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Bio-waste in Europe — turning challenges into opportunities

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Stakeholders

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Key messages

- Bio-waste — mainly food and garden waste — is a key waste stream with a high potential for contributing to a more circular economy, delivering valuable soil-improving material and fertiliser as well as biogas, a source of renewable energy.
- Recently revised waste legislation within the EU's circular economy strategy has introduced a number of targets and provisions that will drive both the prevention and the sustainable management of bio-waste. With a share of 34 %, bio-waste is the largest single component of municipal waste in the EU. Recycling of bio-waste is key for meeting the EU target to recycle 65 % of municipal waste by 2035.
- About 60 % of bio-waste is food waste. Reducing the demand for food by preventing food waste can decrease the environmental impacts of producing, processing and transporting food. The benefits from reducing such upstream impacts are much higher than any environmental benefits from recycling food waste. The Sustainable Development Goals' target of halving food waste by 2030 has helped to put preventing food waste high on the policy agenda in most European countries.
- Approximately 88 million tonnes (173 kg per person) of food is wasted every year in the EU-28 (28 EU Member States) along the entire food value chain. This corresponds to about 20 % of all food produced.
- To enable bio-waste to be used as a source of high-quality fertiliser and soil improver, it needs to be collected separately at source while keeping impurity levels low. Contamination with plastics is a growing concern, and plastics need to be prevented from entering bio-waste. Although the share of municipal waste composted and digested was 17 % in 2018 — up from 11 % in 2004 — a high proportion of bio-waste still ends up in the mixed waste that is landfilled or incinerated, even in many countries with well-established separate collection systems.
- More and more plastic consumer products are labelled as 'compostable' or 'biodegradable', and there has been a proliferation of different labels. This creates risks of confusing consumers, contaminating compost and increasing the costs of treatment. Clear rules on labelling of compostable/biodegradable plastics are needed, and we also need to identify which applications might have overall benefits and under which conditions.
- Quality standards and quality assurance processes for compost, digestate, fertilisers and soil improvers help to build trust in them and are an integral part of a good bio-waste management system. A Europe-wide requirement to implement quality assurance systems covering all compost and digestates would improve trust in and awareness of the value of bio-waste. In many countries such systems already exist.
- Treatment of separately collected bio-waste is dominated by composting, but anaerobic digestion, with biogas production, is increasing. Biogas is a source of renewable energy. Research and innovation increasingly explore the opportunities for using bio-waste, mainly from food processing, as a new source of higher value products such as volatile fatty acids and biofuels, but many challenges remain.

Executive summary

This report provides an overview of bio-waste prevention, generation, collection and treatment in Europe. It aims to support countries by sharing experience and best practice. Bio-waste (Box ES.1) can play an important role in the transition to a circular economy, by both preventing its generation and capturing its potential as a source of valuable secondary resources (Figure ES.1). The focus of this report is on food and garden waste from households and similar public and commercial activities such as food services.

European circular economy and waste policies increasingly address bio-waste as one of several key waste streams. These include new targets for the recycling and preparing for reuse of municipal waste and an obligation for separate collection for bio-waste. Moreover, EU Member States are required to monitor food waste generation and to have a food waste prevention programme, supporting Sustainable Development Goal 12.3 — to halve food waste by 2030. The 'Farm to fork' strategy on sustainable food within the EU's Green Deal (EC, 2019a) will reinforce food waste prevention.

Bio-waste accounts for more than 34 % of the municipal solid waste generated, amounting to 86 million tonnes in 2017 in the EU-28 (28 EU Member States for the period 2013-2020). Recycling bio-waste is therefore crucial for meeting the EU target to recycle 65 % of municipal waste by 2035.

The level of **separate bio-waste collection** differs considerably across Europe. Many countries are far from capturing bio-waste's full potential. Implementing a separate bio-waste collection system is a sometimes lengthy and always complex process. It needs a comprehensive and coordinated policy framework embedding a bio-waste strategy into broader waste and circular economy strategies. Targets or pay-as-you-throw schemes will create clear incentives to divert bio-waste from residual waste. Awareness-raising activities, providing good information to consumers and matching treatment capacity to the volume of separately collected bio-waste are other crucial factors.

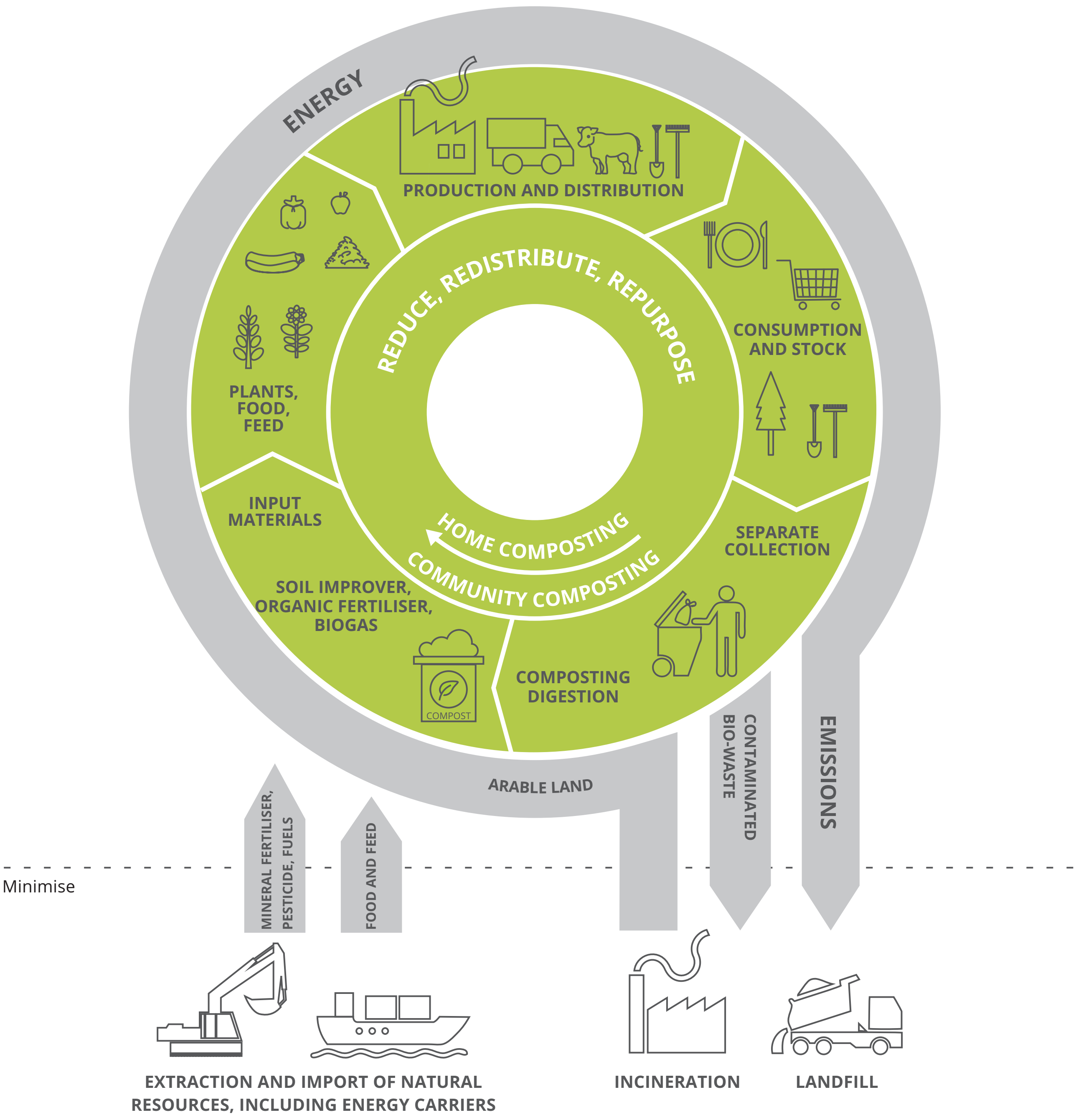
Food waste accounts for nearly two thirds (60 %) of all bio-waste from households and similar sources. More than other waste types, preventing food waste is perceived as an ethical responsibility for society. It is associated with a waste of economic resources and their resulting negative environmental externalities. Generally, in the majority of European countries, food waste stands out as a priority in waste prevention policies. The most common policy actions to address food waste are awareness-raising and information campaigns. Other common measures are food redistribution platforms and increasing promotion of retailers' second-class food sales. However, measuring the effectiveness of waste prevention activities or policies is still a challenge. In the future, harmonised data should enable us to compare the potential impact of different policy mixes for preventing food waste applied in European countries.

Composting (treatment in the presence of oxygen) and **anaerobic digestion** (treatment in the absence of oxygen) are currently the two most widely applied treatment techniques. Composting dominates the treatment capacity but the use of anaerobic digestion is increasing. Anaerobic digestion generates biogas and is thus a source of renewable energy. The preferred treatment technique depends on the composition of the bio-waste and the properties of the separate collection system, but anaerobic digestion tends to deliver higher environmental benefits.

Box ES.1 What is bio-waste?

According to the Waste Framework Directive's definition, bio-waste comprises 'biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food-processing plants'. Food waste, a key component of bio-waste, can be edible (e.g. food purchased but not eaten, leftovers from meals) or non-edible (e.g. banana peel or bones). The edible part is targeted by food waste prevention measures. Apart from bio-waste, there are other biodegradable wastes, for example paper and cardboard waste, wood waste and natural fibres in textiles. However, these are outside the definition of bio-waste and are not addressed in this report.

Figure ES.1 Bio-waste in a circular economy



To close the bio-waste circle, the **compost and digestate** should be of good quality to enable their use as a soil improver and/or fertiliser. To create a market for compost and digestate, managing the quality of the process and the end products is very important, as it can create trust in the outputs. The separation of bio-waste at source is a basic condition for achieving high-quality outputs. Of the countries surveyed for this report, 24 have or are currently developing national standards for compost quality. Out of these, 12 countries have developed compost quality management and assurance schemes, creating access to higher added value markets such as potting compost. Applying compost to European soils — and especially soils with a low organic matter content — improves the soil's ability to retain water and nutrients and store carbon and raises its fertility. Using high-quality compost or digestate to replace mineral nitrogen, phosphorus and potassium fertiliser reduces environmental impacts as a result of avoiding production of virgin mineral fertilisers. An estimated 134 000 tonnes of nitrogen and 44 000 tonnes of phosphate are currently lost through the bio-waste disposed of in mixed municipal waste in Europe.

More and more consumer products, mainly certain plastic bags, but also some other products, are labelled as **'compostable'** or **'biodegradable'**. Strategies for the use of compostable bags for collecting bio-waste vary across Europe. In some countries and municipalities, they are used as a means to ease collection and reduce contamination with conventional plastics, while their use is not accepted in others. Their biodegradation depends on conditions such as presence of moisture and oxygen, so their use needs careful consideration and alignment with the treatment infrastructure. For example, such plastics usually do not biodegrade during anaerobic digestion. Moreover, products suitable for industrial composting do not necessarily biodegrade in nature or in people's household composting bins. Developing clear and consistent labelling and instructions on using and disposing of biodegradable/compostable plastics is of utmost importance, while restrictions for certain applications may be necessary.

New opportunities are arising for **turning bio-waste into valuable bio-products and biofuels**, with a focus on well-defined bio-waste streams from food processing and agriculture. Much research is investigating the many challenges to be tackled. As there is often a gap between laboratory research and its transfer to industrial-scale commercial application, improving the uptake and application of research findings needs collaboration between researchers, industries and governments.

1 Introduction

Bio-waste — mainly food and garden waste — is the largest single component of municipal waste and is also generated in agriculture and industry. Diverging policies for this important waste fraction are found in European countries, and its management varies depending on local conditions and capabilities. Many European countries have already implemented the separate collection of bio-waste, but some are still searching for the best practices and means of implementation.

In 2018, the revised Waste Framework Directive (WFD) (EU, 2008, 2018b) introduced several substantial changes relevant for bio-waste:

- an obligation for all EU Member States to collect bio-waste separately or ensure recycling at source from the end of 2023 onwards;
- new targets for the preparation for reuse and recycling of municipal waste which, in combination with the Landfill Directive's landfill reduction targets for municipal waste (EU, 1999, 2018a), are unlikely to be met without proper management of bio-waste;
- an aspirational target to reduce food waste in line with Sustainable Development Goal 12.3 to halve food waste by 2030, and a mandate for the European Commission to propose a binding food waste reduction target by the end of 2023;
- a requirement for EU Member States to measure and report food waste generation annually, starting in 2020, and to adopt specific food waste prevention programmes.

