waste reduction targets.

The Parliament's amendments to the Landfill directive also call for a maximum of 5% of total MSW to be sent to landfills in 2030, compared to 10% in the Commission's proposal. The Member States are free to set even tighter targets.

Waste management planning is one of the key tools for authorities to convert the principles of EU waste legislation at national, regional, and local level within their Member State. The Member States' authorities are obliged to establish one or more waste management plans (WMP) pursuant to Articles 1, 4, 13 and 16 of the WFD. These must cover the entire geographical territory of the Member State concerned, set out an analysis of the current waste management situation, as well as the measures to be taken with respect to environmentally sound preparation for re-use, recycling, recovery and disposal of waste, and an evaluation of how the plan will support the implementation of the objectives and provisions of the Directive. The waste hierarchy is a good guideline to assess waste management options, particularly when waste management plans are being developed or reviewed at the national or regional level [38]. Any revisions of the WMP must be notified to the Commission, as they play a key role in identifying any gaps in the fulfilment of the requirements and objectives of the EU waste legislation. The European Commission can pursue legal action against the Member States for their failure to comply with waste management obligations under Article 258 TFEU. For instance, the Commission has issued final warnings to Romania for failing to review and adopt its national waste management plan and waste prevention programme, in line with the objectives of EU WFD and the circular economy. The Commission is also forewarning to take Slovenia to the Court of Justice for its alleged failure to close and rehabilitate 28 illegal landfills which represent a serious risk for human health and the environment [39]. The European Commission has also brought several infringement cases against Estonia concerning EU waste directives, including referral to the Court of Justice for incomplete or unreported transposition of the three directives: the Landfill Directive (Case C-195/10), the Mining Waste Directive (Case C-515/10) and the Directive on Waste Electrical and Electronic Equipment (Case C-528/09). These cases are closed now, except for a formal notice concerning the Directive on lightweight plastic carrier bags [40].

5. Waste-to-energy: is there a role of WtE in the circular economy?

One may argue that waste to energy can encourage wastefulness and discourage recycling to ensure regular feedstock to incinerators, which do not have a good reputation due to released toxins and greenhouse gases. Along similar lines, some NGOs, such as Zero Waste Europe (ZWE), declare that conceptually speaking WtE does not have a place in the circular economy as the material loops are closed when ‘there is nothing left to burn’ [41]. Yet, this conclusion is made solely in the context of waste to energy incineration. The European Commission in its recently published communication, which is meant to clarify the role of WtE in the circular economy, expressed that:

> “Waste-to-energy processes can play a role in the transition to a circular economy provided that the EU waste hierarchy is used as a guiding principle and that choices made do not prevent higher levels of prevention, reuse and recycling.” [6].

However, there is a rather sceptical view towards WtE, as the Commission is concerned that, by increasing WtE capacity, recycling will be jeopardised, hence undermining the waste hierarchy. Even though the Commission concludes that WtE could play a role in the transition to a circular economy, the waste hierarchy must be used as a guiding principle to ensure that prevention, reuse, and recycling are not averted. Most certainly, WtE plants meet the requirements set by the Industrial Emissions Directive [42]. In addition, the Commission notes that the Member States in their future waste management plans to invest in WtE must take into account the risk of “stranded assets” and new plants should only be built provided the availability of feedstock would be sustained for the operation of new incineration plants over their lifespan (20–30 years) without neglecting separate collection and recycling obligations [6]. Finally, the Member States are also advised to gradually phase-out public support for the recovery of energy from mixed waste and either introduce or raise incineration taxes. Therefore, the message from the EU is clear that the development of separate collection structures and recycling capacity (preferably in the form of anaerobic digestion) should be a priority.

While there is some scepticism towards WtE from a waste management point of view, there is a different story from a renewable energy point of view. As discussed above, biomass (which embraces the biodegradable fraction of municipal waste) is one of the renewable energy sources defined by the RED. Biomass is encouraged as a renewable energy source in the newest proposal of REDII. ‘Waste’ can cease to be a problem and become a valuable resource. The inclusion of the organic portion of MSW in the definition of potential sources of renewable energy has enabled the Member States to meet their national renewable energy targets via the WtE incineration industry. Statistically speaking, biomass and waste are the largest sources of ‘renewable energy’ in Europe amounting to 63.1% of the total share of renewable energy sources [43]. The Commission in November 2016 published the “Clean Energy for all Europeans” strategy called “Winter package”, where among eight legislative instruments, the Commission recommends setting a new target of at least 27% renewables by 2030 pursuant to REDII [44]. Yet, the Parliament has reiterated its request for a binding target of at least 30% of total energy consumption coming from renewable energy sources by 2030, combined with binding national targets. Therefore, biomass as a renewable source would enable the Member States to meet the constantly increasing EU energy target from renewables.

6. Waste hierarchy and technology: it is not about climbing the ladder

Even though not legally binding, the recent communication on the role of waste-to-energy in the circular economy highlighted that the recovery of energy from waste supports the EU objectives of the circular economy action plan and is firmly guided by the waste hierarchy. This document is very important since it is the first paper published by the Commission where some WtE processes were clearly assigned to various steps in the waste hierarchy, which is shown in Fig. 2 [6]. It is expected that these processes will be transposed into the revised WFD to have more credibility.

As can be seen, incineration with high efficient energy recovery is understood as waste recovery, but anaerobic digestion is considered as recycling. Regrettably, the communication sends a message that WtE should be avoided as much as possible leaving it to the stage where recycling is no longer possible. Additionally, it

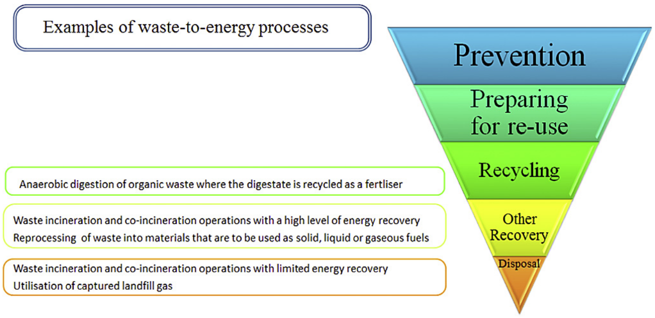

Fig. 2. Waste-to-Energy in the waste hierarchy [6].

provides some guidance to the Member States on how to improve use of economic instruments and capacity planning to avoid potential overcapacity of incineration infrastructure. Finally, the best available technologies and processes with high energy efficiency are also listed. The European Commission recommends several technologies, as follows:

- co-incineration in combustion plants: gasification of solid recovered fuel (SRF) and co-incineration of the resulting syngas in the combustion plant;
- co-incineration in cement kilns;
- incineration in dedicated facilities:
  - o the use of super heaters and heat pumps;
  - o the utilisation of the energy contained in flue gas;
  - o distributing chilled water through district cooling networks; and heat through low temperature district heat networks.
- anaerobic digestion with upgrading of the biogas into biomethane for further distribution and utilisation [6].

Pursuant to the waste hierarchy defined in the WFD, WtE can be attributed to either a 'disposal' classification or 'other recovery' depending of the level of energy recovered. The energy efficiency (EE) of the installation must be ≥ 0.65 for facilities in operation since 2009 and ≥ 0.60 for facilities in operation before 2009. The EE is calculated following the Equation (1)

$$EE = \frac{[Ep - (Ef + Ei)]}{[0.97 \times (Ew + Ef)]} \quad (1)$$

where

EE = Energy efficiency.
Ep = Energy produced (electricity or heat) in GJ/year.
Ef = Energy consumption as fuel in GJ/year.
Ew = Energy content of wastes in GJ/year.
Ei = Annual imported energy excluding Ew and Ef in GJ/year.

All Member States must follow this formula for their WtE plants classification while aiming to achieve a higher rank in the waste hierarchy.

6.1. Existing waste-to-energy technologies

A number of new market technologies, such as anaerobic digestion, pyrolysis and gasification, are in the process of being deployed. These technologies provide the potential to recover products from the waste stream which complete incineration would not allow and a significant proportion focuses on biomass waste.

Waste-to-energy technologies may be divided into three main groups based on the conversion process used: thermochemical, physicochemical, and biochemical. Modern technologies of thermochemical conversion include high-efficiency combustion, pyrolysis [45,46] or gasification [47]. Moreover, sanitary landfilling together with capture and utilisation of produced biogas is an important part of waste management, especially in developing countries [48,49]. Bioethanol produced from waste via fermentation also can be used to produce energy. The compilation of available WtE technologies is shown in Fig. 3 [50].

The heat generated by burning the waste should at a minimum be high enough to warrant proper combustion conditions and produce sufficient amounts of energy to overcome losses and auxiliary consumption. This is possible with a lower heating value of at least 4 MJ/kg. Modern waste-to-energy plants can export energy (usually heat and electricity) with very low environmental impact. A typical plant consists of four basic elements: combustor, recovery boiler, flue gas treatment system, and steam cycle. The hot gas generated in the combustor goes through the recovery boiler to produce steam, which can be used directly as a heat carrier or may be sent to a steam turbine to produce electricity. Finally, flue gases are treated by sorption and filtration [51,52].

The incineration of waste releases the energy fixed in them. However, to enable the transfer of energy to the circulating working medium, devices called boilers need to be used. Nowadays mainly two technologies are used in order to combust municipal waste: moving grate boilers and fluidized bed boilers [52]. The moving grate boilers constitute the vast majority – they are used in 87% of plants in Europe [47]. The technology is well known and investigated for a long time. For instance, this technology was chosen for all new-built WtE plants in Poland. The idea of such a boiler is shown in Fig. 4. A moving grate principle of operation consists in a slow movement of the processed waste in the layer, which is burned in subsequent phases as follows: drying, pyrolysis/gasification, combustion and burnout. The temperature of the gas resulting from the process has to be raised, after the last injection of combustion air, to 850 °C for two seconds (or to 1100 °C if hazardous wastes with a content of more than 1% of halogenated organic substances, expressed as chlorine, are incinerated) [53].

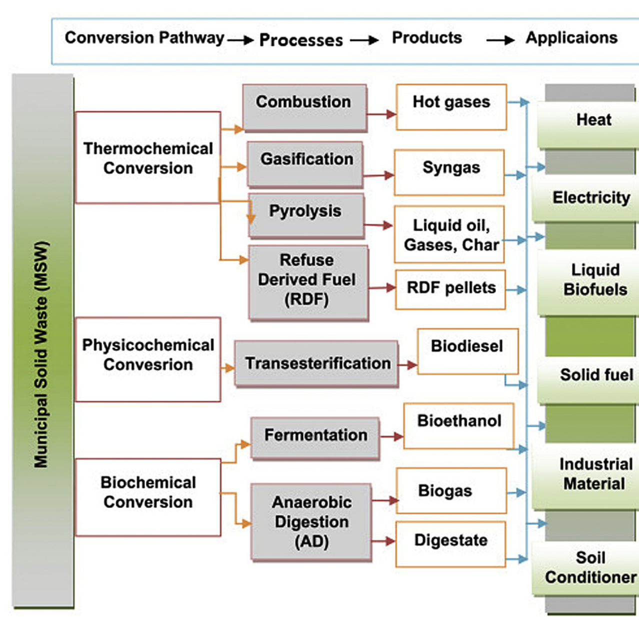

Fig. 3. Waste-to-Energy technologies based on applied conversion process [50].

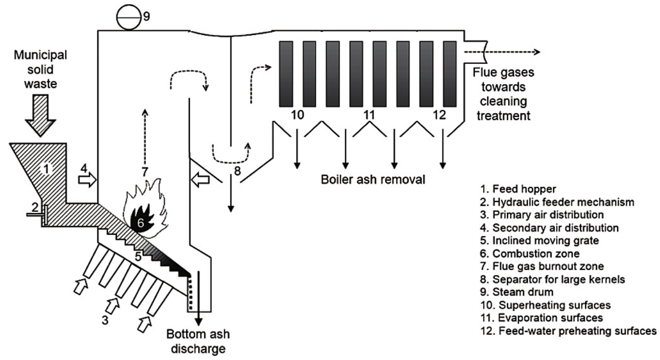

Fig. 4. Scheme of moving grate boiler for waste incineration [52].

7. Overview of MSW management systems in the selected Member States: the Central and Eastern European region

7.1. The Baltic countries: overview

The Baltic countries are regarded as small Member States of the EU with a population ranging from 1.315 million in Estonia to 2.88 million in Lithuania (as shown in Table 2). The population in Lithuania, Latvia, and (to a lesser extent) in Estonia is shrinking mainly due to migration [54]. Over a half of the population lives in the main cities in all three countries. The three Baltic countries joined the EU in 2004. In early 1990s the waste sector in all three countries was poorly developed with heavy reliance on landfilling, over 90% of waste was sent to landfills. The collected waste was dumped in uncontrolled sites which fell well short of EU environmental standards.

EU membership has brought significant changes in all Baltic states: their waste management systems had to be built from scratch mirroring the EU legal framework and policies. At the outset, the priorities in their first national waste management plans were to close old dumpsites and to rebuild new landfills that would meet EU standards, to abolish the Soviet-era regulatory system, and to create the facilities and infrastructure for recycling and composting. For instance, since regaining its independence Lithuania has closed over 840 landfills and dump-sites. Equally, in Latvia the number of waste dump-sites for municipal waste/household waste has decreased from 558 in 1998 to 99 sites in 2006. Waste incineration as a treatment method was excluded because it was regarded to be too costly for the Baltic countries [55]. Despite its lowest priority pursuant to Waste management hierarchy, landfilling has been the predominant method for MSW management in all three Baltic countries.

Even though the Baltic states are quite often portrayed as one unit due to their similar past experiences of being part of the Soviet Union and having small market economies, they are far from similar, especially in their development of waste management. In contrast to Latvia and Lithuania, the waste management system in Estonia is more advanced; alongside Belgium and Slovenia, Estonia is now taking a lead and topping the EU league tables in terms of waste avoidance and recycling in the capital cities (based on 2012 Eurostat data). In 2015 Estonia generated the smallest amount of municipal waste in comparison to Latvia and Lithuania (as shown in Fig. 5 [56]). MSW generation in all Baltic states is below the EU average of 476 kg/per capita. All these countries have seen a decrease in their generation of waste in 2008–2009 linked with the economic and financial crisis. While MSW generation has been stable in recent years in Estonia, the same cannot be said about Latvia and Lithuania. In both countries MSW generation is increasing, failing to achieve the waste prevention objective.

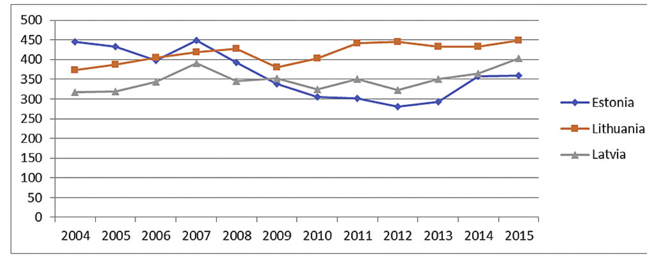

Fig. 5. Waste generation in Baltic countries per capita (2004–2015) [56].

7.1.1. MSW management and organisation: Estonia

The Ministry of Environment of Estonia (MoE) is responsible for the waste management policy and implementation of the EU legislation into national law, as well as practical enforcement in Estonia. Yet, local authorities are in charge of organising the collection, transport, recovery, and disposal of municipal waste for their corresponding administrative territory under the Waste Act [57–63]. In 2007 Estonia moved from a three-tiered (National, County and Municipal) system of waste management to two tiers, National and Local pursuant to the Waste Act, in order to give more responsibilities to the municipalities and stimulate them to pool their resources and strengthen their human and financial capacities for better waste management activities [61]. Municipal waste is defined as "waste from households, and waste produced in trade, provision of services or elsewhere which because of its composition or properties is similar to waste from households." [63]. Household municipal waste is collected and transported by a waste management company, chosen through public procurement [64]. It has been noted that many municipalities (especially small ones) lack capacity and resources to manage tenders effectively and more generally to ensure proper waste collection [65]. There have been contrasting proposals for a reform of waste management that have created uncertainties; the previous government called for a complete removal of the municipal role in organising waste collection, whereby each household would have had a freedom to contract a waste collector, but this was not pursued by the government that took office in late 2016 [40].

Unlike the other Baltic countries, Estonia has had a major transformation of its MSW management system: a shift from predominant reliance on landfilling to a high level of energy recovery [65]. While construction of an incineration plant in 2013 and several MBT facilities has led to a drastic reduction of landfilled municipal waste (from 14% of the total waste in 2013 to 8% in 2014, and 5% in 2015), simultaneously incineration of municipal waste has amplified dramatically from 16% in 2012 to 56% in 2014, becoming the main municipal waste treatment option [66] and reaching overcapacity by 2015. The introduction of a landfill tax in 1990 has also contributed to the diversion of waste from landfills. The rate of the landfill tax depends on the type of waste, where the Environmental Charges Act establishes that increased rates for environmental charges are applied if waste is landfilled in quantities larger than permitted (if these limits are exceeded, then every disposed tonne over the limit will incur a charge of 5–500 times more than the standard fee, depending on the category (hazardousness) of waste) [55]. Furthermore, in 2008 [67] Estonia also introduced a ban on the landfill of unsorted municipal waste with basic requirements to the municipalities for organising source separation of paper and cardboard, green garden waste and hazardous waste, as well as packaging waste, through the public collection system.