In addition, sustainable bio-waste management will substantially contribute to the objective of halving the amount of residual (non-recycled) municipal waste by 2030, as proposed in the 2020 circular economy action plan (EC, 2020b). In accordance with the European policy, national, regional and local policymakers and stakeholders have important decisions to make in the next couple of years about the sustainable management of bio-waste. This report aims to contribute to the knowledge base and support these processes by sharing experience and best practice.

Bio-waste has considerable potential to contribute more widely to the circular bioeconomy through, for example, being processed into fertiliser, soil improvers and non-fossil fuels. Under the EU's circular economy action plan (EC, 2015b), efforts to use bio-waste as a resource have gained additional traction, and technical developments going beyond the current end products of bio-waste treatment, such as biogas and compost, are emerging. Other new or revised rules relevant to bio-waste and its resource-efficient use include the Fertilising Products Regulation, amended in 2019 (EU, 2019b) and the Single-Use Plastics Directive (EU, 2019a). Food waste is also included in the European Commission's monitoring framework of indicators for the circular economy (EC, 2017).

In many countries, action on waste prevention gives high priority to food waste prevention. Countries are implementing policy measures ranging from ecolabelling, through improving consumer awareness, to increasing the responsibilities of producers and distributors. The new reporting requirement on food waste generation introduced under the WFD will for the first time enable tracking of the progress of such policies across Europe in a harmonised way.

This EEA report, produced in collaboration with the European Environment Information and Observation Network (Eionet) countries and the European Topic Centre on Waste and Materials in a Green Economy (ETC/WMGE), continues the work at the EEA on the bio- and circular economies. It builds upon the 2018 EEA report *The circular economy and the bioeconomy — partners in sustainability* (EEA, 2018) and information drawn from Eurostat and the European Reference Model on Municipal Waste (ETC/WMGE, 2019b) (Box 1.1). It describes the current state of play in countries, extending the information on bio-waste management systems and policies with information on specific initiatives related to the new legal requirements on food waste.

The report starts by explaining why it is important to address bio-waste (Chapter 2), followed by an overview of current collection and treatment systems for bio-waste in Europe and their outcomes (Chapter 3). Chapter 4 focuses on food waste and describes recent policy developments and best practice in food waste prevention. As ensuring the high quality of the outputs of bio-waste treatment is of utmost importance, Chapter 5 outlines the current state of quality management of compost and digestate and of creating a market for them in European countries. Finally, looking ahead, Chapter 6 explores some trends in innovative valorisation schemes for bio-waste.

Box 1.1 Sources of information

The analyses in this report are based on the literature, countries' waste prevention programmes, information provided by the EEA member and cooperating countries through the Eionet national reference centres on Waste (NRCs) and information provided by stakeholders. The information from the countries was elicited through a survey that was carried out in spring 2019. Annex 1 shows the countries/regions that responded to the survey and the survey questions.

As well as data provided by the NRCs on waste through the survey, the assessment uses Eurostat data, complemented by data drawn from the European Reference Model on Municipal Waste (ETC/WMGE, 2019b).

No claim is made that this report covers all aspects of municipal bio-waste management and prevention, as countries may have additional related policies, instruments or targets that are not captured in the report.

2 Why is bio-waste relevant?

The Waste Framework Directive (WFD) defines bio-waste as biodegradable garden and park waste; food and kitchen waste from households, restaurants, caterers and retail premises; and comparable waste from food-processing plants. This report focuses on food and garden waste from households and similar public and commercial activities such as food services.

Bio-waste represents an important share of European municipal waste generation. In 2017, the EU-28 (28 EU Member States) generated 249 million tonnes of municipal solid waste (Eurostat, 2019), of which about 34 %, or 86 million tonnes, was bio-waste (Figure 2.1). This includes both bio-waste that is separately collected and bio-waste collected together with mixed (residual) waste but excludes home-composted bio-waste.

Because of its considerable volume, the EU's common objectives for waste management cannot be met without addressing the bio-waste stream. If not managed well, this voluminous waste stream poses significant environmental and economic threats (Pubule et al., 2015). For example, biodegradable waste, including bio-waste, is a key source of greenhouse gas emissions from landfill sites, corresponding to about 3 % of total EU greenhouse gas emissions (EEA, 2019a). Addressing municipal bio-waste is also crucial for moving towards the new targets defined in the 2018 WFD. This directive introduces new targets regarding recycling and preparation for reuse: by weight, at least 55 % by 2025, 60 % by 2030 and 65 % by 2035.

Food waste is an important component of the municipal bio-waste stream. It can be divided into avoidable and non-avoidable food waste (Chapter 4). Preventing avoidable food waste is perceived as an ethical responsibility, because it is associated with the misappropriation of economic resources and their resulting negative environmental externalities (Philippidis et al., 2019). For this reason, the European Commission's bioeconomy strategy has started to focus on food systems. The strategy aims to demonstrate how food waste can be transformed into valuable resources and to create innovation and incentives to help retailers and consumers to cut food waste by 50 % by weight by 2030 and contribute to the transition to a circular economy (EC, 2018a). Most recently, a forthcoming EU 'Farm to fork' strategy was announced, which is intended to address all stages of the food chain, including food waste (EC, 2019a).

Food waste represents 60 % of the total municipal bio-waste in the EU-28 and garden waste accounts for 35 %, while the remaining 5 % of municipal bio-waste is classified as 'other'. On average in 2017, 43 % of municipal bio-waste was collected separately, while 57 % of bio-waste ended up in mixed municipal waste and was thus lost for recycling.

While Figure 2.1 shows the picture for the EU-28, per capita bio-waste generation varies considerably among European countries (Figure 2.2). Hungary and North Macedonia have the lowest levels of bio-waste generation per person, 75 and 79 kg respectively, while the share of bio-waste in total municipal waste generated varies between 17 % in Hungary and 58 % in Montenegro. However, when interpreting country differences, the degree of uncertainty and lack of harmonisation of waste composition data should be kept in mind.

The data in Figure 2.2 show the wide diversity in terms of volumes of bio-waste generated, as well as the relative importance of bio-waste in municipal waste generation. The differences across countries are influenced by a range of factors, including:

- There are differences in how countries report municipal bio-waste from non-household sources, for example to what extent garden waste from parks and food waste from the hospitality sector is included.
- The level of urbanisation of a country or region. For example, in the Munich region, people living in low-density areas produce more and cleaner bio-waste, mainly driven by the higher share of garden waste (Langer, 2017).
- Separate collection system. The introduction of separate collection of bio-waste tends to lead to higher amounts of bio-waste in the waste management system, as some consumers divert bio-waste from home composting to the collection bins (EC, 2015a).
- Prevalence of home-composting. Composting at home decreases the volumes of bio-waste to be collected and managed. This is the case, for example, in Slovenia, which has one of the lowest shares of bio-waste in municipal waste generated in Europe. In Slovenia, producers of bio-waste are encouraged to compost it themselves. If they do not do so, they have to separate it for separate collection by public services (EC, 2015a). Home composting is not included in the data presented in this report because of a lack of data registered at country level.

Impacts of bio-waste

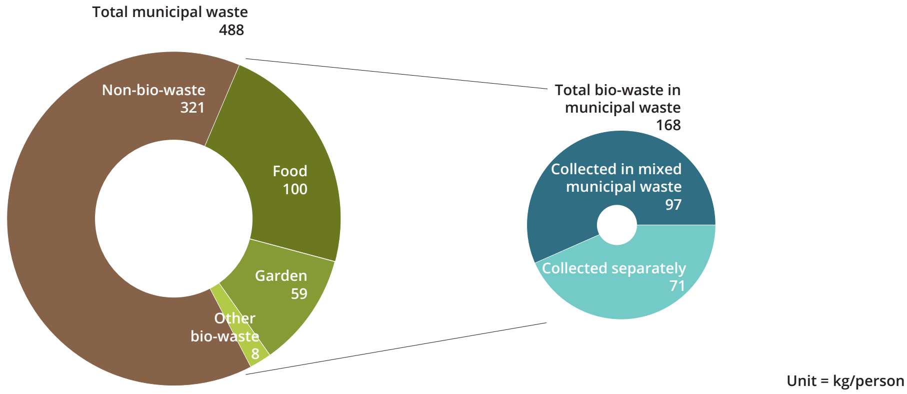
The generation and management of these volumes of bio-waste, especially food waste as the main constituent of bio-waste (see Section 4.1), have various environmental, social and economic impacts.

The food value chain is responsible for a large share of life-cycle environmental impacts related to total consumption in the EU (EEA, 2012). Food production requires the use of resources including land, water, fuel and raw materials. The application of fertilisers and the raising of livestock are major sources of environmental pressures from generating greenhouse gas emissions to the release of nutrients. In addition, other steps in the food supply chain, such as storage, transport and preparation, contribute to the environmental impacts of food. It is estimated that greenhouse gas emissions related to food losses and wastes in the EU-28 are responsible for 15-22 % of the total life-cycle emissions of the food consumed (Scherhaufer et al., 2015, 2018). Scherhaufer et al. (2018) also estimated that a global warming potential of 186 million tonnes of carbon dioxide equivalent (Mt CO_2e) can be attributed to food waste in Europe, or on average about 2.1 tonnes of CO_2e per tonne of food waste.

Food that is produced and marketed but not eaten causes unnecessary environmental pressures along its whole value chain. Most of the environmental pressures related to food waste are generated in the production phase of the food. 73 % of food waste-related greenhouse gas emissions are derived from food production, 6 % from food processing, 7 % from retail and distribution and 8 % from food preparation and consumption, with the disposal of food waste contributing just 6 %. Meat and dairy products make the highest contribution to the overall environmental impacts of food waste in terms of global warming potential, acidification potential and eutrophication potential (Scherhaufer et al., 2018).

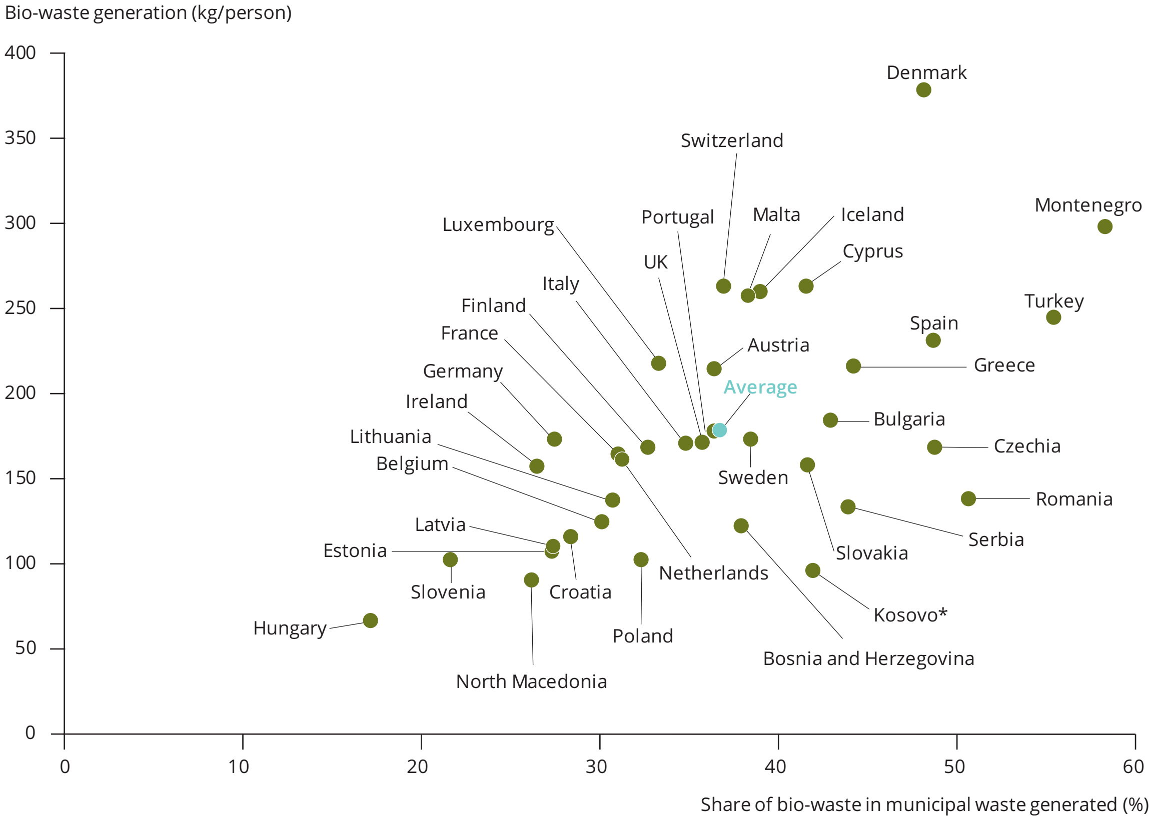
The Food and Agriculture Organization of the United Nations (FAO) estimates that approximately one third of the edible food produced for human consumption is either lost or wasted globally (Gustavsson et al., 2011). In addition to the environmental impacts, the generation of food waste also has social and economic impacts. It results in not only the loss of natural resources but also economic losses for farmers, consumers and other stakeholders in the food value chain. This leads to higher food prices for consumers, which increases food insecurity by making it less accessible to the poorest groups (Gustavsson et al., 2011; Manfredi et al., 2015).

Figure 2.1 Bio-waste in municipal waste and how it is collected, EU-28, 2017



Source: ETC/WMGE compilation based on data provided by the European Environment Information and Observation Network (Eionet) through an EEA and European Topic Centre on Waste and Materials in a Green Economy (ETC/WMGE) survey (ETC/WMGE, 2019a), complemented with data from the European Reference Model on Municipal Waste (ETC/WMGE, 2019b) and Eurostat (2019).

Figure 2.2 Municipal bio-waste generation per person and share of bio-waste in municipal waste generated by country, 2017



Notes: *Kosovo under UN Security Council Resolution 1244/99. UK, United Kingdom. Excluding Albania, Liechtenstein and Norway due to lack of data. Bio-waste that is composted at home is not included in the data. The average is the weighted average of the 36 countries included in this figure.

Source: ETC/WMGE elaboration based on data provided by Eionet through an EEA-ETC/WMGE survey (ETC/WMGE, 2019a), Eurostat (2020) and the European Reference Model on Municipal Waste (ETC/WMGE, 2019b) for Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Germany, Greece, Italy, Lithuania, Luxembourg, Malta, Poland, Spain and the United Kingdom.

Because most of the environmental impacts of bio-waste come from food production, food waste prevention at all stages of the food value chain is highly relevant. If demand for food is reduced by preventing food waste, the environmental impacts of producing, processing and transporting food decrease. Preventing food waste in households and in the hospitality sector has the greatest indirect effect in mitigating environmental pressures. This is, first, because of the high share of potentially avoidable food waste at the household and food service sector levels in terms of weight (see Figure 4.2) and, second, because the environmental impacts at the consumer stage include all the accumulated impacts from earlier stages of the supply chain (Scherhaufer et al., 2018). However, responsibility for preventing food waste lies with all stages of the food value chain.

It is important to collect unpreventable bio-waste separately and choose a treatment option that is sustainable (Scherhaufer et al., 2018). Landfilling of bio-waste has very high negative environmental impacts. In landfills, biodegradable waste decomposes and produces gas that mainly consists of methane, a powerful greenhouse gas, and landfilling of separately collected bio-waste or of bio-waste within residual municipal waste without pre-treatment is not allowed in the EU according to the WFD and the Landfill Directive (EC, 2008).

In a circular economy, bio-waste is directed to treatment options that use the waste as a source of valuable resources such as nutrients, organic substances and energy. For example, composting and anaerobic digestion are biological treatment methods that may be classified as recycling when the compost or digestate produced is used as a recycled product, material or substance, and, in the case of its use on land, it results in benefits to agriculture or ecological improvement (EC, 2008). Anaerobic digestion also produces biogas that can be either used to generate heat and electricity or upgraded into a low-carbon biofuel. There are also other emerging and innovative technologies that aim to valorise bio-waste as products or energy (Chapter 6). In addition to the environmental benefits, separate collection and recycling of bio-waste may also create new employment opportunities (EC, 2008; Maina et al., 2017). Generating biogas from agricultural residues and bio-waste is a well-established practice in many countries and has, for example, been mentioned by North Macedonia (Eionet, 2019) as an opportunity to both reduce greenhouse gas emissions and create employment in rural areas.

3 Bio-waste management in Europe — status and trends

The revised WFD introduced a new requirement for bio-waste separation. By 31 December 2023, bio-waste must either be separated and recycled at source or collected separately and not mixed with other types of waste (EU, 2018b). This aims to increase the quality and uptake of secondary raw materials. In addition, as from 2027, compost derived from mixed municipal waste will no longer count towards achieving compliance with the recycling targets for municipal waste by 2027. Bio-waste consists of food waste, garden waste and other bio-waste. Figure 3.1 shows the composition of municipal bio-waste for 32 European countries.

Again, there are large differences in the composition of countries' bio-waste, and the reasons behind them are often difficult to explain because of multiple influencing factors. First, the bio-waste collection system is likely to have an important impact: when garden waste is collected separately, the share of garden waste tends to be higher. This is the case in, for example, Czechia, which has the second largest share of garden waste in its bio-waste. Moreover, bio-waste that is home composted is not included in these data. In addition to the waste collection and management strategy, external factors can also affect the bio-waste composition. Examples of such factors are seasonality (with seasonal garden waste streams), climate (Edjabou et al., 2018), the level of urbanisation (Shi et al., 2013), geographical area, local traditions, and economic, social and political aspects (Di Maria et al., 2018).

Some of the differences are, however, due to different ways of collecting data. Bio-waste composition, and waste composition in general, is not a regularly reported data flow, and some countries' data include mixed food and garden waste categorised as 'other bio-waste'. Differences in the way countries include waste from parks in reporting municipal waste also affect the data. The analysis therefore provides an approximate picture of the relevance of the different waste streams.

3.1 Collection of bio-waste

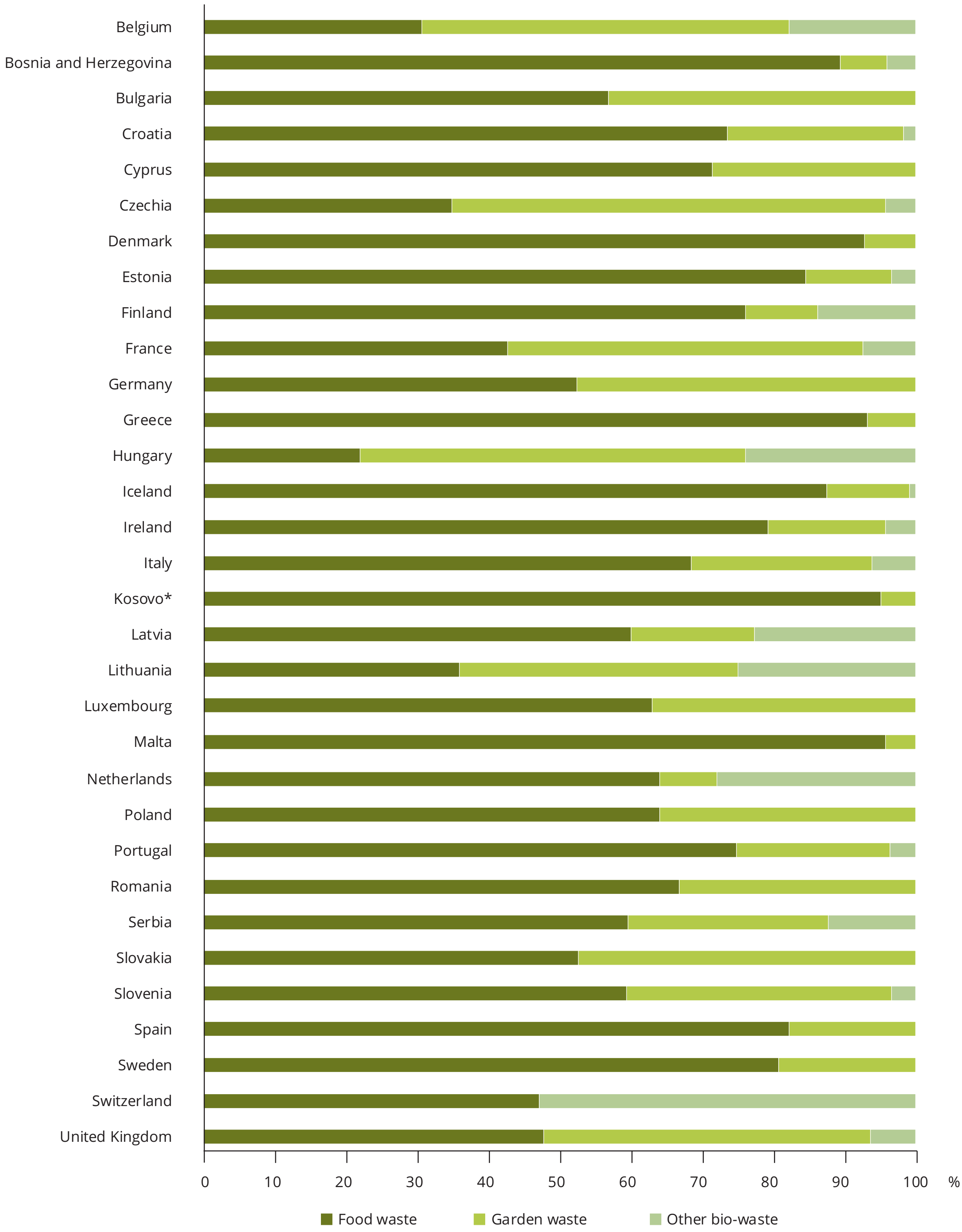
3.1.1 Separation and composting at source (home composting)

Sustainable treatment of bio-waste first of all requires it to be separated from residual waste at source. In principle, the most sustainable way of bio-waste management is home composting or community composting at the local level if it is done properly. This can decrease the need for separate bio-waste collection (EC, 2015a) and thus reduce the waste transport and management costs (Vázquez and Soto, 2017) and the associated environmental impacts. This is especially relevant in sparsely populated areas. Citizens may benefit from a good-quality fertiliser and soil improver (compost) for use in their gardens or vegetable plots. For example, 48 % of people in Slovenia were reported to have home composting systems (Žitnik and Vidic, 2016).

The compost produced by households or small communities (such as blocks of flats in small villages) can typically be used at the local level. This is a textbook example of closing loops locally. Especially in remote areas, this kind of de-centralised system can offer an opportunity for bio-waste treatment (Panaretou et al., 2019). Home composting, however, requires people to have some knowledge of good composting practice to avoid unnecessary environmental impacts and to ensure good-quality compost. Odour and greenhouse gases (e.g. methane, nitrous oxide) can be emitted during the process if not well managed (Colón et al., 2012). For sanitary reasons, animal-based food waste should, however, be excluded from home composting (e.g. animal-based food waste accounts for 21 % of food waste in Denmark (Edjabou et al., 2018)).

Therefore, the success of home and community composting depends on the quality of waste separation and citizens' management of the composting process. Community composting as typically implemented in

Figure 3.1 Composition of municipal bio-waste for 32 EEA member and cooperating countries, 2017



Notes: *Kosovo under UN Security Council Resolution 1244/99.

'Other bio-waste' may include mixed food and garden waste.

Source: ETC/WMGE compilation based on data provided by the European Environment Information and Observation Network (Eionet) through an EEA and European Topic Centre on Waste and Materials in a Green Economy (ETC/WMGE) survey (ETC/WMGE, 2019a), Eurostat (2020), and the European Reference Model on Municipal Waste (ETC/WMGE, 2019b) for Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Germany, Greece, Italy, Lithuania, Luxembourg, Malta, Poland, Spain and the United Kingdom.

urban areas requires additional organisational effort (Dri et al., 2018). Awareness-raising campaigns and training can help to motivate people to separate and manage their bio-waste sustainably (Eionet, 2019). For example, Flanders in Belgium has trained more than 5 000 volunteers in the past 25 years to help citizens practise home composting and closed loop gardening, and 41 % of Flemish households compost at home (VLACO, 2020). In a survey, 84 % of home composters reported that they had never experienced problems with composting or the compost (VLACO, 2018).