For Biodegradable Municipal Waste (BMW), the National Waste Management Plan (NWMP) gives a general priority to separate bio-waste from mixed MW; the NWMP suggests separate collection of garden waste in cities.

Fig. 5 depicts that Estonia has moved from generating the largest share of waste in 2004, namely 445 kg/per capita to the lowest (359 kg/per capita) in 2015 in comparison with the other two Baltic states. Since 2008, while using EU and domestic funds municipalities have built about 100 collection points across the country for recyclables, garden and park waste, household hazardous waste and electrical and electronic equipment. Therefore, recycling of MSW in Estonia has been increasing with some variations as shown in Fig. 6 [56]. For instance, Estonia has significantly increased recycling from 18% in 2013 to 31% in 2014, while composting has remained at the same level of 6% [66]. Tallinn, (the capital of Estonia) has the most advanced scheme for recyclable waste, providing containers for recyclable waste near residential buildings. As a result, Tallinn reached a separate collection rate of 53% for all municipal solid waste in 2012, the third highest among EU capital cities: 85% of glass and 74% of paper waste were collected [65]. Yet, it has been acknowledged that a lack of information on actual waste composition is one of the main barriers to waste management planning (planning of recycling and energy recovery potential) in the Baltic States [47].

Similar to other Member States, Estonia has producer responsibility schemes on packaging waste. Yet, cooperation of private operators of these schemes with municipalities is quite often limited: therefore, they do not always provide data on the sources of the packaging waste. This, in turn, means that packaging waste is not always reported to Eurostat as MSW. Given that Estonia has excluded all or part of the packaging waste from households and similar packaging waste from other sources in its reporting of recycled MSW, the actual percentage of recycling could be higher than stated. For instance, Eesti Pandipakend OÜ (EPP) is an accredited deposit organisation established to organise the collection and recovery of packaging subject to the payment of a deposit, and is the only operator for Estonia's deposit refund scheme, which has been very successful, with close to 90% of PET and glass bottles returned, and 70% of metal cans in 2015 [40]. In its current National Waste Management Plan (NWMP 2014–2020) Estonia places an emphasis on further reduction of landfilling and the promotion of recycling: the NWMP highlights the need to meet the EU's 2020 targets to recycle at least half of four key household waste streams – glass, metal, paper, and plastic [40].

Even though recycling has progressed in Estonia, especially in Tallinn, Estonia has yet to meet its EU target. Since most of the local authorities in Estonia are rather small, they lack competence and resources to fulfil their waste management responsibilities. It has been noted that the waste management co-operation of local governments is still weak [55]. Therefore, the European Commission (DG Environment) called for stronger local government oversight of waste management as well as the introduction of taxes on MSW sent to incineration and to MBT facilities to create stronger incentives for recycling. There is also a need to improve a good co-operation between the public and private sectors in order to secure sufficient separate collection schemes and treatment capacity. Estonia is required to establish a stable long-term strategy-driven institutional framework to move towards a circular economy. Finally, strengthened data gathering and information systems for waste management and the monitoring of the potential impacts of existing and former waste sites are also among further challenges for Estonia [65].

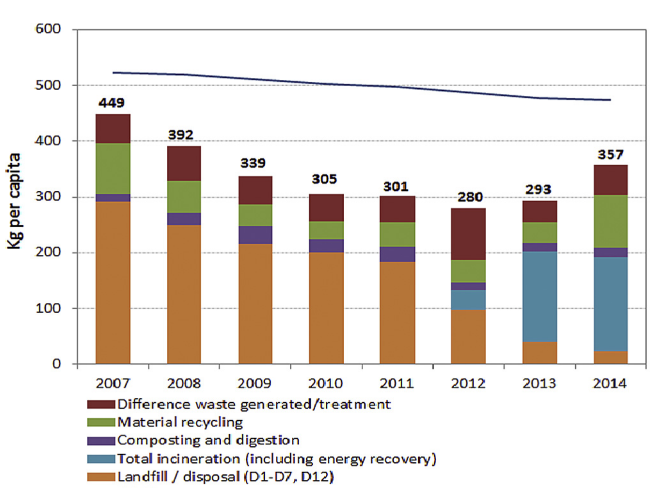

Fig. 6. MSW treatment in Estonia (per capita) [56].

7.1.2. MSW management and organisation: Latvia

The first Waste Management Law in Latvia was adopted in 2001 with the first National Waste Management Plan being implemented in 2002 before Latvia joined the EU. The Waste Management Law ("Atkritumu apsaimniekošanas likums") [68] implemented in 2010 is the main legal act transposing the requirements of the WFD into domestic law. This law provides that "municipal waste [is] waste produced in a household, trade, in the process of provision of services or waste produced in other places that because of its properties is similar to domestic residues". The Ministry of Environment in Latvia is responsible for the implementation of a legislative framework for waste handling; creating institutions and defining responsibilities; developing waste management strategies; setting targets for single waste streams and, at the same time defining measures for the continuous improvement of system [69]. In Latvia, policy planning regarding waste management is carried out at national and regional level with municipalities having responsibility for the procurement of MSW management services.

Fig. 5 shows an increase in waste generation in recent years (reaching 404 kg/per capita in 2015), thus, lagging just behind Lithuania. In contrast to Estonia, the main treatment option of MSW remains disposal in landfills. Fig. 7 demonstrates that in 2014, Latvia landfilled a big proportion of municipal waste (notably, 79% in 2014, only a slight drop from 83% in 2013) [70]. Fig. 7 does not reflect all municipal waste generated in Latvia. Even though a landfill tax was first introduced in Latvia in 1991, it was negligible. The increase in the landfill tax after 2008 has not resulted in a significant reduction in the amount of MSW landfilled. There are 11 active landfills operating in Latvia [71]. Recycling of municipal waste increased only slightly from 17% in 2013 to 21% in 2014, while composting of municipal waste in Latvia dropped from 6% in 2013 to 4% in 2014 [70]. Even though recycling has increased in Latvia (mainly driven by material recycling), its total recycling rate of MSW is still very low and unlikely to meet the EU set targets. Similar to the situation in Estonia, the lower recycling rate of MSW can be explained by the unavailability of the data of recycling packaging waste from producer responsibility schemes who fail to report their recycling of MSW [71]. Therefore, MSW recycling rates would be higher if some of the recycled packaging waste from MSW sources would be included systematically in the reporting of recycled MSW. Incineration of MSW in Latvia accounts for only a negligible fraction of MSW treatment. There is also uncertainty with regard to MBT. While some countries allocate the total amount of MSW sent to MBT, others include only the actual amount of recycled material recovered in the MBT, and not the waste material that is subsequently sent to landfill or incineration. There is currently no information available on which method Latvia uses for

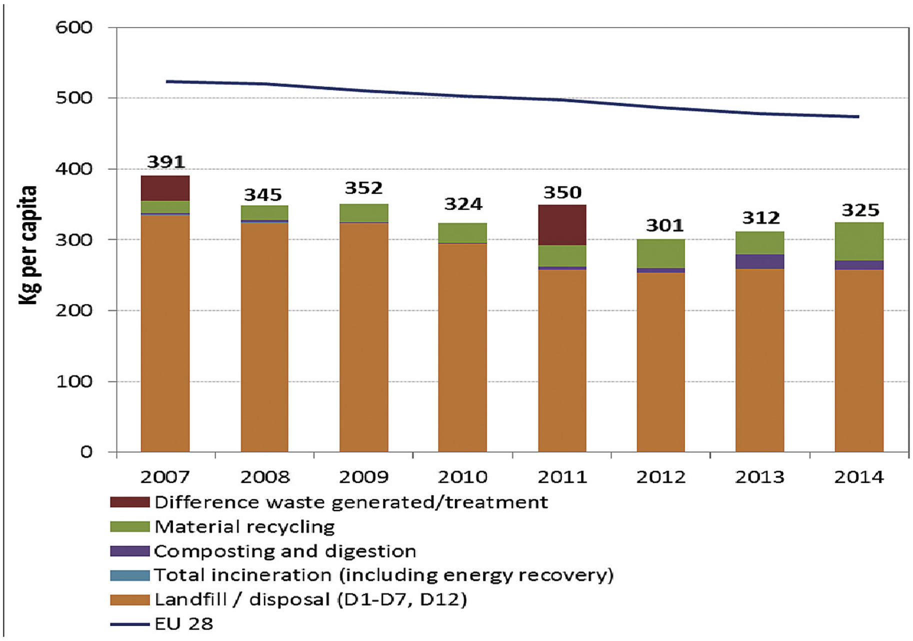

Fig. 7. MSW treatment in Latvia (per capita) [56].

the reporting of MSW treatment to Eurostat related to the material treatment at the MBT plant [71].

The priorities of the current National Waste Management plan of Latvia for the period 2013–2020 are on the prevention of waste generation with a further exploration of waste as a resource, as well as reducing the volumes of landfilled waste. These are in line with the principles of a circular economy. The separate collection of household waste has been identified as one of the planned waste management methods. From 2015 municipalities had to establish a system for separate collection of paper, metal, plastic, and glass waste, (which include both door-to-door collection and containers in publicly available places, as in Latvia they are not observed separately) [72]. Separate collection of some specific waste types (e.g., WEEE, batteries, end-of-life vehicles, packaging) are facilitated by producer responsibility systems implemented through a natural resource tax (i.e. which, *inter alia*, is directed at promoting efficient use of natural resources, limiting environmental pollution, reducing production and sales of products that are harmful to the environment, as well as encouraging the implementation of new environmentally friendly technologies). The European Commission has noted that Latvia, *inter alia*, must put in place an infrastructure to improve the performance of its waste management system in order to meet current EU waste targets, in particular separate waste collection, administrative and regulatory measures to facilitate recovery, including composting, and the introduction and gradual increase in landfill taxes to phase-out landfilling of recyclable and recoverable waste [70].

7.1.3. *MSW management and organisation: Lithuania*

The first Law on Waste Management (Lietuvos Respublikos atliekų tvarkymo įstatymas) was adopted in 1998 [73] in Lithuania and established the basic requirements for prevention, record keeping, collection, sorting, storage, transportation, recovery, and disposal of waste with a view to prevent its negative effects on the environment and human health [74,75]. Municipal waste is defined as household waste or commercial, industrial waste, which by its nature and composition is similar to household waste [73]. Even though the waste management strategy and national plans are set by the Ministry of Environment, which is also responsible for the implementation of EU legislation and administration, municipalities are the main institutions responsible for organising municipal waste management, with the main responsibility of creating effective waste management systems. Local authorities are also responsible for reaching EU targets regarding recycling and recovery - apart from some waste streams (WEEE, packaging, batteries and accumulator waste) which are managed by Extended Producer Responsibility schemes.

There are 10 regional waste management systems created in Lithuania (i.e. Alytus, Kaunas, Klaipėda, Marijampolė, Panevėžys, Šiauliai, Tauragė, Telšiai, Utena, and Vilnius) with regional waste management plans being prepared in all 10 regions. Municipal waste management plans and municipal waste management rules are developed and approved at the municipal level [76].

Lithuania generates the largest proportion of MSW in the Baltic countries, which is slightly below the EU average (448 kg/per capita compared to around 476 kg EU average based on 2015 data), as shown in Fig. 5. Initially, not all of Lithuania was covered by a municipal waste collection scheme; approximately 80% of the population was covered in 2007, rising to 94% in 2010, and to 98% in 2016 [77].

Even though Lithuania decreased the amounts of municipal waste landfilled in 2014 compared to 2013 (64% in 2013, 60% in 2014, 55% in 2016) [76], similarly to Latvia, most of municipal waste in Lithuania is still landfilled. This is because landfilling is regarded as the cheapest option (the most economically favourable option for treatment) without any evaluation of its impact on environment. Lithuania introduced a landfill tax only in 2016. In its current National Waste Management Plan (NWMP) 2014–2020 Lithuania is committing to reduce MSW sent to landfill down to 35%.

As shown in Fig. 8 recycling of municipal waste has slightly increased in 2014 compared to the year before (reaching 31% in 2014). Even though Lithuania met the packaging waste recycling target in 2012, in 2013 the recycling rate decreased from 62.2% in 2012 to 53.5% in 2013 placing it below the target of 55% [75]. The European Commission reported that Lithuania did not fulfil the 2010 target for biodegradable waste diversion from landfills (to no

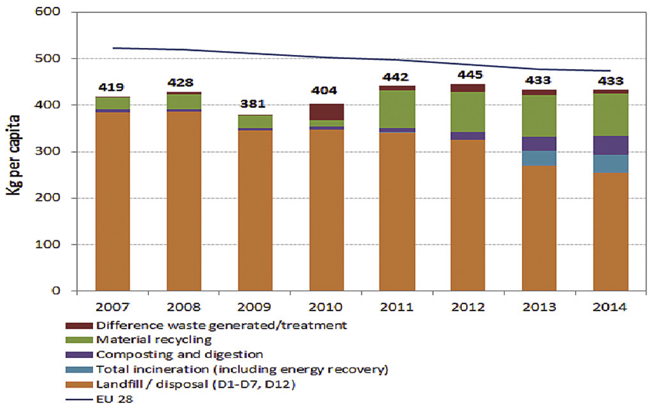

Fig. 8. MSW treatment in Lithuania (per capita) [56].

more than 85% of 1995 level) [78]. Nevertheless, Lithuania has reduced the amount of biodegradable municipal waste being sent to landfill to 55% by 2012 [75]. Composting has also slightly increased from 8% in 2013 to 10% in 2014 (still below the EU average of 16% in 2014). The modest progress in recycling operations in Lithuania can partially be attributed to a lack of landfill tax and the low landfilling fees [79], which hinder the development of recycling operations [80]. Similar to Estonia and Latvia, Lithuania does not include packaging waste in reporting to Eurostat on the recycling of MSW. Due to the specificity of national waste statistics, Lithuania could not identify which part of the separately collected packaging waste was generated by households and which by industries. Similarly, the amount of packaging waste collected by municipal waste collecting systems also could not be named [80]. Provided a certain proportion of the recycled packaging waste from MSW sources was reported as recycled MSW, the distance to meeting the MSW recycling target of 50% by 2020 would be smaller. To improve collection of secondary raw materials and packaging waste, the Ministry of Environment allocated substantial amounts under the Product or Packaging Waste Management Programme for the purchase of containers (the so-called "bells") and distributed them to municipalities. During the 2006–2011 period, 19700 containers for collecting secondary raw materials were acquired and distributed [79]. Yet, in the NWMP plan 2014–2020 discussing the SWOT analysis of MSW management, the Ministry of Environment as its weaknesses identified no proper oversight of waste management in some municipalities; it is economically more viable for waste operation companies to send waste to landfills than recycle, or recover energy.

EU structural and investment funds are an important source of funding to improve the waste management system in Lithuania. For instance, in 2007–2013 190 million EUR were invested into waste management projects, including construction of 9 regional mechanical and biological waste treatment plants, remediation of 340 old landfills/dump-sites, construction of numerous bulky waste collection and green waste composting sites, extension of separate waste collection systems. Further 87,2 million EUR investment from the Cohesion Fund is planned for the 2014–2020 period to support further development of the separate collection of waste, modernisation of capacities to prepare waste for recycling, reuse, or other recovery (sorting lines, other equipment), and modernisation of the waste management information system and monitoring [75]. Apart from allocating funds to the separate collection of waste, the European Commission further recommended that Lithuania should also gradually increase landfill taxes to phase-out landfilling of recyclable and recoverable waste and avoid building excessive infrastructure for the treatment of residual waste (the existing incinerating facilities could treat approximately 30% of municipal waste) [75,78].

7.1.4. *Waste-to-energy in the Baltic countries*

At the outset, all three Baltic countries focused on closing old landfills and building new ones to meet EU standards. While initially largely relying on fossil fuel, the Baltic states are aiming to produce energy from renewable energy sources as required by the EU regulations. Even though biomass is largely used as a renewable energy source, it consists mainly of wood and wood waste since most of the land in all three countries is forested. For instance, the combustion of wood and wood wastes is a common energy recovery technology in Latvia according to the Central Statistics Bureau of Latvia. Overall, the recent study in Lithuania revealed that the energy produced from renewable energy sources is more expensive if compared to conventional fossil energy or the relative initial investment in renewable energy technologies are higher than investments in traditional fossil fuel technologies [81].

Speaking of MSW, initially there were limited options for the recovery of energy from waste in the Baltic countries, as traditional incineration plants were considered to be too expensive for the Baltic countries, even with the EU financial support available [82]. Yet, over the past years, thermal treatment of municipal waste has been discussed more intensely in these countries as one of the waste management options that could enable them to reach the legal targets in a relatively short time [83]. The first WtE facility owned by 'Eseti Energia' AS (a public company) in the Baltic states was built in Estonia, which started its operation in 2013 at the Iru thermal power plant. The WtE facility was planned for a capacity of 220 000 t/y (MSW) and generation of 138 GWh/y electricity and 320–400 GWh/y heat. It was also tested to meet R1 EU classification [84]. This plant has been successful, as waste sent to landfills was significantly reduced in Estonia in recent years as previously discussed. This option is also more economically viable, as it is cheaper to reuse waste in order to produce energy than depositing it in landfills in Estonia.

According to the Estonian Environment Agency's information from the waste reporting information system (JATS), 395,516 tons of garbage were collected in Estonia in 2015, while Eesti Energia's Iru Power Plant burned a total of 245,000 tons and other recyclers nearly 160,000 tons of garbage. This meant that Estonia reached overcapacity: Iru Power Plant's boiler needed constant heating, and the missing amount of waste was imported, which has gradually turned Estonia into a significant importer of waste. In 2015 Estonia imported over 56,000 tons of waste, primarily from Finland and Ireland [85].