Several examples illustrate this option: the Revitaliza programme in the Spanish province of Pontevedra adopts a decentralised system — a combination of home composting, community composting and small composting facilities, including extensive awareness raising and training of 'compost masters' (Mato et al., 2019). The Decisive (2018) project aims to analyse and demonstrate options for decentralised bio-waste management systems in Catalonia, Spain, and the city of Lyon, France. A community composting project in the city of Bratislava, Slovakia, demonstrated the importance of cooperation among the various stakeholders and citizens interested in composting their own bio-waste, and resulted in a reduction in the amount of bio-waste in mixed municipal waste. The French Environment and Energy Management Agency (ADEME) has set up a platform for sharing experiences from small-scale bio-waste management and food waste prevention projects from all over the country. Overall, good cooperation and good information on the source separation scheme can lead to high levels of recovery of bio-waste and related cost savings in waste services (Panaretou et al., 2017).

For most European countries, data on home composting are currently not available. However, EU Member States have the option to include home-composted bio-waste when reporting their rates of recycling municipal waste, as required by the Waste Framework Directive (WFD), following the calculation method adopted in 2019 (EC, 2019b). For those EU Member States that make use of this option, data on home composting will become available in the coming years.

3.1.2 Separate collection

Separate collection is a prerequisite for using bio-waste as a resource in a circular way. Collecting bio-waste separately from other municipal waste keeps the levels of impurities and contamination down as far as possible and enables its use as valuable secondary resources such as soil improvers, organic fertilisers and biogas (Xevgenos et al., 2015; Fricke et al., 2017). The European Commission will propose to harmonise separate waste collection systems (EC, 2020b).

Introducing separate bio-waste collection usually requires an initial investment by the public sector, but cost-benefit analyses have shown that the overall economic outcome for both citizens and the waste management organisation is positive if the whole waste management system is optimised (Bourka et al., 2015; Rodrigues et al., 2015; Niskanen and Kemppi, 2019). The actual costs depend on many factors, including the collection system (door-to-door collection or containers on the roadside), population density, collection frequency and weather conditions.

Optimisation of the system could entail reducing the collection frequency for residual waste, creating economic incentives for waste prevention and participating in separate collection, as well as tailoring the system to local circumstances (Ministry of Agriculture, Food and Environment, Government of Spain, 2013), including ensuring appropriate sanitary conditions. Analysis from a large number of municipalities shows that higher recycling rates for municipal waste, including bio-waste, can be achieved without increasing the costs of the waste management system (Giavini, 2017). The revenues from the sales of renewable energy, soil improvers and fertilisers produced from bio-waste can cover part of the collection and treatment costs (Niskanen and Kemppi, 2019). However, such products have to compete with virgin materials, fuels and energy, which are partly subsidised and their prices often do not take account of the environmental damage they cause.

Figure 3.2 presents separate bio-waste collection rates in 32 European countries in 2017. About 50 % of the municipal bio-waste generated is collected separately in the countries that provided data (weighted average). The remaining 50 % of municipal bio-waste is collected with residual (mixed) waste. The separate collection rates vary from 80 % or more in Austria and Slovenia to less than 10 % in Bosnia-Herzegovina, Cyprus, North Macedonia, Portugal, Spain and Turkey, demonstrating that, at an individual country level there remains ample room for improvement. Malta recently introduced separate collection of bio-waste across the country but data on quantities were not available.

In many countries, pilot projects on introducing separate collection of bio-waste or food waste are carried out in selected cities or regions, or separate collection is already established in some municipalities or regions, for example in Poland, Portugal and Serbia (Eionet, 2019). Others carry out projects to improve or further develop already existing systems, for example

Box 3.1 The example of separate bio-waste collection in Munich, Germany

In Germany, on average 64 % of municipal bio-waste is collected separately. The separate collection systems show regional differences, with parts of the country having a long history of separate bio-waste collection. In Munich for example, the Waste Management Corporation introduced the concept of separate bio-waste collection in 1988 (Langer, 2017) and, following a testing phase, instituted a three-bin system in 1994. This system collected organic waste and paper waste separately from residual waste — and today the system has been modernised and expanded. The Corporation also invested in a biogas plant in 2003, which was enlarged in 2008, and a soil-processing plant in 2012. In 2017, Munich ran a campaign to increase the amount of bio-waste collected. The dry-fermentation biogas plant currently processes 22 000 tonnes of food and garden waste per year, resulting in 2 600 megawatt hours (MWh) of electricity, plus process heat, and 7 000-8 000 tonnes of compost per year. These figures indicate the economic potential of these techniques (Langer, 2017). If the Munich production figures are extrapolated to all European countries included in Figure 3.2 (ignoring the composition and cleanliness of the bio-waste), 52 million tonnes of bio-waste, which is currently not collected separately, could result in the production of about 8 000 gigawatt hours (GWh) of electricity per year and 23 million tonnes of compost.

in the Brussels Capital Region and Flanders in Belgium and in the Netherlands.

Consolidated data on the trends in the separate collection of bio-waste across Europe are not available. However, the amount of municipal waste that is composted or anaerobically digested — which might include some mixed municipal waste treated in mechanical-biological treatment plants — increased by 52 % in the period 2004-2018 (Eurostat, 2020). Collection of data on separately collected bio-waste is needed for monitoring the effectiveness of bio-waste management.

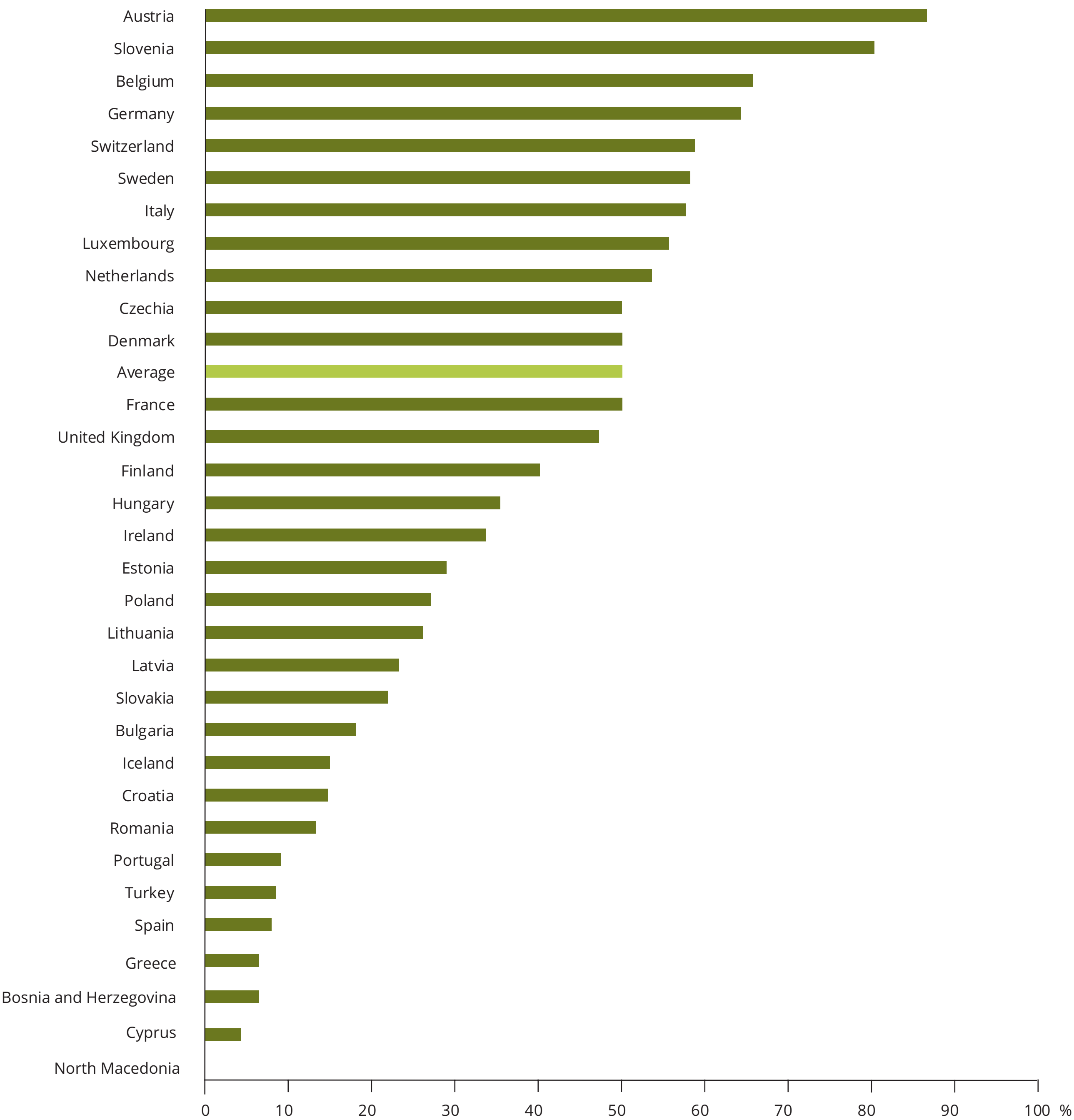
3.1.3 Introducing separate collection of bio-waste

The implementation of a successful system for separate bio-waste collection and management requires a comprehensive strategy, taking into account local circumstances. The following key factors play an important role (EC, 2000, 2015a):

- Bio-waste types targeted, for example food waste, garden waste, other bio-wastes. Some regions might need to focus more on specific types of municipal bio-waste (e.g. food waste in cities).
- A clear (measurable and achievable) set of objectives is set out.
- Selection of collection system. Various solutions have emerged including door-to-door systems, drop-off points in the streets, civic amenity sites, on-demand-collection.
- Economic incentives are offered to separately collect bio-waste, for example pay-as-you-throw systems.
- A treatment infrastructure for bio-waste is created.
- Direction towards waste treatment. Separately collected bio-waste can be directed to treatment installations at community or a more centralised level.
- Financial details. What costs will be accounted for by which parties, and what kind of revenue scheme will be applied (e.g. do citizens contribute or not?).
- Administration of the scheme. A successful separate bio-waste collection system requires detailed planning and design, involving municipalities or local governments.
- Targeted territory. This should take into account local parameters such as population density, ratio of tourists to residents, presence of hospitals, schools, hotels and restaurants, and presence of (urban) gardens (Decisive, 2018).
- Awareness raising. Separate collection systems will require good publicity and knowledge transfer to citizens to guarantee proper source separation, including, for example, targeting schools. This is one of the key recommendations arising from a review of successful separate bio-waste collection systems (EC, 2015a). Awareness raising should be combined with creating a positive image of the waste management authority or company. This is particularly important when a new separate collection system is introduced.

High levels of knowledge and engagement among citizens are crucial factors for successful separate waste collection systems (Xevgenos et al., 2015). In general,

Figure 3.2 **Bio-waste collected separately as a share of bio-waste generated (bio-waste capture rate), by country for 32 EEA member and cooperating countries, 2017**



Notes: Excluding Albania, Kosovo, Liechtenstein, Malta, Montenegro, Norway and Serbia due to a lack of data. Data exclude bio-waste composted at home. Austrian data include a considerable share of park and garden waste.

Source: ETC/WMGE compilation based on data provided by Eionet through an EEA and ETC/WMGE survey (ETC/WMGE, 2019a), Eurostat (2020), and the European Reference Model on Municipal Waste (ETC/WMGE, 2019b) for Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Germany, Greece, Italy, Lithuania, Luxembourg, Poland, Spain and the United Kingdom.

introducing separate collection of municipal bio-waste requires an integrated marketing campaign during the introduction stage for two reasons. First, the campaign needs to convince people to separate their bio-waste. Second, to avoid impurities and contamination, the campaign needs to educate people about what is allowed in the bio-waste bin.

In Munich, for example (Box 3.1), a campaign was set up and repeated several times, which resulted in very low impurity levels. Despite that, its citizens' overall knowledge of bio-waste separation and recycling remains low, as reported by the Munich Waste Management Corporation (Langer, 2017). In the Irish city of Sligo, an awareness-raising campaign significantly increased the number of households participating in separate bio-waste collection and reduced the level of impurities from 18 % to 1 % and the share of bio-waste in residual waste by 10 percentage points (Eionet, 2019). The type of collection system is also important for the level of impurities. Door-to-door collection systems appear to encourage people to source-separate bio-waste better than drop-off systems with containers in the street (EC, 2015a). The level of improper materials such as plastics, paper and glass reduces compost quality, including contamination with heavy metals; thus, efforts to avoid such materials in the bio-waste are important (Rodrigues et al., 2020). The proliferation of plastic products labelled as compostable or biodegradable may create a specific challenge for separate collection and compost quality (Box 3.2).

Other success factors are providing economic incentives, such as higher fees for the disposal of non-separated waste, and regulatory measures (e.g. incineration bans, restrictions or mandatory source separation) (Xevgenos et al., 2015).

A comparative analysis of 19 different cases in Europe also demonstrated that the efficiency of separate bio-waste collection systems, assessed by performance over time, improves with the systems' maturity (EC, 2015a). Nevertheless, the study also found a number of cases that managed to achieve rapid improvements in separate collection in a short period (e.g. Ljubljana). Finally, municipalities with low population density achieve significantly higher participation and engagement rates in their separate collection systems. However, several European case studies indicate that municipalities with low population density should pay specific attention to the cost-efficiency of their separate waste collection systems, mainly because of transport distances (see, for example, Lombrano, 2009; Carvalho and Marques, 2014; Guerrini et al., 2017; Exposito and Velasco, 2018; Bartolacci et al., 2019).

3.2 Treatment of separately collected bio-waste

The potential benefits of separate bio-waste collection can only be reaped if separately collected bio-waste

Box 3.2 Compostable and biodegradable plastics and bio-waste management

More and more consumer products, mainly plastic bags, packaging, single-use cups, plates and cutlery, are labelled as compostable or biodegradable. 'Compostable' in most cases refers to compostability in controlled industrial composting plants, while the term 'biodegradable' is used for plastics that decompose under certain other conditions in the open environment. Many municipalities and waste collectors require citizens to use certified compostable plastic bags for collecting bio-waste, while others do not allow such bags. Strategies also depend on the bio-waste treatment infrastructure. Using compostable/biodegradable plastics for selected specific items that are mixed or attached to food waste such as fruit stickers or tea bags might help to reduce impurities and ease food waste collection (Crippa et al., 2019). Nevertheless, all requirements of the EU Single-Use Plastics Directive (EU, 2019a) also apply to compostable/biodegradable plastics.

However, this comes with a number of challenges. Several industry standards and related certification schemes exist for testing the compostability and biodegradability of plastics. If a plastic item is to actually decompose, this depends heavily on the material's composition and the conditions it is exposed to, such as moisture, oxygen, presence of microorganisms and duration of the process. Many plastics currently labelled as compostable or biodegradable are designed to decompose under controlled conditions in industrial bio-waste treatment plants but do not decompose, or only do so to a limited extent, in anaerobic digestion conditions (Kern et al., 2017), in small compost boxes in people's gardens, in soil or in water. Biodegradability in the marine environment remains difficult.

Moreover, the ambiguous term 'bioplastics' is used sometimes for compostable/biodegradable plastics and sometimes for plastics made from bio-based materials such as starch. However, plastics made from bio-based materials are not necessarily compostable or biodegradable. The proliferation of different labels and claims might therefore confuse people. This can create the risk of contaminating compost and contamination of the environment if people misunderstand such labels as a 'licence to litter'. The new circular economy action plan, adopted in March 2020 (EC, 2020b), commits the European Commission to developing a policy framework on the sourcing, labelling and use of bio-based plastics and on the use of biodegradable or compostable plastics, including their labelling.

is also treated properly. Hence, a region's bio-waste treatment capacity must be aligned with the bio-waste generated and collected separately.

3.2.1 *Treatment paths*

The most common treatment methods for separately collected bio-waste, in line with circular economy principles, are composting and anaerobic digestion:

- **Composting** is a process carried out in the presence of oxygen, usually either in open-air windrows or in-vessel. Through biodegradation of organic solids, a humic substance is generated that can be used as fertiliser, soil improver or a growing media constituent. The process works best with a good mixture of easily degradable, wet organic substances such as food waste and structure-improving organic matter such as garden waste.
- **Anaerobic digestion** is a process carried out in closed vessels without oxygen, which produces biogas that can be used to generate electricity or heat, or upgraded into a fuel and a digestate that can be used as an organic fertiliser or soil improver. The process can use different kinds of organic input materials but does not break down lignin, which is a key component of wood (see Canova et al. (2018) for a more detailed description).

The treatment techniques used for municipal bio-waste are usually also applicable to bio-wastes from other sources (e.g. from the food industry (Montoneri, 2017)). For this reason, municipal bio-waste is often treated along with other bio-waste streams. The bio-waste treatment technology that allows the greatest recovery of both material and energy is generally the environmentally preferable option. Based on life-cycle analysis, the European Commission's Joint Research Centre (JRC, 2011) identified a 'hierarchy' of options for bio-waste but stresses that life-cycle analysis of any given situation may produce results that deviate from that hierarchy.

While waste prevention and reuse (e.g. redistribution or use as animal feed) is clearly environmentally most preferable, anaerobic digestion of separately collected bio-waste (excluding some non-digestible wastes) is the second-best option followed by composting, because anaerobic digestion recovers both materials and energy. Nevertheless, reaping these benefits requires the following: compost is needed as a soil improver, compost obtained from direct composting and from composting of digestate are similar in composition and quantity, energy recovery from the biogas produced displaces fossil fuel-based energy production, and the digestion process is well managed. Comparing different disposal routes for food waste, a Dutch life-cycle analysis found the best results for material and energy recovery were achieved by composting with anaerobic digestion as pre-treatment (Odegard et al., 2015). However, in regions with low levels of organic matter in agricultural soils, composting might be the environmentally preferable option.

Anaerobic digestion is not always technically feasible, for example for high shares of garden waste. Although garden waste can be treated by anaerobic digestion, it often reduces the energy yield of the process because of the presence of lignin, which does not break down without oxygen. When anaerobic digestion is not (technically) feasible, composting of bio-waste should be assessed against energy recovery (JRC, 2011). Life-cycle analysis has proven to be a useful tool in this context, enabling comparison of the environmental benefits of material recovery with the environmental benefits of energy recovery. Various parameters play a role, for example process efficiency, waste composition, transport distance and the characteristics of the electricity mix replaced. One aspect that currently can be covered only qualitatively in life-cycle analyses is the benefit of compost for soil quality (JRC, 2011).

Typically, countries do not exclusively opt for one bio-waste treatment path. Instead they choose a combination of techniques, as this enables them to target different types of bio-waste from multiple sources.

3.2.2 *Treatment capacity*

Assessing the capacity for treatment of municipal bio-waste in Europe is difficult, as only a limited number of countries have data available on their installed and planned treatment capacity for this waste fraction. At present, based on information provided by 20 countries, representing about 59 % of the municipal bio-waste generation in EEA member and cooperating countries, the known annual capacity of treatment infrastructure in these countries is 38 million tonnes of bio-waste. This encompasses an installed capacity of 21 million tonnes for the composting of bio-waste and an additional 17 million tonnes for the anaerobic digestion of bio-waste. The actual treatment capacity is likely to be considerably higher, as a number of European countries did not provide data on the capacity of their treatment infrastructure. These treatment capacities are not exclusively used for municipal bio-waste treatment. In some installations municipal bio-waste is treated along with other waste streams including manure, sewage sludge and waste from the food industry (Eionet, 2019).

The 2018 WFD requires the separate collection of bio-waste or recycling at source (home composting) by December 2023. This new obligation, in combination with the new requirements for municipal waste recycling, is expected to push more bio-waste in the direction of anaerobic digestion and composting, and hence also to increase the installed capacity of these treatment techniques. Information about planned capacity — although very limited — indicates an increasing relevance of anaerobic digestion (ETC/WMGE, 2019a).

The capacity of the installed bio-waste treatment infrastructure varies considerably across the 21 European countries that provided data on this. The treatment capacities vary between 356 kg of bio-waste per person and close to zero. Some countries indicated that they only provided data on their known capacity for bio-waste treatment, possibly missing out part of their installed capacity due to a lack of data.

Linking treatment capacity, which might not only be used to treat municipal bio-waste, to municipal bio-waste generation and separate collection provides some valuable insights, bearing in mind that the conclusions drawn from these insights are restricted by the previously mentioned limitations. However, the countries for which treatment capacity data are available (Figure 3.3) can be broadly categorised into three groups:

- Sufficient treatment capacity for all municipal bio-waste generated: Austria, France, the Netherlands, Slovenia, Sweden and the United Kingdom. These countries' treatment capacity exceeds the volume of municipal bio-waste generated. Hence, in the extreme case that all municipal bio-waste were collected separately, the country theoretically would be able to treat all of this bio-waste. If a country's installed bio-waste treatment capacity exceeds the municipal bio-waste generated, this does not imply that the country has excess treatment capacity.

- Treatment capacity is available for the separately collected municipal bio-waste but not for all of the municipal bio-waste generated: Belgium, Cyprus, Hungary, Italy (although its treatment capacity is very close to the volume of bio-waste generated), Latvia, Poland, Portugal, Romania, Slovakia and Spain. These countries are currently able to treat all of the separately collected municipal bio-waste, given their installed treatment capacity. However, as separate collection increases, the installed treatment infrastructure will need to be extended. Croatia has plenty of anaerobic treatment capacity, but most plants only process animal by-products, and their spatial distribution does not necessarily match the location of bio-waste generation.

- Insufficient treatment capacity for the separately collected municipal bio-waste: Estonia, Greece, North Macedonia and Turkey. These countries are currently not able to (theoretically) treat the volume of bio-waste generated, nor are they able to treat all separately collected bio-waste. However, bio-waste might be treated in mechanical-biological treatment plants or in anaerobic digestion plants that mainly treat agricultural waste, and this capacity might not be included in the reported capacities. Extending separate collection of bio-waste will require the installation of new treatment capacity.

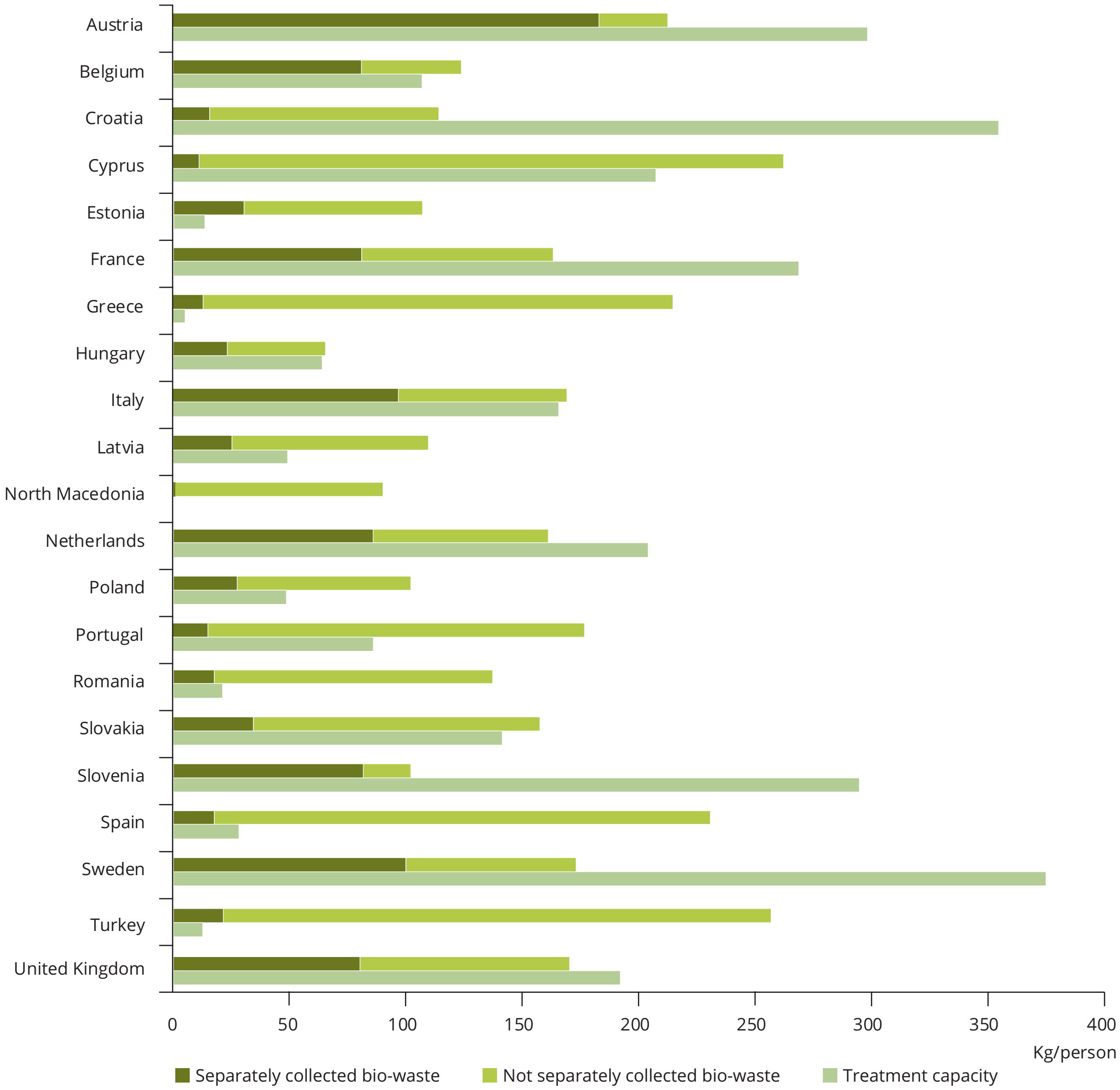
On average, in the 21 countries that provided information, composting facilities currently account for 53 % of the bio-waste treatment capacity, while anaerobic digestion accounts for 47 %; no data are available on the volume of home composting.