The issue of the potential environmental impact from energy recovery from municipal waste (in particular, mass incineration) has recently been raised repeatedly in Estonia. The opinion has also been expressed that the success in diverting waste from landfill to primary energy recovery can have a negative impact on separate collection and recycling schemes for MSW, putting Estonia at risk for not meeting the 50% recycling target for MSW.

In contrast to Estonia, in Lithuania there has been a negligible amount energy recovered from waste as revealed in Fig. 9. The current Klaipeda CHP with a capacity of supplying 20 MW of electricity and 50 MW of heat uses municipal and industrial waste as well as biomass as feedstock and delivers district hearing to the residents and businesses in Klaipeda and electricity to the Lithuanian power grid. It employs Alstom's NID flue gas cleaning equipment, where the NID system is a semi-dry flue gas desulphurisation system that uses advanced technologies for multi-pollutant control and zero-waste water discharge [86]. However, the current NWMP 2014–2020 has plans to expand WtE plants in Lithuania with two

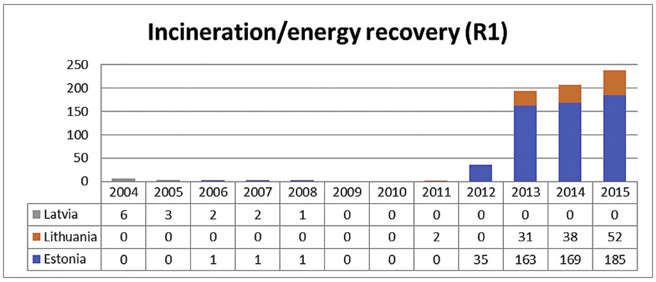

Fig. 9. WtE incineration and energy recovery in the Baltic countries (kg/per capita) [56].

new CHP plants in Vilnius and in Kaunas with a combined incineration capacity of municipal waste of 360,000 t/y [75]. In Lithuania, the incineration industry is controlled by the state; there is a condition that the Lithuanian state energy group Lietuvos Energija must own at least 51% of the market shares in any WtE plant. For instance, Lietuvos Energija has 100% control over the first CHP plant - Vilnius Kogeneracine jegaine (VKJ), which consists of two units: Bio CHP unit with a planned capacity of 70 MWe and 174 MWt and a WtE CHP unit (with the capacity of 18 MWe and 53 MWt). Vilnius CHP was partly funded by the EU (164 m EUR) and should be completed before the end of 2018. The second CHP plant belongs to the joint venture Kauno Kogeneracinė Jėgainė (KKJ), which is jointly owned by Lietuvos Energija (with 51% of Kauno Kogeneracinė Jėgainė shares) and Fortum Heat Lietuva, which has 49% of the shares. This plant would process 200,000 t/y of MSW to produce heat for the Kaunas city district heating network (70 MWt and 24 MWe). This WtE plant is estimated to decrease the CO_2 emissions by 65,000 tonnes per year. The plant marks Fortum's second WtE CHP plant in Lithuania, as the company commissioned the country's first facility of that kind, a 20 MW plant, in Klaipeda in 2013. Fortum has also invested in new CHP plants in Finland, Sweden, Estonia, Latvia, Lithuania, and Poland over the past few years [87]. The power plant construction activities should start at the end of 2017 and commissioning is expected in the middle of 2020. The European Commission expressed the view that the construction of two additional CHPs is likely to lead to municipal waste incineration overcapacity (i.e. Lithuania plans to incinerate 30% of its municipal waste). However, unlike in Estonia, Lithuania's NWMP specifically forbids any imports of waste to Lithuania for the purpose of energy recovery [76].

While Lithuania is about to build two new WtE plants in order to reduce its waste being sent to landfill (to meet the Landfill Directive requirements) [88], it is not clear the extent to which the Commission's recommendation of avoiding the building of excessive infrastructure for the treatment of residual waste is being followed. Given that all Baltic countries have small markets with decreasing and ageing population, it is doubtful whether Lithuania will have enough feedstock for its plants.

There is currently no infrastructure for waste incineration in Latvia [88]. The development of WtE for municipal waste (such as mixed municipal waste) in Latvia is limited due to a lack of available appropriate technology. Even though such limitations provide large opportunities for research and technological improvements, in Latvia there is a lack of research and development of innovative WtE technologies that are adjusted to local conditions. Beloborodko et al. [89] report that this restriction may be offset by improving the cooperation of stakeholders in this sector through development of efficient WtE clusters. Potentially, the COOLSWEEP project mentioned in Section 1 will produce some fruitful results in the future.

7.2. MSW management in Poland

7.2.1. Poland: overview

Poland's waste legislation was introduced before entering the EU in 2004 [90]. Currently, municipal waste management is regulated by the following Acts: Act on Keeping Cleanliness and Order in Municipalities [91], Environmental Protection Law [92]; Act on Obligations of Businesses in Management of Certain Wastes and on Product Fees [93]; Act on Waste [94]; Act on Packaging and Packaging Waste Management [95]. The definition of municipal waste is provided in the Act of 14 December 2012 on Waste, which includes household waste (except, end-of-life vehicles), as well as non-hazardous wastes produced in other places, which by their nature or composition, are similar to household waste [94]. Waste management in Polish law means waste generation, collection, transport, and treatment of waste including the supervision of such activities. The Act on Keeping Cleanliness and Order in Municipalities [91] obliges the municipalities to organise an efficient system of collection, transportation and treatment of municipal waste.

In 2015, 10.9 million tonnes of municipal waste were generated (282 kg per capita as in Fig. 10 [96–98]), which was about 8% of all waste produced in the country. The municipal waste production is related to individual consumption, which depends on lifestyle. Contrary to expectations, with the increase in consumption there has been a decrease in the amount of municipal waste collected in recent years. In 2005, about 12.2 million tonnes of municipal waste was generated; in 2014, it was 10.3. However, until 2004 the causes for progressive decline in the quantity of waste collected were, *inter alia*: a) a lack of sufficient equipment for weighing waste at landfills, only 32% of them had scales; b) avoidance by owners of properties signing contracts with companies responsible for the collection of waste, which resulted in the discarding of waste on illegal dumps or disposing in inappropriate household conditions (e.g. burning); c) insufficient control by the municipalities; d) declining in the weight per volume in time between waste collection and weighting [99,100]. In Poland, solid fuel boilers are very popular. Unfortunately, many citizens are tempted to burn garbage in them. This practice is justified, because of the relatively high cost of coal (about 150 €/tonne). From the average user's point of view, burning waste offers “free” heat and a solution of the rubbish problem without taking into consideration any effect on the environment and human health [101]. Since the Act on Keeping Cleanliness and Order in Municipalities significantly changed in 2012, the amount of waste generated and collected is considered to be the same, because all inhabited real estates were covered by a waste collection system [91]. It can be estimated that the sealing of

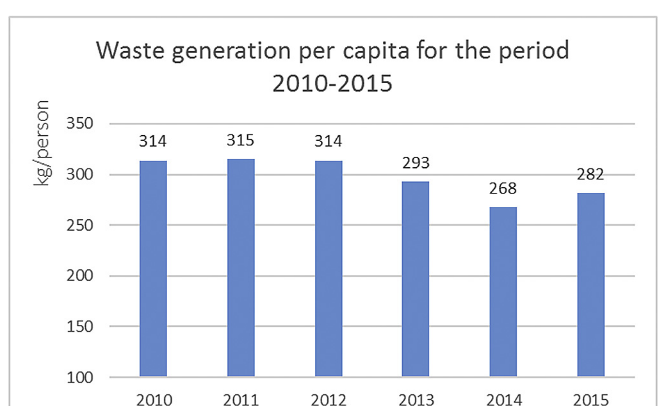

Fig. 10. Waste generation per capita in Poland [96–98].

the municipal waste management system and the elimination of existing gaps should increase the amount of municipal waste produced in Poland by approximately 30%, to the level of about 14–15 million tonne per year [101].

There are significant differences in the composition of municipal solid waste generated in individual areas of the country. Studies on waste composition have been conducted mainly in big cities such as Warsaw, Wrocław, Kraków, Poznań etc. However, some research has also been carried out on the waste from smaller towns and in rural areas [102]. The last comprehensive study of the morphological composition of municipal waste in Poland was made in 2008. Consequently, the composition of municipal waste for 2008 was determined as the most representative of the country in the latest Waste Management Plan 2022 [103]. The most important differences in the composition of waste produced in big cities, smaller towns and in rural areas are shown in Table 4 [104]. In big cities, there is more paper and plastics in municipal waste stream, whereas in rural areas, more kitchen and garden waste, and a fine fraction appears. It should be mentioned, that other factors such as the season or size of households also can significantly influence the content of individual components. For example, in winter in rural areas, the proportion of the fine fraction of waste can be even higher due to the ash generated by burning solid fuels in household boilers.

In 2015 the Chief Inspectorate of Environmental Protection issued 130 permits for imports of waste into Poland from EU countries with a total weight of 253,000 tonnes and 21 permits for imports of waste from other countries with a total weight of 40,000 tonnes. The largest amount of waste imported to Poland came from Germany (30 permits) and Lithuania (24 permits). On the other hand, in the same year 194,000 tonnes of waste was exported from Poland, mainly to Germany [96].

7.2.2. MSW management and organisation: Poland

2479 municipalities are responsible for the organisation of waste management systems in their administrative territories. The Supreme Audit Office inspected the implementation of the new municipal waste management system in municipalities. In 2013 2478 Polish municipalities organised systems of the selective collection of MSW; one municipality did not do this. However, these data also applied to municipalities that have established a two-bin (“dry” and “wet” waste) municipal waste collection system, which, due to its low efficiency, raises doubts as a system for selective collection of municipal waste [103,105]. Some municipalities did not organised Points of Selective Municipal Waste Collection despite such an obligation. Yet, all controlled units obtained required levels of recycling of particular types of MSW. The municipalities can receive a fine for a failure to organise the tender for municipal waste collection. Some municipalities failed to implement the principle of balancing the income from fees and operating costs of the waste management system. The amount of tax was often overestimated in relation to the costs of waste management systems [106]. The waste tax cannot exceed 29.5 PLN per person per month in 2017 (the waste fee may not be higher than 2% of monthly disposable income). In fact, the average amounts paid by citizens are much lower. Additionally, the rate of the waste tax depends on whether the waste is segregated or not; and the fee can be doubled for collecting mixed waste. This motivates residents to separate waste.

The audit also revealed, that the problem of illegal dumps is still unresolved. Unfortunately, the Act on Keeping Cleanliness and Order in Municipalities allows for a joint tender for the collection and disposal of waste, which prevents the municipality from controlling the waste stream entering the local waste disposal plant. Additionally, companies receiving waste from residents can receive a lump-sum payment in proportion to the amount of waste. In both cases, reducing the waste stream ending in the local waste disposal plant obviously boosts the company's income [101]. Some dishonest entrepreneurs use this situation and get rid of waste illegally.

The main form of municipal waste management in Poland is still landfilling. However, the tremendous efforts and financial inputs in the waste management sector have made significant changes [90]. In 2015 347 controlled landfill sites for municipal waste were operated with an area of over 1850 ha. Additionally, about 246 ha was occupied by 74 non-operational landfill sites. However, almost 150 ha of these landfill sites was reclaimed during the year [96]. As can be seen in Fig. 12, about 4.8 million tonnes of municipal waste was landfilled, which was about 44% of all collected MSW.

Recycling is the most favourable of method of waste treatment and means reprocessing of substances or materials included in waste in order to obtain elements for original or other designated usage [94]. Fig. 11 reveals the recycling rates obtained by Poland in recent years [107]. The country is gradually approaching the average EU level. It should be mentioned that these statistics include material recycling, composting and the anaerobic digestion of waste.

Fig. 12 shows the changes in waste management in recent years. There is a gradual decrease in the amount of waste disposed in landfills, while recycling and the recovery of waste is increasing [96–98,108–110]. This trend is very promising and Poland will probably achieve the required recovery and recycling rates by 2020, which are specified in the Regulation of the Minister of Environment of 14 December 2016 [111] and shown in Table 5.

Table 4
Composition (%) of waste in the cities, towns and rural areas [104].

Waste component	Region		
	Cities	Towns	Rural areas
Kitchen and garden waste	28.91	36.68	33.09
Paper and cardboard	19.09	9.59	4.98
Plastics	15.18	10.97	10.26
Glass	9.97	10.25	9.99
Waste from green areas	5.34	5.29	2.61
Fraction <10 mm	4.2	6.84	16.85
Mineral waste	3.16	2.82	5.92
Metals	2.67	1.54	2.43
Bulky waste	2.59	2.6	1.28
Composite waste	2.46	3.95	4.09
Textiles	2.28	4.02	2.14
Hazardous waste	0.75	0.64	0.81
Wood	0.23	0.29	0.65
Other	3.16	4.51	4.9

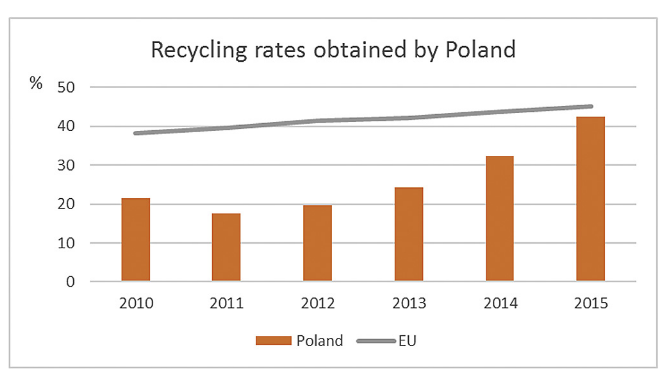

Fig. 11. Recycling rates (%) required and obtained by Poland [107].

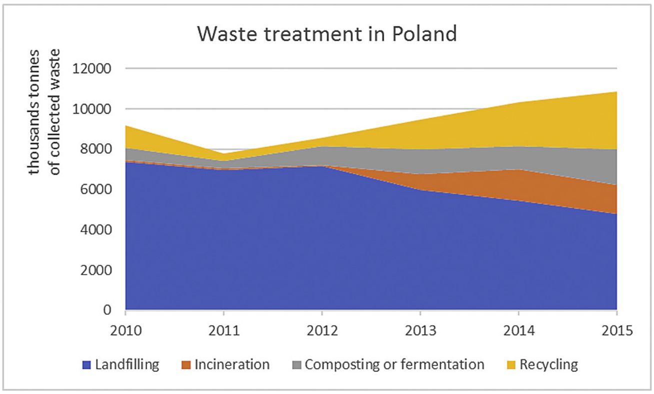

Fig. 12. Waste treatment methods in Poland for the period 2010–2015 [96–98,108–110].

With regard to the management of biodegradable municipal waste, it was agreed, that in 2020 the mass of such waste directed to landfills should not exceed 35% of the mass biodegradable waste, which was produced in 1995. In this reference year 4.38 million tonnes of biodegradable MSW was produced in Poland. The required mass reduction level of landfilling this waste was achieved in 2014, in which about 1.53 million tonnes of this waste was landfilled [103]. It is recommended, that the amount of separately collected biodegradable waste should increase. Moreover, municipalities promote the development of home composters on single-family housing areas. In practice even more biowaste than reported is selectively collected and utilised, but there is no detailed data about home-composting in Poland.

The latest National Waste Management Plan 2015–2022 outlines the main objectives for municipal waste management, which include among others: a) reduce waste generation and improve public awareness of proper waste management; b) achieve the assumed levels of recovery and recycling for particular types of waste; c) increase the proportion of waste collected selectively by covering all residential properties with a system of selective collection of municipal waste; d) stop disposal (storage) of biodegradable waste selectively collected and mixed municipal waste without treatment [103]. Waste prevention must be implemented on a wider scale. Proposed solutions include the reuse of items, eco-design and creating of food banks. It is suggested, that at Points of Selective Municipal Waste Collection (PSZOK in Polish) points should be created for exchanging or repairing used items. Additionally, the network of food banks will be responsible for gathering and distributing food with short expiry dates [103]. A charge for disposable plastic bags was also introduced and a deposit for glass bottles. However, in practise those two solutions are only partially successful. The charge is usually very low and does not effectively motivate consumers to use their own bags. Additionally, the deposit applies only to specific types of glass bottles and sometimes shops require a receipt to return the fee. The automatic machines that allow the return of different packaging, which are popular in other countries, seem to be a much more effective solution. Green public procurement and the promotion of reusable materials and double-sided printing also reduces waste generation especially in offices. Recently there have been some initiatives to create locations next to the PSZOK points, where used items can be left or repaired for reuse. In Poznań, such points were created within the program 'Transwaste' [112]. Unfortunately, waste prevention in Poland still needs much effort – especially in education - to give clear and measurable results. To conclude, the main problems of waste management in Poland are due to an unsealed system of MSW collection; burning of waste in home boilers; and insufficient education in term of waste management and waste prevention.

7.2.3. *Waste-to-energy in Poland*

There is no doubt that municipal waste that needs to be disposed of cannot be avoided completely. There will always be some residual waste. The Polish government regards WtE as an important and necessary step from landfilling towards higher levels in the waste hierarchy. The aim is to maximise the amount of energy recovered from residual waste [113]. In addition, Poland is obliged to obtain 15% of its energy from renewable sources, including waste, in the gross final consumption of energy in 2020 [114]. It can be estimated that about 50% of energy produced from waste may be consider as renewable. This is really important from the Polish government point of view, because WtE recovery will become an important part in the Polish "green" energy market, especially in terms of heat production [115]. In recent years, the proportion of energy from waste in the production of renewable energy was below 0,5% [116].

Until the end of 2015 there was only one waste incineration plant in operation in Poland, located in Warsaw. The processing capacity of the plant is about 60 000 tonne per year, which is definitely too low to cover the demand of the capital city [103]. Therefore, the operation of one waste incineration plant does not influence the waste management sector in the whole country. The deficiency in municipal waste incineration plants in Poland is surprising, because even at the beginning of the 20th century such plants were in operation. Since the 1960s Western European countries had started to build WtE plants on mass scales, while in Poland the first modern incineration power plant was finished in 2000 [115]. There are at least two possible reasons for this situation. First, a WtE plant is a very expensive investment. The costs are estimated to be three (or more) times higher than for waste landfilling per tonne [117]. Secondly, there is a clear opposition from local communities against the construction of waste incineration plants in their neighbourhood.

The waste to energy sector in Poland is currently developing dynamically. There are a number of projects underway, including the construction of several modern municipal waste incineration plants. However, in the latest national waste management plan, it has been pointed out that the number of newly designed plants should be reconsidered in order not to overestimate the processing capacity [103]. Most of the WtE plants are built in medium and large cities. This is a reasonable decision since the majority of the population live in cities. Additionally, MSW generation is lower in rural areas; the residents buy fewer goods and have higher levels of reuse and recycling [117]. Moreover, the location of waste incineration plants in the big cities gives better capabilities for energy utilisation, especially when cogeneration is used, since the heat can be distributed more easily in the city. The locations of Polish WtE plants are shown in Fig. 13. The total capacity of newly opened plants is almost one million tonnes of waste per year, which will

Table 5
Polish targets for reuse and recycling levels of paper, metal, plastic, and glass [113].

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Target	10%	12%	14%	16%	18%	20%	30%	40%	50%

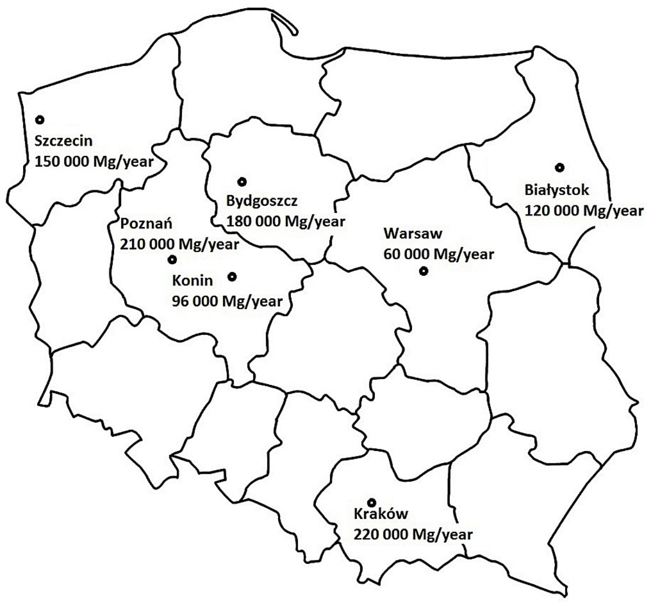

Fig. 13. Waste to Energy plants in Poland in operation (2017).

allow them to process about 9% of MSW generated in the country [101].

As far as innovative projects are concerned, two main ones can be identified. The first project "Innovative technological process of converting organic waste into high-quality solid fuels" (co-financed by Smart Growth Operational Programme for 2014–2020) aims to carry out industrial research and development work in order to develop the innovative process of converting organic waste into high quality solid fuels and obtaining biocarbon from organic waste with low energy consumption. Due to urbanisation, the production of waste is growing and the process of torrefaction can help to utilise a large proportion of non-cellulosic biomass. A project is proposed to develop and validate the conversion of organic waste into biochar. This technology will have two innovative aspects: i) the concept of carbon bio-sequestration from the (relatively difficult to dispose of) waste, and ii) the original concept of integration of thermochemical processes in the proposed technology leading to waste disposal and the production of valuable, innovative biochar [118].

The second project "High-performance "gasification" biotechnology of sludge and organic waste (industrial and municipal) using the process of co-fermentation in order to produce biogas and organic-mineral products; and heat and electricity generation" (also co-financed by the same program) aims to manufacture compact modules equipped with integrated multifunctional cascade reactors, together with control units [119].

7.3. MSW management in Slovenia

7.3.1. MSW management and organisation: Slovenia

The Environmental Protection Act (adopted in 2004) [120], Decree on the Landfilling of Waste ýý(adopted in 2006) [121], and the Decree on Waste (adopted in 2011) ý [122] are the most ýrelevant legal acts related to waste management in Slovenia. According to the Slovenian ýEnvironmental Protection Act, MSW is defined as waste generated in households or ýsimilar to household waste in nature or composition ýgenerated from trading, ýmanufacturing, commercial, business services and other activities and also from surfaces ýand in public buildings, which is mostly hard. As a result of its heterogeneous composition, due ýto diversification of the sources of origin and quantities at the source, the handling ýis ensured at the local level. Municipal waste management is the responsibility of local ýcommunities/municipalities. There are a high number of municipalities (i.e. 212 ýmunicipalities) in Slovenia, administering a relatively small number of inhabitants ýý(around 2 million). However, a positive solution for efficient energy waste management ýwas introduced in Slovenia to build "Regional municipal waste management centres-ýCERO". Every regional municipal waste management centre or CERO serves different ýmunicipalities. There are several regional municipal waste management centres in ýoperation, but most do not have all the necessary infrastructure built yet, and upgrades ýare needed, for instance, CERO Ljubljana, Centre Zasavje (CEROZ), CERO Puconci II, CERO ýSlovenska Bistrica, CERO Dolenjska II, CERO Nova Gorica (Stara Gora), and CERO ýGorenjska. Carinthian Waste Management Centre (KOCEROD) is a new centre with the ýconstruction almost completed. There is discussion between other municipalities to ýbuild a new CERO in the area of Podravje. There is only one CERO completed in Celje. ýNevertheless, the Regional Waste Management Centre in Ljubljana (CERO Ljubljana) is ýone of the most modern waste treatment facilities in Europe, serving 37 ýmunicipalities, which is also a good example of cooperation among ýmunicipalities. This environmental project in Slovenia was one of the biggest in terms of ýits budget (co-financed by the Cohesion Policy) and waste treatment capacity, which led ýto the best performing EU-13 Member State in municipal waste recycling ý [123].

The amount of municipal waste per person generated in 2015 in Slovenia was on average ýý451 kg, of which 4 kg was hazardous. The yearly amount of municipal waste generated ýper capita in Slovenia [124] for the period from 2010 to 2015 is shown in Fig. 14 ý.

Slovenia introduced a landfill tax in 2001, when the Decree on environmental tax for environmental pollution caused by waste disposal was adopted [125]. All operators of landfill sites for hazardous, non-hazardous, and inert waste are obliged to pay tax for the disposal of waste [126]. The tax collected went into the governmental budget until 2010, but since October 2010 it goes to municipalities, who are responsible for waste management. The quantity of municipal solid waste to landfill has decreased by a factor of 3.2 in 2015 in comparison to 2005 (from 680 kt or 85% in 2005 to 211 kt or 22% in 2015 [124]), ýindependent of the increase of 18% in the waste generated in the same period. The ýrecovery of municipal solid waste has increased approximately thirteen times in 2015 in comparison to 2005 and the treatment (including energy) has increased by 116% in the same period (Fig. 15). The share of landfilled MSW varies significantly from region to region (within a range from 10% to 41%). For instance, in 2015 only 10% was sent to

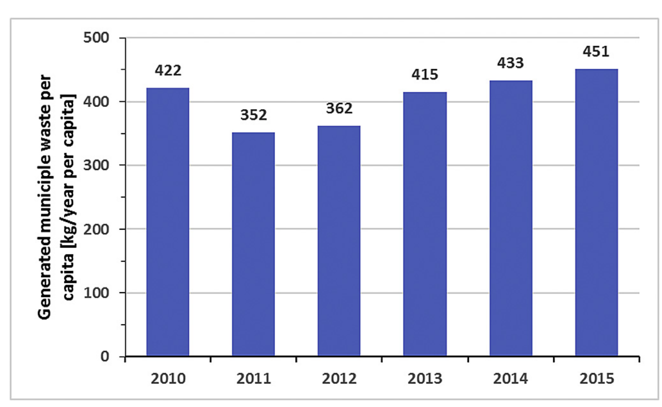

Fig. 14. Amount of generated municipal waste per capita in Slovenia [124].

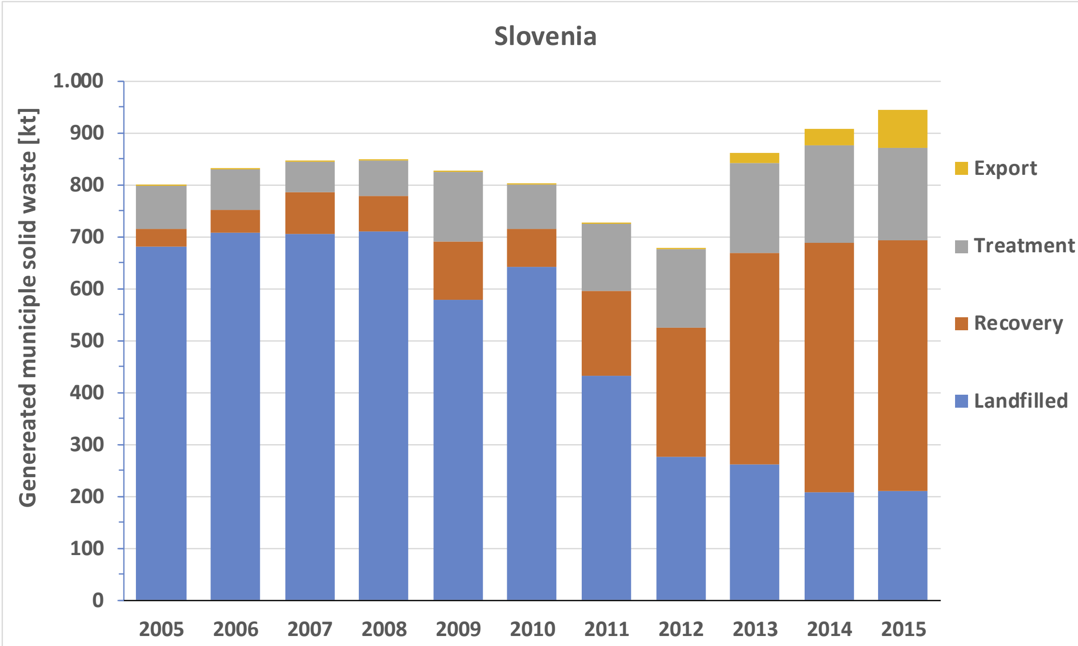

Fig. 15. Generated, treatment and measures of municipal solid waste in Slovenia.

landfill in the “Koroska” region (similarly 11% in “Podravska”), however, in the “Primorsko-notranjska” region and in Zasavska 41% and 40% respectively were landfilled.

According to the 2014 data reported to Eurostat, Slovenian municipal waste recycling rates are among the highest in the EU (61%), and they have more than doubled since 2007. Yet, as mentioned above, the amounts of waste generated by municipalities and waste management performance in individual municipalities differ considerably. On a positive note, based on the national legislation for separate bio-waste collection, many municipalities introduced a frequency of collection and door to door collection systems. Many local authorities have installed collection systems that exceed the requirements of the national legislation. NGOs are very active in the waste sector in Slovenia, which led to a number of municipalities (including the city of Ljubljana) to develop Zero Waste policies [127].

Furthermore, the Slovenian Government adopted ýits ”Waste Management Program and the Waste Prevention Program of the Republic of Slovenia ý [128] ýor Operational Plan for Waste Management of the Republic ýof ýSlovenia (thereafter, Operational program)” as “an instrument for complying with the ýprevention of waste generation, ensuring the prescribed waste management and achieving ýwaste management targets for the period up to 2020 and 2030”. The objectives of the Operational program are divided into general and specific objectives. The general objectives include the prevention of waste and the prevention of illegal waste management, in particular, dumping in the environment. The specific objectives and measures for achieving these objectives relate to, *inter alia*, municipal waste, industrial waste, and waste from other activities. The Operational program defines measures for achieving the objectives, which require cooperation between different Ministries (Ministry of Economic Development and Technology, Ministry of Agriculture, Forestry and Food, Ministry of Health and Ministry of Public Administration). The general objectives of the Operational program focus on: i) avoiding or reducing the adverse effects of waste generation and handling: prevention of waste; ii) preventing the illegal dumping of waste; iii) direct collection of waste for recycling; iv) use of unrecycled waste to process into solid fuel or for heat treatment, preferably by using energy; and v) reducing the disposal of waste exclusively to waste that cannot be reused and recycled. Specific objectives related to municipal waste are focused on collection, preparation for re-use and disposal of municipal waste. For instance, to achieve the target defined by the WFD two scenarios of measures to increase separate collection and preparation of municipal waste by 2020 were proposed. The first scenario (Scenario I) is a minimum scenario for achieving the targets of EU Directive, but the second scenario (Scenario II) is more ambitious. Targets of both scenarios regarding the percentage of preparation for reuse and recycling of different waste fractions are shown in Table 6.

The Operation plan for waste management also promotes house composting of biodegradable waste generated in an individual household, such as kitchen waste or green garden waste.

The European Commission further recommends an increase in the costs of residual waste treatment, either by increasing the current rate of landfill tax, or by introducing a residual waste tax on the other non-recycled outputs from MBT systems (including outputs to thermal treatment), to improve data on waste management (to eliminate inconsistencies between different sources and a large gap between waste generated and treated), and finally, to improve

Table 6
Objectives of the preparation for reuse and recycling of municipal waste by scenario I and scenario II.

Type of waste	Processing	Preparation for reuse and recycling	
		Scenario I	Scenario II
	Share, 2014 [%]	Share, 2020 [%]	Share, 2021 [%]
Paper	72,8	76,9	84,6
Biological	74,2	76,7	86,6
Plastics	20,1	35,0	40,4
Glass	69,7	79,8	79,8
Metal	72,6	87,6	89,7
Others	42,6	46,0	46,0

the cost-effectiveness, monitoring and transparency of existing EPR schemes [127].

7.3.2. Waste-to-energy in Slovenia

The Operational program discussed in the previous section aims at implementing measures for preparation for reuse and recycling of municipal waste, which have priority over energy recovery, where the measures are environmentally sound. According to this program, energy recovery of municipal waste can be carried out, if it is energy efficient and if the goals of municipal waste recycling are fulfilled (50% recycling in 2020 and 65% in 2030). The energy recovery of municipal waste is mainly carried out in the cogeneration of electricity and heat (CHP) using fuel prepared from combustible fractions that are formed as residues of the processing of separately collected fractions of municipal waste or are excluded from mixed municipal waste in their MBT in municipal waste treatment centres.

The production of energy from municipal waste in Slovenia is carried out in one unit for combined heat and power, electricity production from landfill gas on municipal waste site and in several biogas plants using biological waste as a substrate for the production of biogas.

Currently, there is only one combined heat and power plant in Slovenia, for thermal waste treatment at Celje Regional Waste Management Centre [129,130] ýoperating with an annual incineration capacity of 24,900 t of municipal fuel, which corresponds to an average annual thermal input of about 20 MWth. The statistical data of quantities of biological and biodegradable waste used in CHP unit in 2015 were 24.15 kt (20.36 kt biological and biodegradable waste and 3.78 kt sewage sludge) or 330.32 TJ, as is shown in Table 7. The quantities of gross and net produced electricity and heat from waste in 2015 were 7.5 GWh or 6.2 GWh and 119.5 TJ or 107.5 TJ (Table 7).

There are three plants for electricity production from landfill gas installed in Slovenia [131]ý. ýThe data for gross and net electricity generation in 2015 from landfill gas ýwere 16.88 GWh (gross production) and 16.73 GWh (net production). Fig. 16 presents a ýconcept of the system for utilising landfill gas for electricity production. ýý.

There are also three combined heat and electricity production system (CHP) biogas plants installed in Slovenia for electricity and heat production with a power capacity of 2.5 MWe, using mainly biological and biodegradable waste [131].

8. Overview of MSW management systems in the selected Member States: the southern region

8.1. MSW management in Greece

8.1.1. MSW management and organisation: Greece

As a Member State of the EU, the legal framework that delegates

Table 7
Electricity and heat production from waste in Slovenia in 2015.