At country level, however, there are significant differences (Figure 3.4). Estonia, Greece, Hungary, Latvia, North Macedonia and Romania provided data only for their composting infrastructure for municipal bio-waste. Anaerobic digestion capacity may exist in these countries. In Austria, Belgium, Cyprus, Italy, the Netherlands, Slovakia and Spain, composting is the dominant treatment route. Only in a few countries, especially Croatia, Poland, Portugal, Slovenia, Sweden and Turkey, do anaerobic digestion capacities exceed those for composting. Finally, it is possible to combine bio-waste treatment capacity — the bio-waste is first digested and then the digestate is composted, for example as happens in Portugal. However, no data are available on the prevalence of this combined capacity.

The uptake of anaerobic digestion can be affected by environmental regulations such as the Renewable Energy Directive (EU, 2009, 2018c; Achinas et al., 2017; Araya, 2018). The directive requires EU Member States to ensure that at least 10 % of their transport fuels come from renewable sources by 2020 and establishes renewable energy targets for the EU of at least 20 % by 2020 and 32 % by 2030.

Comparable policies at national level can simultaneously encourage anaerobic digestion. In the United Kingdom, for example, the introduction of the renewable transport fuels obligation, which since 2014 has required fuel suppliers to source 5 % of their fuels from renewable sources, significantly encouraged the development of its anaerobic digestion capacity (Allen and Wentworth, 2011). In addition, Araya (2018) indicated that other types of policies that govern land use and waste disposal can also encourage

Figure 3.3 **Bio-waste generation and treatment capacities for 21 EEA member and cooperating countries, 2017**



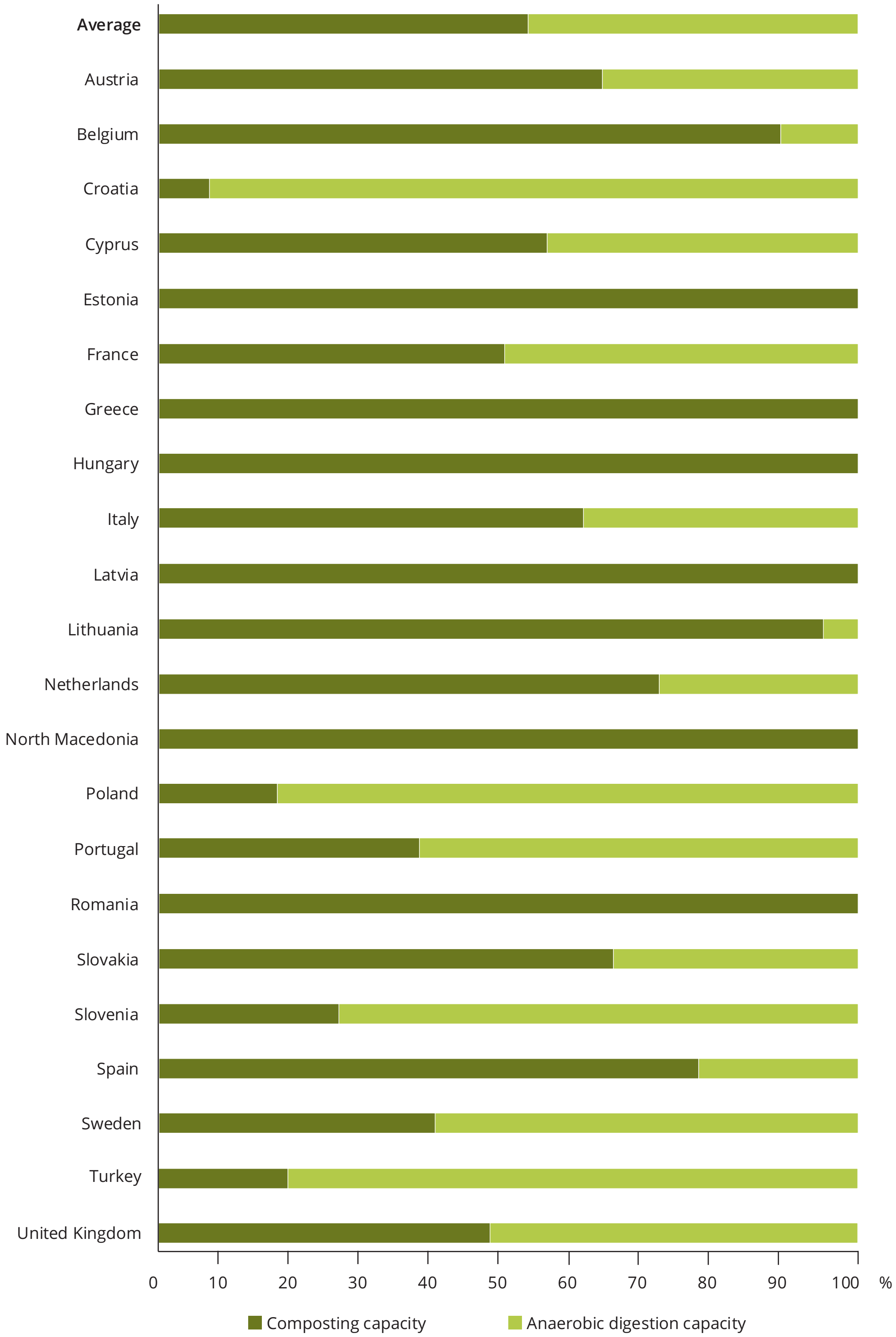
Note: Home composting is not included because of a lack of data. Data refer to 2017 or latest available data.

Source: ETC/WMGE compilation based on data provided by Eionet through an EEA and ETC/WMGE survey (ETC/WMGE, 2019a), Eurostat (2020), and the European Reference Model on Municipal Waste (ETC/WMGE, 2019b) for Belgium, Croatia, Cyprus, Estonia, Germany, Greece, Italy, Poland, Spain and the United Kingdom.

anaerobic digestion, such as regulatory frameworks for agriculture, policies to reduce greenhouse gas emissions, incentives (e.g. subsidies) that have ensured the success and viability of anaerobic digestion, and mandatory requirements to divert biodegradable waste from landfill sites (Araya, 2018). In the future, technological advancements in the field of anaerobic digestion are also expected to increase its potential and improve its economic viability (Fricke et al., 2017).

Currently, composting and anaerobic digestion are the technologies most commonly used for managing bio-waste. In the future, bio-waste could increasingly be used as a source of higher value products in line with the principle of the circular economy, namely to keep the value of products and materials in the economy as far as possible. For example, in Denmark, Germany, Italy, and Norway, methane from anaerobic digestion plants is used to produce automotive fuels and for domestic purposes, or it is fed into the gas grid after purification (Eionet, 2019; ECN, 2020). Further innovations are explored in Chapter 6.

Figure 3.4 **Shares of treatment capacities for bio-waste for 22 EEA member and cooperating countries, 2017**



Note: The average refers to the weighted average across the 22 countries for which data are available. Home composting is not included because of a lack of data. Data refer to 2017 or latest available data.

Source: ETC WMGE compilation based on data provided by Eionet through an EEA and ETC/WMGE survey (ETC/WMGE, 2019a) complemented with data provided by the European Reference Model on Municipal Waste (ETC/WMGE, 2019b).

4 Improving food waste prevention in Europe

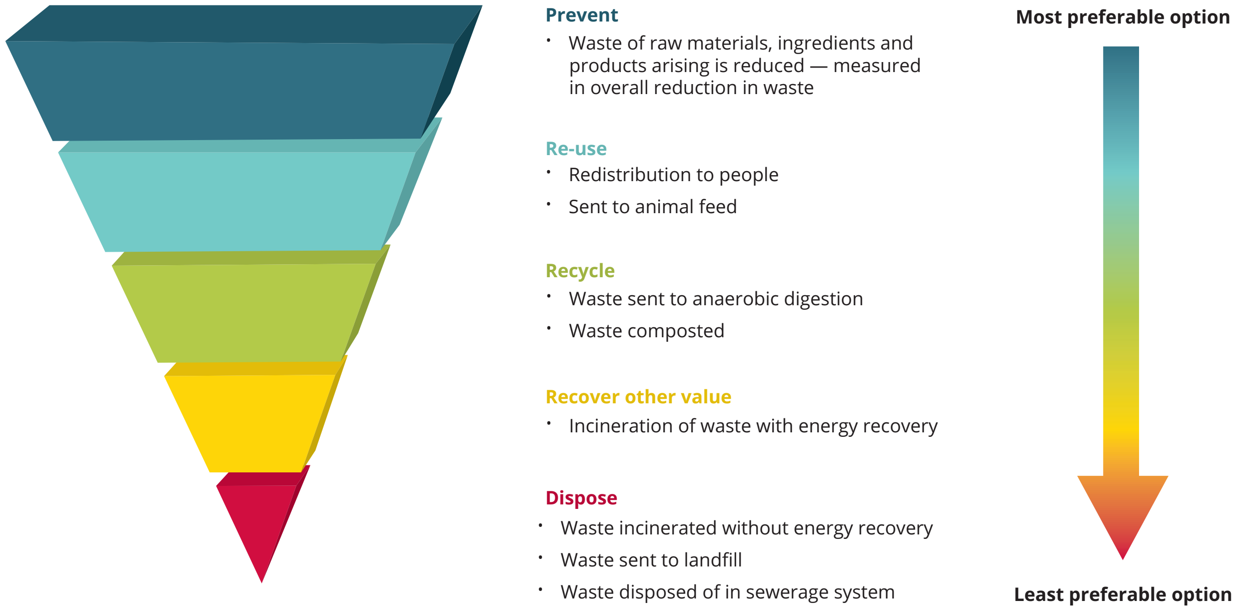
About 60 % of bio-waste is food waste, and a considerable share of this waste is avoidable. The Waste Framework Directive (WFD; 2008/98/EC) established the waste hierarchy as the overarching principle guiding waste policies in the EU. According to this hierarchy, waste prevention has the highest priority, followed by recovery, and disposal is the least desirable option. For food waste, the waste hierarchy could be interpreted as shown in Figure 4.1.

This hierarchy poses an intrinsic dilemma. If capacity is created for bio-waste treatment, there might be less incentive to prevent food waste (which remains the preferred option). However, not all food waste will be prevented, so investments in treatment capacity remain necessary.

The EU and its Member States are committed to meeting Sustainable Development Goal (SDG) 12.3, adopted in 2015, which aims to halve food waste per person at the retail and consumer levels by 2030 and to reduce food losses along the food production and supply chains. To support achieving this goal, the EU Platform on Food Losses and Food Waste was established in 2016, bringing together EU institutions, experts from the EU Member States and relevant stakeholders. The platform aims to support all stakeholders in defining measures needed to prevent food waste, sharing best practice and evaluating progress made over time, and it aids the European Commission in identifying appropriate policies at EU level (EC, 2019c).

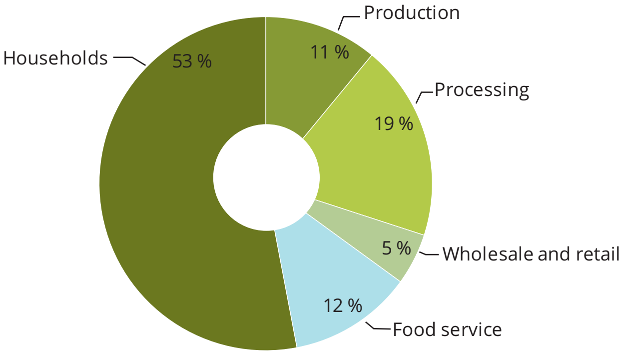
Studies on quantifying the amount of food waste use different methodologies and definitions of food waste (Caldeira et al., 2019b), and this also influences the quality of the data presented in this report. A reliable baseline for monitoring progress against this target has still to be established. The WFD obliges EU Member States to monitor the generation of food waste and take measures to limit it. A common EU methodology for measuring food waste entered into force in autumn 2019 (EC, 2019d). It is intended to be compatible with the methodology for monitoring progress towards SDG 12.3.

Figure 4.1 The food waste hierarchy



Source: Modified with permission from SEPA (2016).

Figure 4.2 **Food waste generation by sector, EU, 2012**



Note: Includes food and inedible parts associated with food. The production sector includes harvested crops leaving the field/cultivation and intended for the food chain and mature crops not harvested, for example for economic reasons. Again, manure and gleanings are not counted as food waste. A detailed definition of the sectors is given in Tostivin et al. (2016).

Source: Stenmarck et al. (2016).

In the context of waste prevention, food waste is recognised as comprising both avoidable (edible) and unavoidable (inedible) components (Shaw et al., 2018). Banana peel, egg shells and meat bones are examples of inedible and unavoidable food waste. In contrast, avoidable food waste is food and beverages that are thrown away despite still being edible, including, for example, slices of bread, apples and meat. When prevention is considered, only the avoidable fractions generated in each sector (Figure 4.2) are considered preventable and monitored in accordance with the common methodology laid out in Commission Delegated Decision (EU) 2019/1597. Losses generated in the retail sector and by households are a particular concern, especially at the household level where individual behaviour and cultural differences are critical (Thyberg and Tonjes, 2016). Households are identified as the sector contributing the most to food waste (Figure 4.2).

The avoidable component of household food waste is substantial. Estimates suggest that, across the EU, 50-60 % of losses and waste in the food supply chain are generated by households and the retail sector (DEFRA, 2012; Stenmarck et al., 2016; Hebrok and Boks, 2017). The European Fusions project reported that about 60 % of waste generated by consumers (equivalent to 32 % of all food waste) consists of avoidable waste. Waste generation in Greece, 30 % avoidable, and in Sweden, 35 % avoidable, fall into this range (Abeliotis et al., 2015; Bernstad Saraiva Schott and Andersson, 2015). Estimates, however, vary: for example, in Germany avoidable food waste has been estimated to account for around 65 % of the total food waste from households (Braun, 2012).

However, Schanes et al. (2018) point out that food waste generation in households cannot be seen in isolation from other parties in the food chain — from the production to the consumption stages. This is because food waste in households can arise from action taken further back in the food chain – through, for example, incomprehensible date labels, packaging that is not resealable, and sales strategies such as bulk packaging and special multi-offers.

4.1 Environmental and economic impacts of food waste

It is estimated that approximately 88 million tonnes of food — about 20 % of all food produced — is wasted every year in the EU-28 (28 EU Member States) along the entire food value chain, excluding food waste used as animal feed (Stenmarck et al., 2016). This waste is responsible for a global warming potential of about 186 million tonnes of carbon dioxide equivalent (CO_2e). Together, the impacts of total food waste on climate, acidification and eutrophication contribute 15-16 % of the environmental impact of the entire food value chain (Scherhaufer et al., 2018). In Switzerland, the 2.8 million tonnes of food waste generated along the whole value chain are estimated to be equivalent to a land area corresponding to half of the agricultural land in the country (FOEN, 2020).

Different food categories generate substantially different environmental impacts per kilogram across their life-cycle. For example, meat has a large impact on climate change per kilogram, while coffee, cocoa and some fruit, such as citrus fruit, have relatively greater impacts on biodiversity. Therefore, although food waste contains only about 5-12 % meat, this fraction contributes 25-55 % of the climate impacts of food waste. In contrast, the larger amount of bread and starch, around 20 % of all food waste, contributes less than 10 % of the climate impacts (Scherhaufer et al., 2018; Beretta and Hellweg, 2019). Consequently, a reduction in meat products in food waste would significantly reduce the life-cycle impacts of food waste on climate change.

A comparison between studies in different countries on savings in greenhouse gas emissions achieved through preventing food waste shows high variability, ranging from 0.8 to 4.5 kg CO_2e per kilogram of food waste avoided (WRAP, 2012; Bernstad Saraiva Schott and Andersson, 2015; Antonopoulos et al., 2018; Scherhaufer et al., 2018; Tonini et al., 2018; Beretta and Hellweg, 2019; Slorach et al., 2019). The wide discrepancy in the results of environmental impact assessments on food waste is due to the different ways in which the studies are framed — whether they include the full food chain or only part of it, the composition of the waste and the inclusion, for example, of emissions related to indirect land use. Furthermore, food production data sets should be chosen carefully to avoid double counting and overestimation of the final impact (Tonini et al., 2018). Nevertheless, a strategy to minimise food waste would result in lower greenhouse gas emissions than in the current situation. Most studies have pointed out that, although modern alternatives for treating food waste can avoid greenhouse gas emissions through nutrient and energy recovery, preventing food waste yields far greater life-cycle savings of greenhouse gas emissions than incineration and anaerobic digestion (Bernstad Saraiva Schott and Andersson, 2015).

A wide analysis of the environmental impact of food waste (Scherhaufer et al., 2018) also concluded that the production phase accounts for almost three quarters of the greenhouse gas emissions associated with food waste and that the effects of food waste treatment and disposal are not the main cause of food waste-related impacts.

Finally, the rebound effect — when consumers spend the income saved through preventing food waste on other goods and services — can substantially reduce the environmental benefits of preventing food waste if it is not addressed (Salemdeeb et al., 2017).

Reducing food waste in the catering sector not only saves environmental impacts but also offers considerable potential for making financial savings for both companies in the sector and households. New policies are therefore justified not only by meeting environmental targets but also because of their potentially positive effects on the economy (Beretta and Hellweg, 2019). The value of avoidable food waste has been estimated in a number of European countries and ranges between EUR 3.2 and EUR 6.1 per kilogram of waste (Table 4.1). Moreover, the European Commission's Joint Research Centre has developed a calculator to quantify the environmental and economic savings that can be achieved through preventing food waste (EC, 2020a).

The figures in Table 4.1 relate largely to the upper end of the food chain, that is, the catering and household sectors. Across the whole food supply chain, two thirds of the cost is associated with food wasted by households. The cost of food waste in the EU in 2012 are estimated at around EUR 143 billion, of which around EUR 98 billion is attributed to household food waste. This is due to households generating more avoidable food waste than any other sector and the fact that the costs associated with a tonne of food, for processing, packaging and retailing, for example, accumulate along the supply chain (Stenmarck et al., 2016).

Analysis of the economy-wide effects of reducing food waste in the food industry shows that the relevant costs are not only those avoided by saving food inputs and purchases but also those incurred by measures to reduce food waste, for example additional labour costs or investment in better storage facilities. Moreover, reducing food waste might lead to a decrease in food prices, in turn encouraging increased use of agricultural products (Britz et al., 2019). This points to some of the key mechanisms that drive food waste generation along the food value chain and to potential economy-wide mechanisms that can reduce the theoretical cost and environmental benefits of preventing food waste.

Table 4.1 Estimated amounts and value of avoidable household food waste

Country and reference year	Avoidable food waste generated (kg/person per year)	Cost of food waste (EUR/kg)	Cost of avoidable food waste per year and capita (EUR/person per year)	Reference
Netherlands, 2013	47	3.2	150	van Dooren et al. (2019)
Netherlands, 2019	34	3.5	120	van Dooren (2019)
Germany, 2012	53	4.4	235	Braun (2012)
Norway, 2015	42	6.1	256	Stensgård and Hanssen (2016)
Finland, 2011	23	4.0	92	Silvennoinen et al. (2014)
Belgium, 2016	37	4.3	159	Criel and Fleurbaey (2019)

Note: The data may differ in terms of inclusion or exclusion of liquid food waste.

4.2 Policies applied to reduce food waste in European countries

In the majority of European countries, food waste stands out as a priority fraction in waste prevention policies. The WFD requires all EU Member States to develop specific food waste prevention programmes. Although the development of such programmes is still under way, analysis of 32 national and regional waste prevention programmes (EEA, 2019b) shows that measures on food waste are already included in the prevention programmes of 28 countries and regions (Wilts and Schinkel, 2018). Such measures include, for example, awareness-raising and information campaigns and programmes to reduce food waste. These measures typically target the consumer. Moreover, developing guidelines on preventing food waste for businesses and public institutions is also quite common. Voluntary agreements for businesses, sometimes in collaboration with public organisations and non-governmental organisations (NGOs) are also part of waste prevention programmes in a number of countries, including Bulgaria and Spain.

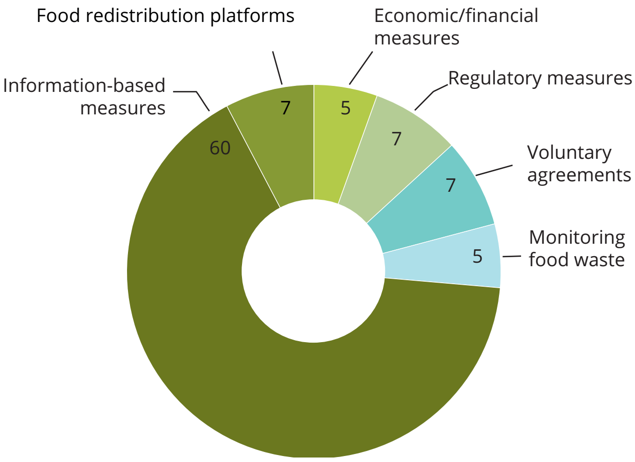
Many European countries' waste prevention programmes were adopted around 2013 and have been updated since. In the meantime, preventing food waste has risen up the global and EU policy agendas. As policy development is expected to be significant for a high-priority waste stream, the EEA asked the European Environment Information and Observation Network (Eionet) countries about the introduction of new prevention measures that are not specifically mentioned in their waste prevention programmes. Of the 32 countries that replied, 24 mentioned new measures on food waste (ETC/WMGE, 2019a).

Countries reported a total of 91 examples of new waste prevention measures, among which information-based measures, 60 measures, were mentioned most frequently (Figure 4.3). Other measures reported included food redistribution platforms, voluntary agreements, economic/financial measures, regulatory measures and monitoring food waste.

Figure 4.4 presents the number of countries reporting new activities to prevent food waste. Various information-based measures/activities were mentioned by 23 countries, while food distribution platforms have been set up in seven countries. Five countries have monitoring systems in place for measuring food waste, while seven countries mentioned ongoing analyses and/or the development of monitoring systems, 12 in total. In addition, five countries, Croatia, Estonia, Greece, Latvia and Switzerland, mentioned having dedicated plans and measures in preparation for preventing food waste.

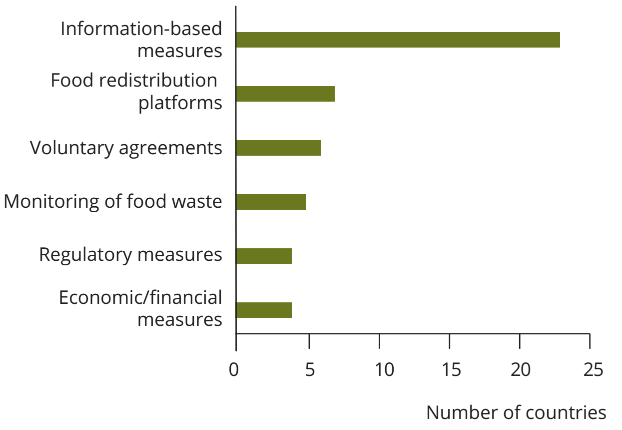
The present review is not a complete overview of all food prevention measures in the participating countries, rather it provides a snapshot of some of the latest developments in Europe.

Figure 4.3 **Number of food waste prevention measures not included in waste prevention programmes reported by 32 EEA member and cooperating countries, 2019**



Source: ETC/WMGE (2019a).