A) Production			
	Electricity (GWh)	Heat (TJ)	Efficiency (%)
Gross production (CHP)	7.5	119.5	44.4%
Net production (CHP)	6.18	107.5	39.3%
B) Consumption of waste			
Electricity	Heat	Total	
Used waste (kt)	4.46	19.69	24.15
Used waste (TJ)	60.96	269.36	330.32

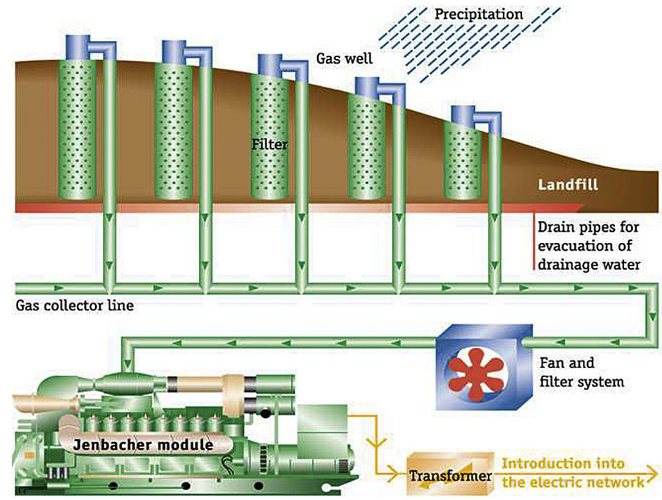

Fig. 16. System CHP for utilisation of landfill gas.

the direction of municipal waste management in Greece closely follows the European waste management directives and more specifically the WFD [9] which is transposed into the Greek legislation by Law 4042/2012 [132]. The biggest effort in coordinating waste management in Greece so far has been the Joint Ministerial Decision 50910/2727/2003 on ‘measures and conditions of solid waste management’ [133], where MSW are defined as domestic waste, as well as other types of waste that due to composition or nature are similar to domestic waste. The National and Regional Management Plan introduced in 2003 set specific rules and targets at national and regional levels that must be met in the waste management planning [134]. The complex administrative structures and procedures are often seen as the major cause for the significant delays in the implementation of environmental legislation in Greece [135].

Nearly 63% of the total population Greek population (over 10 million as shown in Table 2) live in urban areas [136]. The economic development, intense urbanisation, and change in consumption patterns in Greece have led to an increase in solid waste generation. As a result, the quantity of municipal waste generated in the country increased by more than 75% from 1995 to 2010. In recent years a slight trend in reduction of the generated waste is observed. According to Eurostat, the amount of generated municipal solid waste (MSW) in Greece in 2015 was about 485 kg of waste per person per year, a figure close to the average for the EU28 – 476 kg/year (Fig. 17) [56]. Fig. 18 shows the composition of MSW in Greece [136].

The Ministry of Environment, Energy, and Climate Change (MEECC, YPEKA in Greek) is responsible for the development and implementation of environmental policy at the national level. The municipal waste sector falls under differently aligned Ministries (MEECC, Ministry of Interior and Ministry of Development). Such variations cause difficulties for the central administration in coordinating and providing leadership for the sector. Greece is divided into 13 Regions with a total land area of 131,957 km^2, of which nine are located on the mainland and four on the islands. Their responsibility includes certain aspects on licensing and elaborating Regional Waste Management plans (RWMPs), while municipalities have the responsibility for the aspects of planning (collection).

Greece established a Green Fund in 2010. The objective is to stimulate growth through protecting the environment and providing support for environmentally friendly projects and initiatives. In consistency with the RWMPs, 28 Materials Recovery

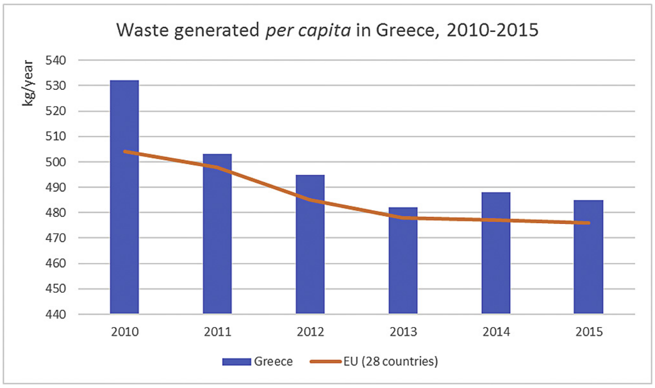

Fig. 17. MSW generation in Greece [56].

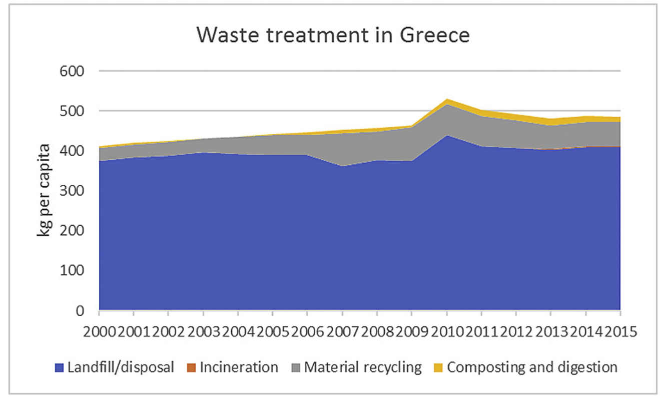

Fig. 19. Waste treatment in Greece [56].

Facilities (MRFs) are in operation. With these facilities in 2011 around 478,000t of recyclables have been collected and 274,000t have been recovered [136]. The operation of two new state-of-the-art MBT plants, one in the greater Athens area and one on the island of Crete, reinforced the waste management capacity of Greece from 2004 to 2006. The MBT plant in Athens with an annual capacity of ~450 000 tonnes, one of the biggest plants in Europe, treats mixed municipal waste and produces Refuse Derived Fuel (RDF) and compost of good quality. The waste treatment plant in Chania, in Crete, has an annual capacity of 70 000 tonnes [137]. However, the products from these plants, (i.e. RDF and compost), have no market, thus, in most cases they are sent to landfill [138].

Greece as a member of EU still maintains high rates of landfilling. Until the early nineties, waste management in Greece relied on semi-controlled landfills. In total, there are 79 landfills, of which 75 sites are in operation and this high level of landfilling also results in a correspondingly high level of direct emissions mainly due to the methane emissions from landfills. Today, the majority of municipal waste in Greece is still landfilled (81% compared to 31% for EU-28 average), with only 16% being recycled (EU-28 – 27%) and 4% composted (EU-28 – 15%) [138] and there are still no incineration installations with or without energy recovery [136]. Greece will need to make an exceptional effort in order to fulfil the 50% recycling target by 2020. As depicted in Fig. 19, the majority of MSW generated in the country is still landfilled or disposed of in another way. Unfortunately, energy recovery processes are only marginal.

According to the EU Landfill Directive, Member States must reduce the amount of biodegradable municipal waste (BMW) landfilled to certain percentages by 2006, 2009 and 2016. The targets are set based on the amount of BMW generated in 1995. Greece

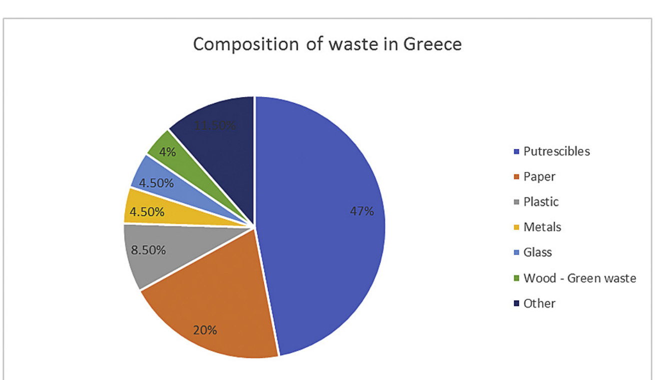

Fig. 18. Composition of waste in Greece [136].

generated 2 100 000 tonnes BMW in 1995. Thus, Greece has been granted a four-year derogation period, as one of the countries that landfilled more than 80% of the generated MSW in 1995 [137].

Addressing the issue of illegal landfilling is a key priority whilst illegal landfills remain open (or new ones are being created). It is difficult to make an economic success of legal waste management operations and the jobs and growth potential of the recycling sector cannot be realised [138]. The European Commission further recommends the advancement of separate collection, sorting and recycling (including composting) in the coming years, in order to reach the 2020 recycling target; to improve the cost-effectiveness, monitoring and transparency of existing EPR schemes, and finally to complete missing Waste Management Plans in order to cover the whole territory [135].

8.1.2. Waste-to-energy in Greece

WtE is a well proven and preferred MSW management practice in the EU and worldwide since it results in both the minimisation of environmental impacts in landfilling and renewable energy generation. Thermal treatment technologies, such as mass burn incineration are the most widely applied options for conversion of the energy content of waste to generate electricity or for combined heat and power production. The EU directive for the Incineration of Waste is harmonised to the Greek legislation [139]. The immature WtE market in Greece leaves significant margins for action and investments. According to RES 3851/2010 the Waste to Energy Feed-in-Tariff for electricity production from the Biodegradable fraction of municipal waste is 87,85 Euro/MWh for interconnected systems and 99,45 for non -interconnected islands [140]. However, Greece is one of the few countries of the EU that still has not incorporated WtE in its waste management practices. The main reasons for this can be found in failures to implement the legislation properly, administrative issues, poor quality of environmental information and problems with public acceptance in terms of site selection [141]. The lack of a Landfill Tax is another factor resulting in the lack of motivation for the implementation of WtE technologies in Greece [142]. On the other hand, the EU legislation for Sanitary Landfills (1999/31/EC) is pushing the Greek MSW management to decrease the amount of biodegradable waste deposited to sanitary landfills (further details are provided in Table 8) [143].

According to the new National Waste Management Plan (NWMP), priority targets include the increase in source separation, reuse and recyclability and the implementation of WtE processes when the recovery options have been exhausted [144]. Specifically, the new NWMP features the following targets for 2020: i) drastic reduction in waste generation per capita; ii) 50% of aggregate MSW to be prepared for recycling or re-use through separate collection of

Table 8
Sanitary landfills in Greece [143].

Region	Sanitary Landfills	Munic/ties Served	Population served	Sanitary Landfills Under construction	Munic/ties Served
East Macedonia & Thrace	3	20	44.7%	1	5
Central Macedonia	7	15	34.4%	4	17
West Macedonia	0	0	0%	1	10
Thessaly	3	47	55.6%	3	58
Epirous	2	20	4.1%	0	0
West Greece	1	2	20.9%	3	19
Sterea Ellada	3	14	24.8%	3	26
Peloponesos	1	3	47%	2	7
North Aegean	0	0	0%	2	3
South Aegean	7	11	12.6%	0	0
Crete	11	38	24.9%	2	17
Ionian Islands	3	21	61.6%	2	18
Attica	1	70	93%		
Thessaloniki	1	23	71%	1	13

recyclables and bio-waste; iii) waste to energy as a complementary form of management when no other recovery options are possible; iv) less than 30% of MSW landfilled and only as a final option, when all other recovery/recycling options have been exhausted.

The Greek Waste-to-Energy Research and Technology Council SYNERGIA has already proposed a number of WtE schemes/scenarios to overcome the waste management problems in the Attica region which is the main contributor to waste generation in Greece. The integration of WtE practices in the Greek Regional Plan for waste management is considered a promising alternative to achieve compliance with the EU targets, bringing benefits from the production of renewable energy [138].

8.2. *MSW management in Italy*

8.2.1. *MSW management and organisation: Italy*

The total population of over 60 million in Italy is highly concentrated in specific areas of the country. From a total of 8040 municipalities only 741 have a number of inhabitants higher than 15000, while the remaining are small municipalities. These 741 towns contain overall more than 36 million inhabitants, with the six main cities being Rome, Milan, Naples, Turin, Palermo, and Genoa. In Italy, the most important waste legislation was issued in 1997 (Legislative Decree 22/97), which shaped the national waste management system, introduced targets about separate collection of municipal waste, established the National Packaging Consortium and provided for the progressive replacement of the old waste tax with a new waste tariff. The Decree was, then, repealed by Legislative Decree 152/2006 which embraced most of its provisions [145]. MSW is defined waste originated in households and similar to household waste by nature and composition found on the roads or in public areas, private areas subjected to public use (i.e. on sea or lake beaches, on the bank of rivers or streams); garden waste originating from gardens, parks and cemeteries, waste deriving from exhumation and any other waste deriving from cemetery activity; some types of commercial, craft and industrial waste with characteristics similar to MSW (i.e. packaging material, textile clippings, rubber, waste from the food industry, wood scraps and scrap from furniture, etc.).

In 2016 ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) published a yearly report on municipal waste [146]. The calculation of the per capita waste production in Italy (kg of waste/inhabitant per year) indicates that there was a decrease from 504 in 2012 to 491 in 2013, and 488 in 2014 (close to the European Average (476 kg per capita)), as depicted in Fig. 20.

A national program for prevention [147] was generated by the Minister of Environment in October 2013 in order to monitor the efficacy of the measures proposed by National, Regional, and Municipal planning. The program sets the target of a 5% decrease in municipal waste production for 2020. The target has been achieved in 2015.

In 2015 the national production of municipal waste was 29.5 million tonnes with a decrease of 0.4% compared to 2014 and an overall decrease of 5.9% compared to 2011, giving an extremely good indication of the effort of the country to address the principal way of improving the waste management issue: prevention. Political changes in the management of municipal waste have been indicated as potentially influencing factors in this decrease:

- Diffusion of house collection systems (for recyclable items as well as general waste);
- Direct management in case of valuable products;
- Reduction of production through prevention measures.

In 2015 the percentage of recyclables collected has increased by 2.3% reaching 47.5% (~14 million tonnes), still below the objectives set by the government for 2012, but nevertheless indicating the efficacy of the measures undertaken (i.e. house collection). The main role is due to the organic fraction which saw an increase of 6.1%. Organic and cellulose-based waste formed 66% of the total recyclable fraction collected (i.e. out of which ~28% is formed by packaging material). Glass and plastic formed the two main types of packaging materials that are collected for recycling at up to 85 and 91% respectively.

Based on the data reported by ISPRA in 2016, in 2014 33% of MSW went to landfill, 23% to incinerators, 16% to compost and

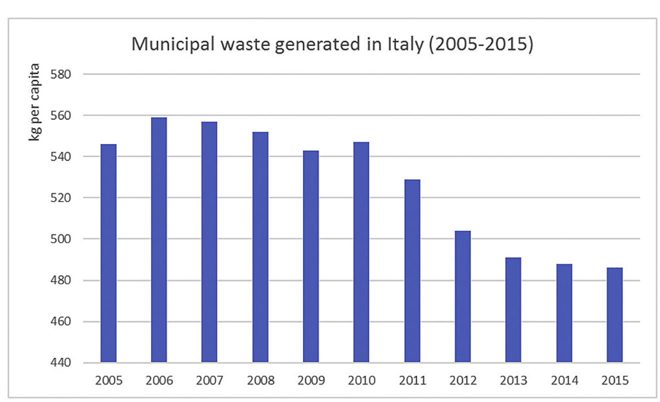

Fig. 20. MSW generated in Italy (2005–2015) [56].

anaerobic digestion and 28% in recycling [146]. The proportions of particular treatment methods in recent years are shown in Fig. 21. However, there are major differences in performance at a local level, particularly, the Southern and Central regions are lagging. For instance, in 2010 Sicily landfilled 93% of its generated municipal waste, Molise 84%, and Basilicata 83% (ISPRA, 2012). The reasons for the disparities are principally due to the late industrialisation of the southern regions, difficulties with administrative capacity and an economic imbalance between the municipalities which implement the separate collections [148]. The variable waste and landfill gate fees applied in the regions further widen the gap between the different regions [149].

Italy does not have a NWMP, since planning is mandated to regions, where each region is obliged to devise a management plan every 2–3 years or depending on when new rules and regulations arrive from the EU and then are required by the government [150]. Yet, as discussed above, there is the National Programme for waste prevention, which focuses on these following points: sustainable production with changes in raw materials and technologies, Green Public Procurement, where the Minister of Environment produced a plan for the environmental sustainability for Public Administration [151], re-use, research, and raising awareness and education on waste prevention [147,152].

The European Commission, *inter alia*, further recommends that Italy should introduce a national landfill tax (or harmonise the regional taxes) to phase-out landfilling of recyclable and recoverable waste, to improve the separate collection and alternative infrastructure (while avoiding building excessive infrastructure for the treatment of residual waste), to improve co-operation between regions to use waste treatment capacity more efficiently, and finally to extend and improve the cost-effectiveness, monitoring and transparency of existing EPR schemes [153].

8.2.2. *Waste-to-energy in Italy*

Italy is one of the countries with the highest number of incinerators in the EU [6]. Nationally there are 41 incinerators, 26 of which are in the North (mainly, in Lombardia, with a surplus of 578 k tonnes per year, and in Emilia Romagna, Friuli Venezia Giulia, and Bolzano province which are self-sufficient). Only 8 plants are in the Centre and 7 in the South with further indication of a need for incinerators in Liguria, Valle D'Aosta, and Trento province where the plants are absent. As a result, Liguria and Veneto require 400 k tonnes of waste to be treated per year [148]. In 2015 about 5.6 million tonnes of municipal waste (including dry fraction, secondary solid fuel, and bio-dry fraction) were treated in plants with energy recovery. Yet, only 24 out of these plants can generate electrical energy. These 24 plants in 2015 generated 2.7 million MWh of thermal energy from 3.4 million tonnes of municipal waste. On the other hand, in the same year, 15 plants, which are equipped with co-generative cycles, treated 2.6 million tonnes of waste and recovered 2.7 million MWh of thermal energy and 1.7 MWh of electricity. Additionally, there is also a production of 1.6 million tonnes of fertiliser from aerobic and aerobic/anaerobic treatments [146].

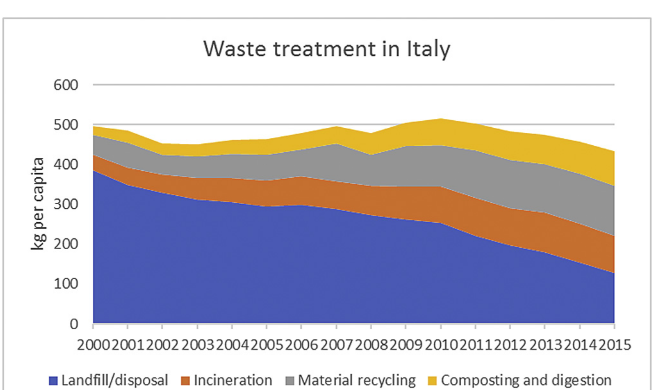

Fig. 21. Waste treatment in Italy (2000–2015) [56].

Remarkably, a large percentage of the waste produced in the Central and Southern regions of the country are treated in plants located in the Northern regions, hence, indicating a national movement of waste from South to North where high specification thermo-valorising plants are located. For instance, the large incinerator plants cover large regional areas such as the newly built Gerbido plant in the Turin area [154].

Around 5.2 million tonnes of municipal waste are now recovered in biological treatment plants with ~3.4 million tonnes being sent to composting plants, 1.6 million tonnes to integrated treatment plants for anaerobic/aerobic treatment, and the remaining approximately 220,000 tonnes are treated in pure anaerobic digestion treatment plants (i.e. the large anaerobic digestion to biogas plant present in Milan) [155].

The biological processes indicated above find space in the ISPRA report [146]. Three types of biological processes can be identified and they deal with ~6.5 million tonnes of waste per year:

- Aerobic treatments (~5.5 million tonnes), consisting of municipal food waste (46%), gardening waste (35.8%), sludge (10.2%) and other waste mostly from agriculture and food processing plants (8%);
- Integrated anaerobic/aerobic (~2 million tonnes) consisting of municipal food waste (81.7%), garden waste (11.6%), sludge (4.1%) and other waste mostly from agriculture and food processing plants (2.6%);
- Anaerobic digestion (847 thousand tonnes) consisting of municipal food waste (30.5%), sludge (42.5%) and other waste mostly from agriculture and food processing plants (27%).

The latter is of particular interest because of its double potential within the circular economy: renewable energy production (i.e. production of biogas), control of emissions, stabilisation of biomass and further use of the solid residue as fertiliser (secondary raw material). In 2015 there were 26 plants equipped with this technology and in the same year they treated ~30% of the organic fraction collected from municipal waste at national level.

8.3. *MSW management in Spain*

8.3.1. *MSW management and organisation: Spain*

Spain with its population of 46 million is not a federation, but, nevertheless, a largely decentralised country. The system of decentralisation is organised into 17 autonomous communities, 2 cities with statutes of autonomy (i.e. Ceuta and Melilla), and 8125 local institutions [156]. The first Spanish Waste Law was passed in 1985, which encouraged Spanish municipalities to deal with the problem of waste and to take measures for protecting the environment, with the first Packaging Law (11/1997) issued in 1997 [157]. The current RD 22/2011 on waste and contaminated soils [158], which transposed the WFD, regulates waste management in Spain. MSW is defined as household waste generated by households (i.e. the domestic activity of households) and similar waste from small commercial activities, office buildings, institutions such as schools and government buildings, and small businesses.

While at national level the Ministry of Agriculture, Food and Environment is responsible for the national plans and attends to the authorization and inspection of waste shipments to/from third countries (outside EU), waste legislation in Spain is administered by the relevant authorities at different administrative levels. Given that the RD 22/2011 law requires the elaboration of a National Waste Management Framework Plan and its transposition to Waste Management Plans at regional level (Spanish Autonomous Regions), this means that different strategies and approaches to waste management have been adopted in different regions of Spain. In the framework of municipal waste, the RD 22/2011 has transferred the competences of collection, treatment, and final disposal to municipalities. Municipalities generally perform these responsibilities by grouping themselves into associations of municipalities (Mancomunidades, Consorcios, etc). They are also responsible for the authorization, inspection and sanction of waste management activities and the shipment of waste to/from EU countries [159].

In 2014 Spain generated 21.9 million tons of MSW which means an average amount of 459.1 kg of waste per person per year [160] (see Fig. 22). Fig. 23 shows the composition of MSW waste [161]. Only 18% of MSW (3.8 million tonnes) was source-selected while the rest of MSW was collected as mixed waste. The source-selected fractions were paper and cardboard (27%), organic matter (20%), packaging (16%) and other fractions (18%) mainly collected at green service points (see Fig. 24).

Recycling has improved in the last 10 years showing an increase of more than 10% from 21% in 2001 to 33% in 2010. Despite this progress, Spain has not yet met its 50% target. The first and second National Municipal Solid Waste Management Plans (for the periods 2000–2006 and 2008–2015 respectively) have been instrumental in the development of MSW recycling by introducing several initiatives, including separate collection of recyclables and upgrading recycling facilities. The Landfill tax which was adopted by the most highly populated regions of Spain contributed to the diversion of MSW from landfills and the valorisation of material resources through recycling [157]. Yet, landfilling is still a problem in Spain. For intance, in 2014 55% of MSW was landfilled.

To treat the MSW, Spain has 373 waste treatment facilities [162], distributed in:

- 94 packaging sorting facilities (0.6 million tonnes/year),
- 5 MSW sorting facilities (1.0 million tonnes/year),
- 86 Mechanical-Biological Treatment plants (7.9 million tonnes/year, 23 with Anaerobic digestion and 3 with composting),
- 44 composting facilities for source-selected organic fraction (0.6 million tonnes/year),
- 10 incinerator facilities with and without energy recovery (2.3 million tonnes/year),
- 134 landfills (13.1 million tonnes/year).

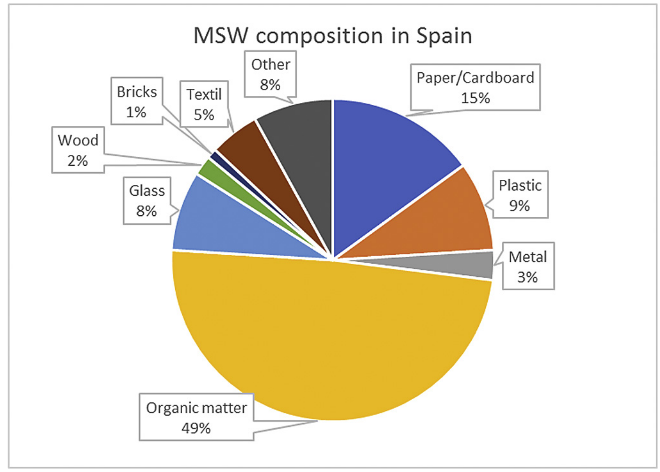

Fig. 23. Composition of MSW in Spain [161].

Landfilled and incinerated waste includes rejected materials from the other treatment facilities (e.g. MBT plants) but also wastes without previous treatment. A total amount of 5.5 and 1.03 million tonnes were landfilled and incinerated respectively without any previous treatment during 2012. One of the goals of the current National Waste Management Plan in Spain (PEMAR 2016–2022 [161]) (and accordingly a goal of the regional waste management plans), is to treat 100% of MSW by 2020 increasing, in that way, the resource efficiency, and the recovery of valuable materials in Spain.

The PEMAR 2016–2022 [161], sets up the strategic guidelines for waste management in the next six years and the measures necessary to meet EU targets. PEMAR introduces an obligation of results on the Autonomous Communities, requiring regions to align and review their regional strategies so as to achieve the specific objectives of the national Plan. The European Commission has expressed further recommendations encouraging Spain to introduce a national landfill tax (or harmonise the regional taxes) in order to phase-out landfilling of recyclable and recoverable waste; to support the separate collection and alternative infrastructure, yet, to avoid building excessive infrastructure for the treatment of residual waste; to improve the effectiveness of separate collections to increase recycling rates (including specific plans for bio-waste management); to improve the cost-effectiveness, monitoring and transparency of existing EPR schemes, and to intensify co-operation between the regions to use waste treatment capacity more efficiently and to achieve the national recycling targets [163].

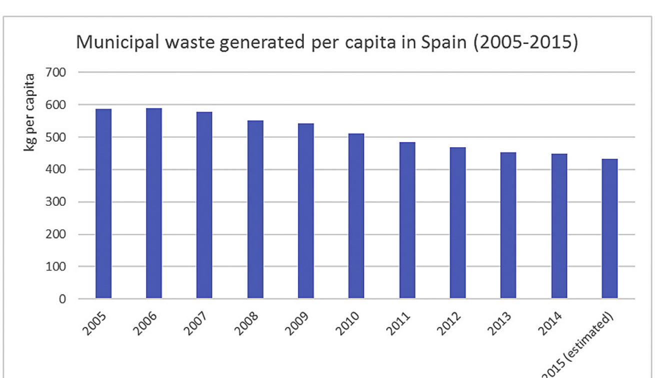

Fig. 22. Municipal waste generated in Spain (2005–2015) [56].

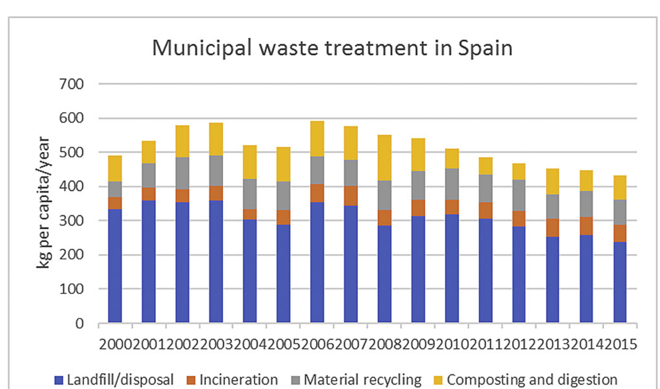

Fig. 24. MSW treatment in Spain (2000–2015) [56].

8.3.2. Waste-to-energy in Spain

Incineration (with or without energy recovery) covers the wastes used at incineration or co-incineration facilities as fuel to produce energy (WtE) and at the plants in which the main goal is to reduce waste volume and toxicity to obtain a product that can be safely landfilled. Spain has 10 incineration facilities and their main characteristics are summarised in Table 2. Seven out of ten Spanish Incineration facilities are considered WtE plants so that only 30% of installations are considered elimination facilities (i.e. do not meet the EU's R1 requirements).

In 2007, with a treatment of 1,792,737 tonnes, the electricity produced and sold in WtE plants was 1,606,191 MWh [164]. During the last years, the treatment capacity of the 10 incineration facilities has increased and in 2012, 2.33 million tonnes of wastes were incinerated in Spain, which means 11% of the total waste generation. The distribution of waste was as following: 1.03 million tonnes of mixed MSW, 1.24 million tonnes of rejected materials from MBT plants, 0.02 million tonnes from packaging sorting plants and 0.04 from recycling facilities [161].

According to the waste treatment hierarchy, energy valorisation should be only applied when no recycling is possible and as stated above, according to PEMAR 2016–2022, 100% of waste should receive a treatment process before its final disposal. Therefore, as the total amount of waste treated in MBT plants will increase (6.5 million tonnes a year does not yet receive any treatment before its final disposal), it is expected that that in 2020 the energy valorisation could increase up to 15% mainly because of the increased amount of rejected materials coming from the MBT plants. PEMAR stablished as a goal the use of only rejected materials in WtE plants in 2020.

One way increasingly used to valorise the rejected materials coming from MBT plants in Spain is the production of RDF and SRF. In 2010, 111,794 tonnes of RDF were produced and used mainly as substitute for petroleum coke. According to Sánchez [165], taking into account the rejected materials from MBT plants of the four Spanish regions with highest waste generation (Andalusia, Madrid, Catalonia and Valencian Community) there is an estimated RDF potential of 640,000 tonnes a year and according to MINETUR (2011) [166] an estimated amount of thermal energy production due to using RDF in 2020 will be around to 350 ktoe.

In the National Action Plan on Renewal Energies it is stated that 20% of the energy consumption in Spain should come from renewable sources, the biodegradable fraction of industrial and municipal wastes is included as a renewable source. The estimated amount of the biodegradable fraction from MSW in 2020 with energy valorisation is 6.7 million tonnes (1.8 million tonnes in WtE, 0.1 million tonnes of SRF, 0.3 million tonnes to industrial furnaces, 1.2 million tonnes to AD and 3.3 million tonnes of biogas from landfills) which is equal to an estimated primary energy production of 726 ktoe, which will contribute to achieving the goals of the National Action Plan on Renewal Energies (PANER 2011–2020) [166].

One of the main concerns of WtE plants is the emission of contaminants in flue gases; these emissions are regulated by RD 16/2002 on the prevention and integrated control of pollution [162] and RD 815/2013 on industrial emissions [167]. Table 9 summarises the limiting values for gaseous emissions in WtE plants.

In terms of taxes, in all but one Autonomous region of Spain (Catalonia) there is no environmental tax for the incineration of MSW. The Catalan law 8/2008 taxes the MSW incineration with a current tax of 5,7 €/t, in comparison taxes the landfilled MSW with 16.5 €/t. These taxes are used to finance the treatment of source-selected OFMSW and the implementation of new source-selection schemes [168]. Therefore, promoting recycling over energy recovery and promoting energy recovery over landfilling complying in that way with the EU hierarchy.

9. Overview of MSW management systems in the selected Member States: the Northern region

9.1. MSW management in Norway

9.1.1. MSW management and organisation: Norway

Although not a member of the EU, Norway is a European Free Trade Association (EFTA) member and a signatory of the European Economic Area (EEA) agreement, and therefore must comply with the EU policies on waste management. A third of the total population of 5,267,146 live in one of the five largest urban settlements, including Oslo, the capital. Since Norway is a relatively large country with a small, dispersed population, significant challenges exist for waste management [169]. Waste is regulated in various ways, with interaction between central and local regulation. Responsibility for household waste management lies at the municipality level, with compliance from municipality and other MSW management operatives ensured according to national environmental rules and regulations by the Norwegian Environment Agency (‘Miljødirektoratet’) [169]. There are 19 administrative regions and 426 municipalities in Norway.

In 2016, 2,277,000 tonnes of household waste were generated in Norway, equal to 433 kg per inhabitant [170]. The overall treatment of MSW in Norway is mainly split between incineration and material recovery [169]. In Norway, national and municipality statistics are not prepared for municipal waste, but for household waste only [169], which makes up about 90% of total MSW. ‘Household waste’ is commonly reported and defined as waste deriving from normal activities in households, including food residuals, packaging material, paper, textiles, electric and electronic waste, garden waste, furniture and wood waste, and other large objects [170]. Some municipalities also report amounts of household-like waste

Table 9
Main characteristics of the incineration facilities in Spain.

Autonomous Region	Treatment capacity		EE	Furnace type	Flue gas treatment
	no of furnaces	t/year			
Balearic Islands	2	517,398	0.70	Moving grate	semi-dry wash, bag filter, active carbon
Cantabria	1	115,450	0.66	Moving grate	dry wash, bag filter, active carbon
Catalonia	3	609,982	0.63	Moving grate	semi-dry wash, bag filter, active carbon
	2		0.45	Moving grate	semi-dry wash, bag filter, active carbon
	2		<0.60	Moving grate	semi-dry wash, bag filter, active carbon
	2		0.65	Moving grate	semi-dry wash, bag filter, active carbon
Galicia	2	544,207	>0.6	Fluidized bed	semi-wet wash, bag filter, active carbon
Madrid	3	611,772	0.66	Fluidized bed	semi-wet wash, bag filter, active carbon
Melilla	1	49,411	<0.60	Moving grate	semi-dry wash, bag filter, active carbon
Basc Country	1	211,376	0.63	Moving grate	semi-dry wash, bag filter, active carbon

from other sources, which are used to calculate a weighted national average, and used to estimate the total amount of MSW for the whole country [169].

Fig. 25 shows the composition of household waste in Norway [170]. Much of this is biodegradable. For 2016, 68% of MSW generated consisted of paper and card, wet organics, wood waste and park and garden waste. Most of the waste produced is treated within Norway, although the country is also a major waste importer and exporter. These activities are regulated through EEA regulations and the Basel Convention [171]. Registered exports of waste have increased significantly in recent years, from 1 million tonnes in 2010 to 1,7 million tonnes in 2011 [171,172], with much of this to Sweden for WtE activity [173,174]. Reasons for the export increase include an insufficient combustion capacity in Norway and a ban on the landfilling of biodegradable waste, coupled to changes in economic and market factors [175].

The Norwegian waste management strategy is similar to the goals and vision set by the EU and is based on increased material recycling and reduced landfilling. As shown by Fig. 26, waste treatments in Norway mainly involve material recovery (recycling) and incineration, with incineration accounting for the disposal of the majority (58%) of household waste generated in the year 2016 [176]. Quantities of landfilled household waste have decreased since 2006, whereas the quantity of waste incinerated has increased. The quantity of waste recycled has remained relatively constant between 2006 and 2016. According to the EEA [169], if Norway were to continue to increase MSW recycling at the same pace as in the period 2006–2010, the country would reach 46% by 2020, which is slightly under the EU target of 50%. Thus, Norway will have to increase its recycling efforts to meet the EU targets of 65% for recycling MSW and of 75% for recycling packaging waste by 2030.

In the last decades, Norway has worked towards reducing the quantity of waste landfilled, increasing the quantity of waste recycled, and decoupling waste generation from economic growth. The first unified law concerning pollution and waste was the Pollution Control Act of 1981 [177]. Aside from implemented EU regulations, such as the EU landfill directive, a significant number of other Norwegian policy initiatives have been undertaken with varying degrees of success towards waste management aims. For instance, landfill and incineration taxes were introduced in 1999. Landfill taxes were differentiated according to the environmental standard of the landfill site since 2003, and abolished in 2015, since the amount of waste being landfilled was so low that the costs for local governments and businesses to implement the tax was greater than the financial revenue the tax created [169]. The incineration tax was abolished in 2010. In 2009 a landfill ban for biodegradable waste such as paper, tree, and food waste, containing more than 10% total organic carbon (TOC) [178].

Norway's waste prevention strategy was highlighted in the 2013

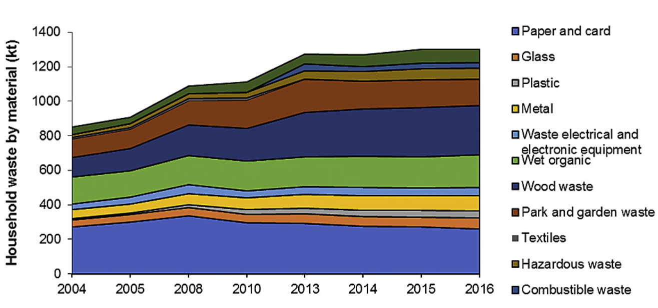

Fig. 25. Household waste by type in kilotonne (kt). Data is sourced from SSB [170].

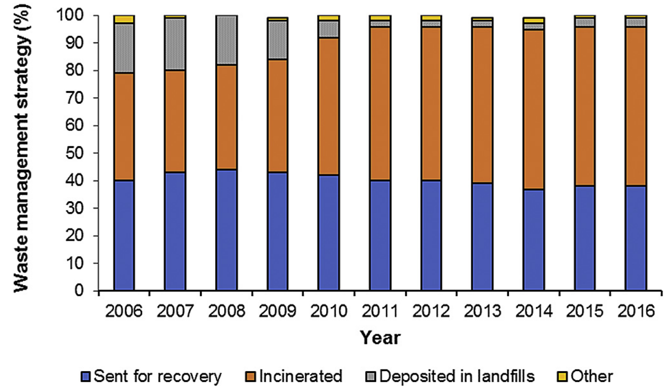

Fig. 26. Household waste by type in kilotonne (kt). Data is sourced from SSB [170].

waste strategy [171], which primarily has a long-term goal of decoupling economic growth from waste generation and which also adopts the waste hierarchy principles. The government only aims to a small degree at directly preventing waste, but uses many measures in environmental politics to provide incentives for waste prevention, including relying on EPR arrangements and bringing about changes to consumer behaviour [178]. Norwegian waste prevention activities focus on selected types of waste, including food waste, waste from building and construction, electric and electronic waste, and textiles [171]. Measures for waste prevention are assessed based on where prevention will have the greatest environmental effects throughout the life cycle of each product, and where there will be the largest potential and socioeconomic use of the measures. Food waste is a major targeted topic, with a target to reduce food waste by 50% by the year 2030 [179]. In Norway, an average of 42 kg of food is disposed of per person per year, with total food waste in the food supply chain equalling 68 kg per person per year [179].

The environmental authorities ensure that municipalities and other MSW management operatives comply with rules and regulations. Non-compliance entails a deadline for resolution, along with follow-up supervision and ultimately, financial penalties and police involvement [169].

9.1.2. Waste-to-energy in Norway

Improved waste separation technology and centralised materials recovery facilities for, *inter alia*, paper, glass/metals, plastic and bio-waste, and the development of infrastructure for waste utilisation have been implemented. This reflects the concept of waste as a resource [171,180]. Norwegian WtE schemes include incineration with energy recovery, as well as the production of biofuels.

Although Norway has large resources of oil and gas, it is also a country with high renewable energy resources. This particularly regards hydropower, since for example in the year 2013, production of Norwegian hydroelectric power corresponded to around 40% of the total for the then EU-27 block [181]. As laid out in the Norwegian national bioenergy plan, Norway has a target to double bioenergy production (including contributions from both biomass and MSW), from 14 to 28 TWh, between 2008 and 2020 [181]. In 2016, 20.5 TWh, or around 1% of the total energy products supplied in Norway, originated from biofuels (solid or liquid), biogas, and waste (renewable and non-renewable) [182]. Around 25% of this was waste, amounting to a total quantity of 1415 kt [183]. The main barrier for an increased use of bioenergy in Norway are the relatively low prices of electricity in relation to the investment costs for bioenergy systems [181], but there is also some debate about the ‘renewability status’ of the resulting energy produced. For example, only about 50% of WtE is considered as renewable in Norwegian national statistics [174]. However, WtE has been outlined in government reports (e.g. Ref. [171]) as part of the waste hierarchy after waste prevention, reuse, and recovery steps.

According to Becidan [174], in 2015 there were 17 WtE plants in Norway processing around 1.7 kt waste, of which approximately 60% derived from households. The most widely used and well proven technology is a moving grate on which the waste is combusted [184]. The main output of these plants is about 4 TWh for district heating networks, although not all energy is always delivered to the customer [174]. Quantities of steam for industry and electricity are also produced; total electricity production based on biomass is around 3.4 TWh, and is based mainly from waste and waste-wood incineration [181]. The capacity of Norwegian WtE plants is relatively small, with the smallest national average size in Europe (60 kt per year). In recent years there has been a strong increase in total WtE, with total capacity increasing by approximately 36% since 2010 [174]. WtE is particularly important for some sectors, such as district heating (Fig. 27.) [185].

An example of a WtE plant is the Klemetsrud facility near Oslo, with an annual capacity of 415 kt waste. Composed of several plant trains, a new combustion line was commissioned in 2011 and has an annual capacity of 160 kt, producing 55.4 MW heat and 10.5 MW electricity [184]. Full technical specifications of the KA3 line based on a reciprocating grate, with a combustion performance of 20 t/h and a heating value of 12 MJ/kg, have also been reported [186]. Currently, Klemetsrud is undergoing a test program for the establishment of at least one full-scale industrial plant in Norway for CO_2 capture by the year 2020 [187].

According to the Ministry of Petroleum and Energy [188], as of 2012, around 35 biogas plants were established in Norway, which delivered almost 200 GWh per year. Of these, 23 plants were based on sewage sludge, five on food waste, one for co-treatment of sewage sludge and food waste and five small plants for manure with co-treatment with waste [188]. The gas produced is used for heating, power production and transport. In Oslo and Akershus, there are plans for the bus fleet to be powered only by renewable sources by 2020, with around 40% from biogas [189].

Bioenergy use has increased since the landfill ban for organic waste in 2009(Becidan et al., 2015, EEA, 2016) and other government initiatives including the creation of Enova SF in 2001 – the public enterprise for economic support of environmentally friendly projects. During the last years, Enova has had several programmes that have offered investment aid (subsidies) to bioenergy facilities [181,188]. Trømborg [181] summarises other support measures, including measures from Innovation Norway, the Norwegian Agricultural Authority, and research and development grants from the Norwegian Research Council, as well as inclusion in government plans. A challenge is that the Norwegian-Swedish green electricity certificate market established in the year 2012 does not include WtE [174]. Some issues also exist with profitability; WtE plant processing capacity exceeds the waste produced in the Scandinavian market, where the gate fee is basically set by Swedish plants [174,190].

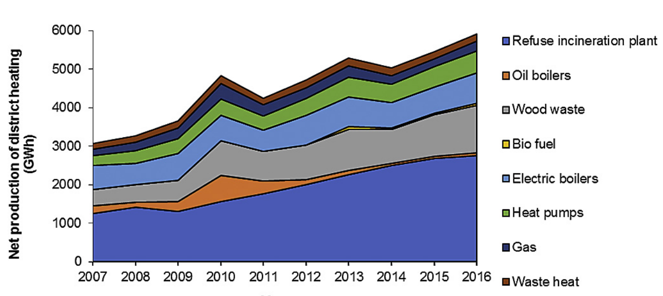

Fig. 27. Net production for district heating by type of heat (GWh). Data is sourced from SSB [185].

10. Overview of MSW management systems in the selected Member States: the Western region

10.1. MSW management in the United Kingdom

10.1.1. MSW management and organisation: the United Kingdom

The United Kingdom (the UK) is a large European country with a 65.6 million population. The population is increasing and growing older. Additionally, it is estimated, that the UK population could exceed 74 million by 2039 [191]. On average, the population density is more than 250 people per km^2. However, in London it is above 5000 and in Scotland it was only 67 in 2010 [192]. Given that the UK consists of England, Scotland, Wales, and Northern Ireland, there are different waste management systems applied in different regions. For instance, Defra the UK government Department for Environment, Food and Rural Affairs has a policy on waste and recycling and this applies to England. However, it deals closely with the devolved administrations in Wales, Scotland, and Northern Ireland, and generally leads on negotiations in the EU and internationally [193]. The three major waste management authorities in England and Wales are: the Environmental Agency, the main regulator, Waste Collection Authorities, controlled by local authorities, and finally, the Waste Disposal Authority. While waste management policies are set by the Central Government, local authorities are responsible for waste collection and disposal. In England, for example, waste collection is managed at the District level and waste disposal at the County level (a County typically consists of up to six Districts) [194]. The UK current government has an ambition to make their generation the first to leave the natural environment of England in a better state than they found it [195].

The Waste (England and Wales) (Amendment) Regulations 2012 amended the Waste (England and Wales) Regulations 2011 to include the separate collection of waste (i.e. paper, metal, plastic, and glass), as required by the EU regulations. Similarly, there are the Waste Regulations (Northern Ireland) 2011, and Waste (Scotland) Regulations 2012. Due to a lack of an explicit EU definition of MSW, there was a discrepancy in understanding MSW in the UK. Until recently the term 'municipal waste' in Britain referred to all waste collected by Local Authorities, but it did not include a significant proportion of waste similar in nature and composition to household waste generated by businesses and not collected by Local Authorities [196]. After a redefinition of the meaning of MSW, this type of waste is also included, which also led to changes in national diversion targets.

In 2014, 251 million tonnes of waste were produced in the country, according to Eurostat data [197]. About 10.7% of it was accounted as municipal waste (26.8 million tonnes) [198]. During the last decades, the annual amounts of municipal waste produced per capita varied between 602 kg in 2004 and 477 in 2012. The generation on MSW in the UK is shown in Fig. 28. As can be seen, there was a gradual decrease in MSW production from 2004 to 2012, and after that the amount of waste increased slightly. It is worth noting, that in 2015 the generation of MSW was approximately 20% lower than in 2004. Additionally, amounts of MSW are growing at a rate slower than GDP [199].

The UK imports about 125 million tonnes of goods and raw materials each year (apart from fossil fuels), and also imports and exports waste. Approximately 250 thousand tonnes of waste were imported in 2011. Moreover, each year about 15 million tonnes of waste is directed for recycling to other countries. The waste

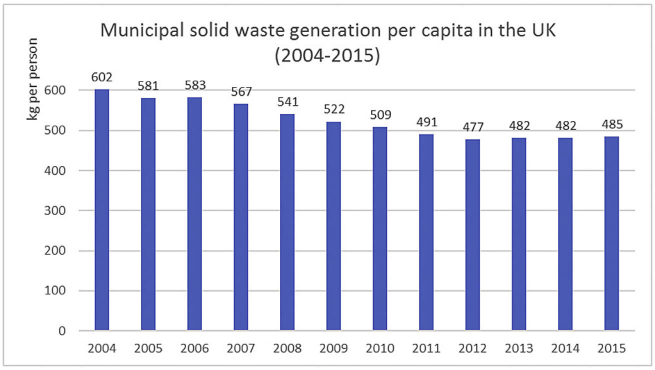

Fig. 28. Municipal solid waste generation in the UK [56].

materials that are exported include glass, paper, plastic, and scrap metal. The most important trading partners for the UK are the rest of the EU and European Free Trade Association (EFTA) countries, but also Turkey, India, and China. It is interesting, that the UK exports refuse derived fuel mainly to North Europe for energy recovery. Exports of RDF have risen from zero in 2009 to 887,465 tonnes in 2012! This was caused by the rising costs of landfill in the UK [200]. Additionally, a UK Plan for Shipments of Waste was prepared [201] and this document regulates waste import/export issues. It also provides practical solutions in waste shipment.

There is an aspiration to reduce the amount of household waste not reused, recycled, or composted to 12.2 million tonnes (a reduction of 45%) [199]. The UK recycling rate for household waste was 44.3% in 2015, falling from 44.9% in 2014. Despite this slight fall, it is possible that the UK will meet its 2020 targets. It is commendable, that Wales has already reached the national target in 2012 (52.1%) and is still improving the recycling rate [198]. The UK as a whole has met the packaging waste recycling target (61%) [202].

The amount of biodegradable municipal waste (BMW) sent to landfill has to be reduced in all Member States. In 2020 landfilled BMW must be reduced to 35% in relation to 1995. Fig. 29 shows, that the 2020 target was reached in 2011. A Landfill Tax, introduced in the UK in 1996, was directed at minimising waste generation and its landfilling. Each year - since 2011 - the tax has increased by 8 pounds per tonne, up to 80 pounds in 2014. Importantly, solid inert waste has a lower rate of the tax that promotes suitable pre-treatment of residual waste before landfilling (see Fig. 30).

The national waste management plan for the United Kingdom was presented in December 2013. The key aim of the plan is to direct efforts towards a zero-waste economy and a sustainable economy in the long term [200]. This document, together with

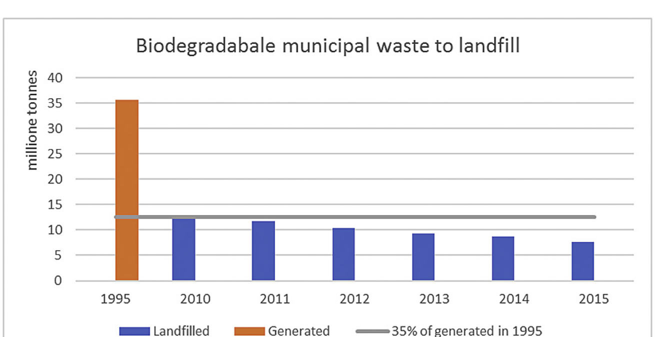

Fig. 29. Biodegradable municipal waste to landfill (2010–2015) (based on [198]).

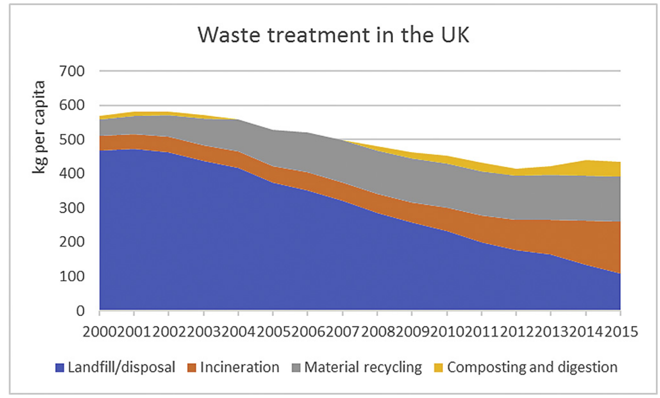

Fig. 30. Waste treatment in the UK (2000–2015) [56].

Waste Strategy for England 2007 [199], show the UK's aims in the waste management sector and ways to achieve them in the coming years. First of all, the government aims to incentivise efforts to reduce, re-use and recycle waste and to recover energy from waste. Additionally, regulations should be reformed to drive the reduction of waste and diversion from landfill together with cost reduction. National, regional, and local governance need clearer performance and institutional frameworks to deliver better coordinated action and services on the ground. Furthermore, investment in collection, recycling and recovery infrastructure, and markets for recovered materials, that will maximise the value of materials and energy recovered, is also one of the priorities of the UK's government.

The UK government implemented successful measures to promote high quality recycling and increase the frequency and quality of waste collections. For example, the Department for Communities and Local Government's £250 million Weekly Collection Support Scheme funded 82 councils to organise weekly collections of municipal waste. It is promising, that about half of these councils planned to use some of their funding to implement recycling reward schemes. Moreover, since 2015 separate collection of waste paper, metal, plastic, and glass is required, which simplify further recycling. The Waste and Resources Action Programme (known as WRAP) was initiated by the UK government to improve waste management [200]. The WRAP programme (in England, Wales and Northern Ireland) which aims at showing how businesses, organisations, and consumers can be part of a resource revolution, is a good example of best practice for waste and resource efficiency.

Furthermore, the government also promotes high quality recycling and prepared suitable guidance [203]. It is estimated, that the UK has sufficient residual waste management treatment infrastructure, since there is no need for new plants, because “the Government aims to obtain the most energy from waste, not to get the most waste into energy recovery” [200]. More information about government action in the waste management sector is published regularly on-line [204]. For example, large retailers in England have been required by law to introduce a charge (5 pence) for all single-use plastic carrier bags since 5 October 2015. Reported data indicated, that major retailers issued about 83% fewer bags in 2016–2017 compared to 2014! Approximately 6 billion bags were saved. It can be said, that each person in the population used around 25 bags during 2016–2017, compared to around 140 bags a year before the charge. Moreover, the majority of money raised from the fee was contributed to charities [205].

Waste prevention in the UK is widely promoted and the action plan is extensive and multidimensional. For instance, an efficient waste prevention action proposed in the country is called Reused Credits. The authorities responsible for waste collection and disposal can pay credits to third parties who collect or reuse MSW. This results in savings in waste management costs, because of higher rates of recycling and the reuse of household waste. For example, Devon's authorities introduced this solution to support the local community. The community used the credits to organise a network of “Refurnish” shops. People with lower incomes can buy repaired items at a lower price; and many unemployed residents are trained to repair different products [206]. To improve waste prevention, the Innovation in Waste Prevention Fund (as part of the waste prevention programme) was launched in May 2014, funded by Defra for partnerships with creative ideas for preventing waste [207].

While there are many good practices in MSW management in the UK, the European Commission recommends that the UK, similar to other Member States, should improve the performance of the extended producer responsibility (EPR schemes) covering the main waste streams to ensure appropriate and sustainable funding of separate collection, sorting/recycling [202].

10.1.2. Waste-to-energy in the United Kingdom

Renewable energy resources are one of the most important topics of recent years since reliance on fossil fuels is not sustainable. The United Kingdom government recommends the anaerobic digestion (AD) of organic waste and released the *Anaerobic Digestion Strategy and Action Plan* in 2011 [208]. The potential of AD in greenhouse gas reduction and benefits from energy recovery and fertiliser production were taken into account. Therefore, the number of AD plants in the UK doubled during the two years after the Strategy was published. Additionally, the UK supports energy recovery from residual waste through efficient thermal processes. Residual waste means waste that is left over when all the recycling possible has been done. Therefore, the environmental or/and economic costs of further cleaning and separating the waste are bigger than potential benefits of doing so. Many issues surrounding energy recovery from MSW are discussed in *Energy from waste. A guide to the debate.* This extended guide provides information for members of the public, waste and planning officials in local government, elected members of local and national government, the waste management industry, energy companies etc. [209]. An analysis of the social costs and benefits from different WtE scenarios in the UK was made by Jamasb and Nepal [210]. They concluded that energy recovery from MSW plays an important role in both waste management strategy and renewable energy policy. However, the full potential of WtE cannot be achieved unless the heat delivery networks are developed. Tunesi [211] studied local strategies for WtE in England and emphasised the importance of waste transportation to treatment plants and the estimation of waste streams in investment planning. Additionally, the flexibility in the choice of technology may improve the efficiency of the sector. As these studies prove, there is a need to develop new technology and study their potential in the WtE industry.

Up to date, in 2014 there were 29 Energy recovery facilities (with R1 accreditation) of which 5 were dedicated to MSW processing with a total capacity about 2.3 million tonnes annually. Facilities without formal R1 accreditation are not included and are concerned as ‘incineration’ rather than ‘energy recovery’ plants. The UK has 83 such facilities with total capacity exceeding 9.8 million tonnes of waste treated per year based on 2014 data [198]. In general, about 8–9% of MSW generated in the UK can be incinerated with high efficient energy recovery using national plants. According to data compilation made by the Office for National Statistics, production of energy from renewables has been increasing stably during the last two decades and reached 17.4 Mtoe in 2015. More than 2 Mtoe of this energy was taken from MSW, which accounts for about 11.5% [212].

As far as innovative technologies are concerned, there is an ongoing development of the patented [213] micro-scale Home Energy Recovery Unit (the HERU), which is a heat pipe based waste treatment unit, invented to process all unwanted domestic materials to generate energy for the household. In contrast to a usual pyrolysis system which requires pre-treatment, and which relies on direct heating techniques, such as electric heaters, heating with naked flames or exposure to hot media and involves very high temperature, the HERU technology is more efficient, as pyrolysis of waste is possible at low temperatures (below 300 °C) without the need of any pre-treatment of the waste prior to its loading. The key feature of the unit is that the heat injection into the treated materials operates by providing a controlled working temperature rather than controlled heat fluxes. Furthermore, the use of heat pipe technology achieves high uniformity of heat distribution throughout the chamber volume as well as enabling high efficiency of energy recovery, which can further contribute to meeting the energy recovery targets [38].

11. Concluding remarks

In a circular development model, materials and their value in circulation within the economic system are retained for as long as possible, by optimising the integrated waste cycle in order to put resources to efficient use. In the EU vocabulary re-use, recycling, and recovery are the key words that a new paradigm is built upon to promote sustainability, innovation, and competitiveness. This paper has argued that multifunctional technology solutions presented by WtE should be given more attention in the circular economy due to their capacity to bridge and enhance resource and energy efficiency improvements. WtE has a role to play in the circular economy, contributing to synergies in three EU policies – waste management, energy union, and environmental (climate change) policy enabling the Member States to meet their targets linked to these policies, especially in the context of resources and energy efficiency. Given that the EU is the main driver of change in the EU Member States (including the EEA), the paper also reviewed recent changes to the legislative framework on waste management. It seems that the European Commission is set to provide further clarity on the notion of MSW to avoid any ambiguities among the Member States. Yet, further harmonisation at EU level is required, especially in the context of setting well-defined criteria for the ‘end-of-waste’ status and the calculation rules (i.e. there is currently no single homogenous method on how to calculate what is recycled, composted, or landfilled, which has caused some uncertainties, particularly in newer Member States). Among new legal initiatives, the first Commission document to define the role of WtE in the circular economy is welcome, despite not being legally binding. In this document, the Commission assigned some WtE processes to various steps in the waste hierarchy, where it also noted that WtE could play a role in the transition to a circular economy provided the waste hierarchy is used as a guiding principle to ensure that prevention, reuse, and recycling are not averted. Yet, the communication could have gone a step further assigning other technologies to the waste hierarchy. Indeed, apart from anaerobic digestion, there are a number of new market technologies, such as pyrolysis and gasification that provide the potential to recover products from the waste stream which complete incineration would not allow. These should be further utilised in the European countries.

The examination of waste management development in the selected European countries revealed that the biggest proportion of waste (above the EU average) was generated in Italy (486kg/per capita), Greece, and the UK (each 485kg/per capita). Even though GDP is higher in the UK and Italy, the same cannot be said about

Table 10
Summary of the main findings.

GEO	Main legislation	Definition of MSW	Organisation of MSW management: regional, national, local	Waste generation	Landfilling	Recycling	WtE with Energy recovery (R1)	Waste Shipping
Estonia	The Waste Act	It includes waste from households and similar waste from trade.	Two tiers system: national and local.	Low - below EU average.	Landfilling has been largely reduced mainly due to WtE.	Recycling has improved recently, yet, it is largely uneven across different regions.	Largely increased in recent years. Overcapacity is reported.	Imports waste for energy recovery from Ireland, Finland.
Greece	The Criminal protection of the environment Law.	MSW refers to domestic waste, as well as other types of waste that due to composition or nature are similar to domestic waste.	Complex system at national and regional levels.	High – above EU average.	Landfilling is the main waste disposal option. Illegal landfilling is one of the main issues.	Less than 1/5 of waste is recycled.	Energy recovery is marginal. The immature WtE market. Some new developments are underway, especially in the Attica region.	N/A
Italy	Legislative Decree 152/2006 (Environmental Protection Code)	Waste originated in households and similar to household waste by nature and composition found on the roads or in public areas, private areas subjected to public use (i.e. on sea or lake beaches, on the bank of rivers or streams); garden waste originating from gardens, parks and cemeteries, waste deriving from exhumation and any other waste deriving from cemetery activity; some types of commercial, craft and industrial waste with characteristics similar to MSW (i.e. packaging material, textile clippings, rubber, food waste, wood scraps and scrap from furniture, etc.).	Regional and local levels.	High – just above EU average. Yet, it shows trends of regular decrease due to the prevention programme.	On average about 1/3 of MSW is landfilled. However, there are big differences across different regions, especially in southern and central regions.	On average over ¼ of MSW is recycled.	One of the top EU countries with regard to WtE capacity. There is a national movement of MSW from South to North, where the most plants are located.	It is among the largest exporters in Europe.
Latvia	The Waste Management Law	It includes waste from households and similar waste from trade.	National and regional levels.	Low – below EU average.	Landfilling is the main waste disposal option and is currently largely utilised.	Less than ¼ of waste is recycled.	Only a very small amount is sent to MBT.	Latvia imports from the UK.
Lithuania	The Law on Waste Management.	It includes waste from households and similar commercial waste. In addition, it also includes industrial waste (which by its nature similar to household waste).	Regional and national levels.	Medium – but below EU average.	Landfilling is still the main waste disposal option.	Improving, but less 1/3 of waste is recycled.	Only a negligible amount of energy if recovered in Klaipeda CHP. Yet, two new WtE CHP plants are on their way. This is main option to divert waste from landfills in the future.	Exports have recently been decreased; exports only small amounts of waste (i.e. Poland). Imports of waste to Lithuania for the purpose of energy recovery are not allowed.
Norway	The Pollution Control Act	Statistics is prepared for household waste only, which is about 90% of total MSW. 'Household waste' is defined as waste deriving from normal activities in households, including	Regional and national levels.	Medium – but below EU average	Marginal landfilling. Quantities of landfilled household waste have significantly decreased since 2006 due to incineration.	Recycling is relatively well established (42%) and is the second waste disposal	WtE is the main waste disposal option. WtE schemes include incineration with energy recovery, as well as the production of biofuels.	Exports of waste have increased in recent years, mainly to Sweden.

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Table 10 (*continued*)

GEO	Main legislation	Definition of MSW	Organisation of MSW management: regional, national, local	Waste generation	Landfilling	Recycling	WtE with Energy recovery (R1)	Waste Shipping
		food residuals, packaging material, paper, textiles, electric and electronic waste, garden waste, furniture and wood waste, and other large objects.				option after incineration.		
Poland	The Waste Act; Act on Keeping Cleanliness and Order in Municipalities; Environmental Protection Law.	It includes household waste (except, end-of-life vehicles), as well as non-hazardous waste produced in other places, which by their nature or composition, are similar to household waste.	Regional and national levels. Municipalities are responsible for waste management local systems.	Very low - much below EU average. Potentially, due to the lack of reporting and illegal dumping.	Landfilling is still the main disposal option, yet it has been decreasing in recent years.	Improving, currently about ¼ of waste is recycled.	Intensive development in recent years. About 9% of waste can be utilised – good estimation of new plants capacity.	Export to Germany; Smaller amount imports from Germany, Lithuania.
Slovenia	The Environmental Protection Act.	Waste generated in households or ýsimilar to household waste in nature or composition ýgenerated from trading, ýmanufacturing, commercial, business services and other activities and also from surfaces ýand in public buildings.	Regional and national levels. Municipalities are responsible for waste management.	Medium – just below EU average.	Landfilling has been drastically reduced despite increase in generation of MSW. There are big differences across regions (ranging from 10% to 40%).	MSW recycling rates are among the highest in the EU.	Mainly produced in the CHP. Given that the main waste disposal option is recycling and a small size of the country, there is only one main CHP plant for thermal waste treatment.	About 8% of MSW is exported (mainly to Austria, and Hungary).
Spain	The Law on waste and contaminated soils	Household waste generated by households (i.e. the domestic activity of households) and similar waste from small commercial activities, office buildings, institutions such as schools and government buildings, and small businesses.	Regional, and local levels.	Medium – just below EU average.	Landfilling is still a problem, approximately ½ of MSW is sent to landfills.	There is a steady increase in recycling (nearly 1/3 of MSW was recycled)	Relatively well developed WtE system. Yet, not all WtE plants meet the R1 requirement. There is a goal to use only rejected materials in WtE plants.	Exports of waste have recently decreased.
UK	The Waste (England and Wales) (Amendment) Regulations 2012; Waste Regulations (Northern Ireland) 2011; Waste (Scotland) Regulations 2012.	Recently updated, now includes household waste collected by Local Authorities and waste from businesses, which composition similar to household waste.	National, regional, and local levels – depending on the part of the country.	High – just above EU average.	Largely reduced since 2000, only about ¼ of waste is landfilled at the moment.	High level – more than 40% of waste is recycled, 75% of which is material recycling.	Well-developed infrastructure. Overcapacity in the context of circular economy – more than 1/3 of waste is incinerated.	Low import. The largest exporter in Europe, especially RDF. Directions: EU, India, Turkey, China. Special Plan for Shipments of Waste was introduced.

Greece (i.e. which together with Latvia has one of the lowest GDP rates per capita). The lack of correlation between GDP and waste generation can be noted in Norway; despite having the highest GDP rate, its waste generation was below EU average and some other countries analysed, such as Slovenia, Spain, and Lithuania. Poland generated a remarkably low amount of MSW in comparison to the other countries analysed. This can be surmised to be due to illegal dumping and, therefore, a failure to report waste generated. Additionally, the definition of MSW differs across the analysed countries in Europe. Some of them identify rather detailed potential sources of waste similar to household waste, whereas others (i.e. Estonia, Latvia) provide limited sources, referring to "similar to household waste from trade". Therefore, this can influence statistical data on the generation of MSW.

Despite attempts to transfer to waste-to-energy, landfilling is still a problem in most Member States, especially in Greece (81%) and Latvia (79%), followed by Lithuania and Spain (reaching 55% each). There is no surprise that two countries with the lowest GDP rate send the largest amount of their MSW to landfills, as landfilling is regarded the cheapest option in terms of investment (provided there are barely any regulatory government policies in place to divert waste from landfills). Yet, if the government introduces a high tax and landfilling fee, it may just be that it is more economically viable to reuse waste in order to produce energy than depositing it in landfills as the example of Estonia proves. Indeed, the most advanced country for averting its MSW from landfills is Estonia, which moved from landfilling almost all its MSW just after the Soviet era to only 5% in 2015. This is mainly due to energy recovery, which increased from 16% in 2012 up to 56% in 2014. However, the success in diverting waste from landfill to primarily energy recovery can potentially have a negative impact on separate collection and recycling schemes of MSW. The best recycling rate (61%) is demonstrated in Slovenia, especially in the Ljubljana area. This is due to its Regional Waste Management Centre (CERO Ljubljana), ýone of the most modern waste treatment facilities in Europe. Although Ljubljana in Slovenia and Tallinn in Estonia have been named as the best performers in terms of waste generation and recycling, the amount of waste generated by municipalities and waste management performance in individual municipalities differ considerably. The same experience can be shared in other countries, particularly in small municipalities, which as a rule of thumb, lack competence and resources to fulfil their waste management responsibilities, therefore, proving that further cooperation among municipalities and central government is essential.

While waste management and prevention policies are defined in all countries, a further focus to view waste as a source is lacking. Currently, Italy and the UK have the most WtE plants in terms of their capacity, with the aerobic and the aerobic/anaerobic treatments being successfully utilised in Italy, especially in the Milan area. The recent UK government encouragement to bring further focus on anaerobic digestion has proven also flourishing as the number of AD plants in the UK doubled during the two years after the Strategy was published. Yet, the UK exports relatively large amounts of MSW either for recycling, to long-distance destinations, such as China, India, and Turkey, or for energy recovery, mainly in Northern Europe, which can barely be justified from an environmental point of view (and does not comply with the principle of proximity). Even though Norway has 17 WtE plants, their capacity is small in contrast to its nearest neighbour Sweden (its waste export destination), which alongside with Denmark processes the largest amount of waste in Europe [6]. It is important to note the current development of WtE plants in Central and Eastern Europe. Initially, WtE plants were considered a relatively expensive solution in the Baltic countries and Poland with landfill being the main viable option. Yet, this situation has changed – the WtE plants are now growing in the Baltic countries (except for Latvia) and Poland. During the past few years Poland has been able to build a system of WtE plants, which can produce 'green energy' through the effective utilisation of about 9% of MSW generated in the country with each newly built plant (five in total) being equipped with an efficient flue gas cleaning system to minimise any negative effects to the environment and human health. Estonia's experience has revealed that the capacity of WtE should be considered in advance to ensure that countries, especially with small markets, would have enough feedstock for their plants. Given that two modern WtE mass incineration plants are set to be built in Lithuania in the forthcoming years, it would be useful to see whether overcapacity will be avoided. Unlike Estonia, Lithuanian's NWMP categorically forbids any MSW import for energy recovery. Additionally, the near future will show whether (or not) the current State monopolies of the WtE industries in Estonia and Lithuania would lead to technology lock-in and, therefore, stagnation. It has been noted that flexibility in the choice of technology may improve the efficiency of WtE. At the other end of the spectrum, Greece and Latvia are two of the few European countries with no WtE infrastructure. Further key findings are encapsulated in Table 10.

To conclude, it seems that most issues in the countries analysed are due to political factors and the decentralised nature of waste management with multi-level governance. WtE in the MSW management context varies significantly in the European countries considered. In most cases 'waste' is still regarded as a 'nuisance' rather than a resource. This must change when moving towards the circular economy. A political will is a key driver for change. Therefore, further cooperation between local waste management authorities and the different ministries responsible for diverse policies, including waste management, energy, and environment, should be employed in order to explore the full potential of the WtE industry embracing a holistic approach. There exists the CEWEP – the Confederation of European Waste-to-Energy Plants, the umbrella association of the owners and operators of WtE plants from 22 countries in Europe. Yet, it is essential for the industry to have regular links with the regulatory bodies, which could be facilitated via a network platform enabling a bottom-up approach. Building on the CEWEP and COOLSWEEP, a European-wide WtE network should be set up for different Member States (including the EEA) to share their experiences in research and development of innovative technology to unravel the potential in the WtE industry and any regulatory framework to accommodate it. Additionally, there is also a need for a top-down direction with the EU set targets being clearly communicated, as well as a future driven long-term long waste management strategy and priorities to achieve them being defined. Finally, further cooperation between Member States is largely advisable especially with neighbouring countries, as the example of Norway and Sweden indicates, where 'waste' could be transported to neighbouring countries with overcapacity for treatment, thus, benefiting both countries involved.

Therefore, despite some remarkable improvements, the destination is far from reached as there are still many steps to be taken moving towards a circular economy.

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