Figure 4.4 **Number of countries reporting new food waste prevention measures not included in waste prevention programmes for 32 EEA member and cooperating countries, 2019**



Source: ETC/WMGE (2019a).

4.2.1 Information-based measures

Awareness raising is the dominant policy option. Although consumers are mentioned as the most targeted group, measures targeting the catering industry, mentioned by 12 countries in total, also stand out and include general awareness raising, training, technical support and ecolabelling. Education on preventing food waste has also been taken up by primary schools and kindergartens in seven countries. Cooperation with industry was mentioned by five countries and included sharing best practice.

4.2.2 Economic/financial measures

Economic measures aim to reduce food waste through incentives or other market signals (Fusions, 2016). They comprise fees, taxes and subsidies and are considered a powerful tool for shifting consumption patterns towards more sustainable food practices (Schanes et al., 2018).The assumption is that, if the real cost of using natural resources is reflected in prices, consumers would be more likely to prevent food waste. Reported economic and financial measures principally include subsidies and grants and/or tax credit schemes. Subsidies and grants have been directed at food banks (Czechia) and at research into and developing food waste prevention measures. Reductions in value-added tax (VAT) have been implemented, for example in Italy, on sales of leftover food.

4.2.3 Regulatory measures

Regulatory measures were mentioned by four countries: Czechia, France, Italy, and Poland. Since 2016, the destruction of unsold consumables has been forbidden in France — large supermarkets are obliged to donate unsold but edible food to social institutions or alternatively to use it as animal feed or compost it. Redistribution requires formal agreements with charitable institutions. There are, however, no rules on the proportion of food to be donated, which means that it is sufficient for a store to sign an agreement to donate 1 % of its unsold food. France also obliges restaurants providing more than 180 meals a day to allow customers to take leftover food home, providing them with a container if requested. In Italy, a law was passed in 2016 that facilitates and clarifies the conditions for the redistribution of surplus products, including food, for charitable purposes. There are no penalties in Italy — companies are exempted from paying VAT and income tax on their donations and passing on surplus food is facilitated (Azzurro et al., 2016).

In Czechia, an amendment to the Food Act, aiming to reduce food waste, that came into effect in 2018 requires all supermarkets larger than 400 m^2 to donate unsold but still consumable food to charities. According to the Czech Federation of Food Banks, approximately 1 900 tonnes of food were collected in 2017, which were then redistributed to 70 000 people in need. Thanks to the new regulation, the amount of food donated to charity increased fivefold. In Poland a new act to counteract food waste entered into force in September 2019. It regulates the obligations of food sellers and organisations distributing food for public benefit (Sejm, 2019).

4.2.4 Voluntary agreements

Voluntary agreements are typically a form of cooperation between public administrations and participating stakeholders, usually businesses. In the survey, seven countries reported on voluntary agreements targeting food waste produced by catering business and retailers. Ireland's Food Waste Charter, launched by the Minister for Communications, Climate Action and Environment in 2017, is based on voluntary commitments by companies to reduce their food waste. Five of the six major supermarket chains in Ireland have signed the charter and, as a first step, have committed to measuring and reporting their food waste. Austria's Federal Ministry of Agriculture, Forestry, Environment and Water Management has a voluntary agreement (Vereinbarung 2017-2030) that involves both retailers and food producers in halving food waste by 2030. The document includes lists of measures by means of which the partners can contribute to achieving the goal.

4.2.5 Targets

Six countries specifically mentioned having set targets for reducing food waste, which are generally in line with the target of SDG 12.3 of halving retail and consumer food waste per person by 2030. France, however, has a National Pact Against Food Waste that aims to reduce food waste by 50 % as soon as 2025.

4.2.6 Food redistribution platforms

Food redistribution and donation platforms have recently been set up in several European countries, largely to complement regulations and voluntary agreements involving retailers and catering companies in donating leftover and second-class food and food products. The impact of such measures on food waste generation is direct and can be easily monitored.

Experience shows, however, that to be effective distribution platforms need to be complemented with proper support, which traditionally has been provided on a non-profit and/or voluntary basis (e.g. Gram-Hanssen et al., 2016). Insufficient logistical resources and storage can easily lead to a situation in which only a minor part of the redistributed food actually reaches its proper destination. In a pilot project, the Federation of Polish Food Banks started using cooling devices and cooled transport, allowing more fresh food to be donated (Eionet, 2019). Nevertheless, relying on donations as the main channel for reducing food waste implies that, if charities' need for donated food declines, the problem of excess food will return, as its underlying causes have not been adequately tackled.

4.2.7 Measuring the effectiveness of food waste prevention policies

Measuring the effectiveness of waste prevention activities or policies has been identified as a fundamental challenge, and many countries measure the effects of waste prevention activities through proxy indicators such as number of signatories to voluntary agreements or similar. The question is particularly relevant in the case of information-based measures, which make up about 70 % of the activities listed in countries' waste prevention programmes (Wilts and Schinkel, 2018). It is often very difficult to measure the effects of such activities because of the long time lags and very indirect impacts on specific consumption or production patterns; however, frameworks for assessing food waste prevention measures have been developed (Caldeira et al., 2019a).

Given its complex nature, the evidence on drivers of food wastage and barriers to reducing it remains scattered. This is especially true when it comes to food waste generated in households. Despite a growing number of studies, little is known about the determinants of consumer food waste and the underlying factors that drive or impede food waste behaviour and practices. Schanes et al. (2018) point out that, to be effective, information initiatives have to address the specific knowledge gaps that drive wasteful practices. Education on the meaning of date labelling combined with efforts to increase the acceptability of imperfect food — food that is less fresh, less aesthetically attractive or nearing its expiry date — have been a key component in countering and avoiding confusion among householders.

Until now, data on food waste generation have usually been based on ad hoc studies. This will change, as all EU Member States will report data on food waste generation from 2022 onwards, in line with the recently adopted harmonised monitoring methodology. In the future, this will enable the comparison of the potential impact of different policy mixes for preventing food waste adopted in European countries. Such new data will enable the effectiveness of policies to be analysed, complementing the knowledge available today, which tends to link specific amounts of waste avoided to specific activities without making a solid connection to national/regional policies. The availability of food waste data at the national level will help to assess the effectiveness of prevention initiatives conducted at national level; nevertheless, there is a wealth of initiatives conducted at smaller scales (e.g. city/neighbourhood level), which cannot be precisely monitored with national-level tools. Robust monitoring systems should be put in place to assess the effectiveness and efficiency of such local actions. This will enable us to identify best practices and promote the implementation of certain types of initiatives (Caldeira et al., 2019a).

4.3 Good practice

Waste prevention includes a variety of measures that can be employed at national, regional and company levels.

The following sections discuss examples of good practice implemented in some European countries.

4.3.1 Food donation policy in Czechia

Czechia is an example of a country that has recently amended its legislation to facilitate the prevention of food waste and to promote food redistribution. In 2014, the 15 % VAT rate applied to donated food was abolished and, in 2018, Czechia introduced an obligation on stores of more than 400 m^2 to donate unsold but still consumable food to charitable organisations. As the new regulation forced many stores to start donating, the volumes of redistributed food increased dramatically. The distribution takes place through food banks, not-for-profit organisations that handle donations on a large scale and distribute them further to NGOs. In total, there are 15 food banks in Czechia serving in Prague alone through around 120 NGOs. The increasing volume has been challenging for the food banks, especially the redistribution of perishable foods such as vegetables, milk and meat. To handle this, some food banks have widened their activities, establishing kitchens in which meals can be prepared from donated products. This increases the window of time that food banks have to find clients and broadens their clientele to include meal distributors. The average total food waste generated in Czechia is almost half that of the EU (Brno Daily, 2018).

4.3.2 Ecolabels

Certification and labelling schemes operating within the food supply chain are important policymaking opportunities. A label can motivate a company to start measuring and implementing waste reduction policies/processes, and the related certification can form the basis for a good public procurement policy for food waste.

According to the results of the survey, ecolabelling schemes are in use or planned in at least Austria, Denmark and Finland. The target group consists of mainly catering companies and retailers. New labels and existing schemes can be used. Finland, for example, is planning to use the criteria of the established Nordic Swan Ecolabel or the EU Ecolabel to steer supermarkets and the hospitality sector towards action consistent with the circular economy. The aim is to reduce waste volumes and to cut down on the amount of unsorted waste destined for incineration. Supermarkets will, moreover, be required to measure their food losses.

The Danish DAKA ReFood recycler has launched the ReFood Label in collaboration with the Danish Agriculture and Food Council and the consumer movement Stop Wasting Food. The label functions as a green seal of approval for organisations and companies that are making an active effort to reduce food waste and increase recycling. In 2015, more than 300 restaurants in Denmark were members of the ReFood Label.

4.3.3 Best before, but ...

Date labelling on food packaging is a key food policy instrument, positioned between production, retailing and consumption. A lack of knowledge about what date labels mean and confusion over the difference between the expiry date and the date of minimum durability, or 'best before date' (Regulation 1169/2001/EU) have been identified as major contributors to avoidable consumer food waste (Ceuppens et al., 2016; Priefer et al., 2016). The European Commission estimated in 2018 that up to 10 % of the 88 million tonnes of food waste generated annually in the EU is linked to date labelling (EC, 2018b). There is great potential for reducing food waste by optimising labelling of pre-packed food products to prevent confusion among consumers over expiry dates. More specifically, food waste could be reduced by removing sell by dates or date labels completely from some product groups and extending the list of food products exempted from indicating best before dates (Schanes et al., 2018).

In 2018, two major dairy companies and an egg producer in Norway introduced packages stamped with 'best before, but not bad after' as a way to combat food waste. This decision was partly based on the fact that nearly one third of Norwegians have thrown away milk on the expiry date without first checking whether it was still good.

5 Quality management and creating a market for compost and digestate

To close the bio-waste circle, compost and digestate produced from bio-waste should be of good quality to enable their use as a soil improver or fertiliser. To create a market for compost and digestate, managing the quality of the process and the end products is very important, as it is an integral part of a bio-waste management system. It aims to build trust in the products by guaranteeing the quality of the end products.

Compost has two main uses as a product: as a soil improver/organic fertiliser and as a component in growing media. The application of compost in or on soil usually improves the physical, biological and chemical properties of soil. Repeated application of compost leads to an increase in soil organic matter, it often helps to reduce erosion, increases the water retention capacity and pH buffer capacity, and improves the physical structure of soil (aggregate stability, density, pore size). Compost may also improve the biological activity of soil. Compost also contains different nutrients, micronutrients and has a neutralising value for soil. The phosphate and potassium demand of agricultural soils can, in many cases, largely be covered by adequate compost application, while the supply of plant-available nitrogen by compost needs repeated applications over a longer period of time to achieve a measurable effect (Saveyn and Eder, 2014).

5.1 Production of compost and digestate

5.1.1 Compost

In European countries with separate bio-waste collection, composting delivers more than 11.8 million tonnes of compost. Austria, the Belgian region of Flanders, Germany, Italy, and the Netherlands, which pioneered bio-waste recycling in the 1990s, remain frontrunners in the (per person) generation of compost from bio-waste today, but others have caught up (Figure 5.1). The recycling targets for municipal waste in the Waste Framework Directive (EU, 2008, 2018b) and the Landfill Directive's (EU, 1999, 2018a) target to reduce landfill to a maximum of 10 % of the municipal waste generated by 2035 will encourage composting and anaerobic digestion of bio-waste. This can be seen, for example, in Slovenia, which has become a frontrunner in collecting and treating bio-waste, since its decree on biodegradable kitchen and garden waste management was introduced, and in Lithuania, where a ban on landfilling bio-waste has led to the establishment of many small-scale garden waste processing plants (ECN, 2019). In these countries compost production exceeds 30 kg per person per year.

5.1.2 Digestate

Historically, anaerobic digestion of bio-waste often started with the co-digestion of manure and/or sewage sludge in, for example, Denmark, Flanders and Italy. However, renewable energy policies and subsidies for generating electricity, gas and heat from biomass improved the economic conditions for anaerobic digestion of bio-waste or food waste in Austria, Flanders, Germany, Slovenia and the United Kingdom and for co-digestion of bio-waste, manure and other feedstock, which has become common in, among others, Denmark, Flanders and Germany. In Sweden the target for renewable biogas for transport fuel led to anaerobic digestion becoming the preferred bio-waste treatment method (ECN, 2019).

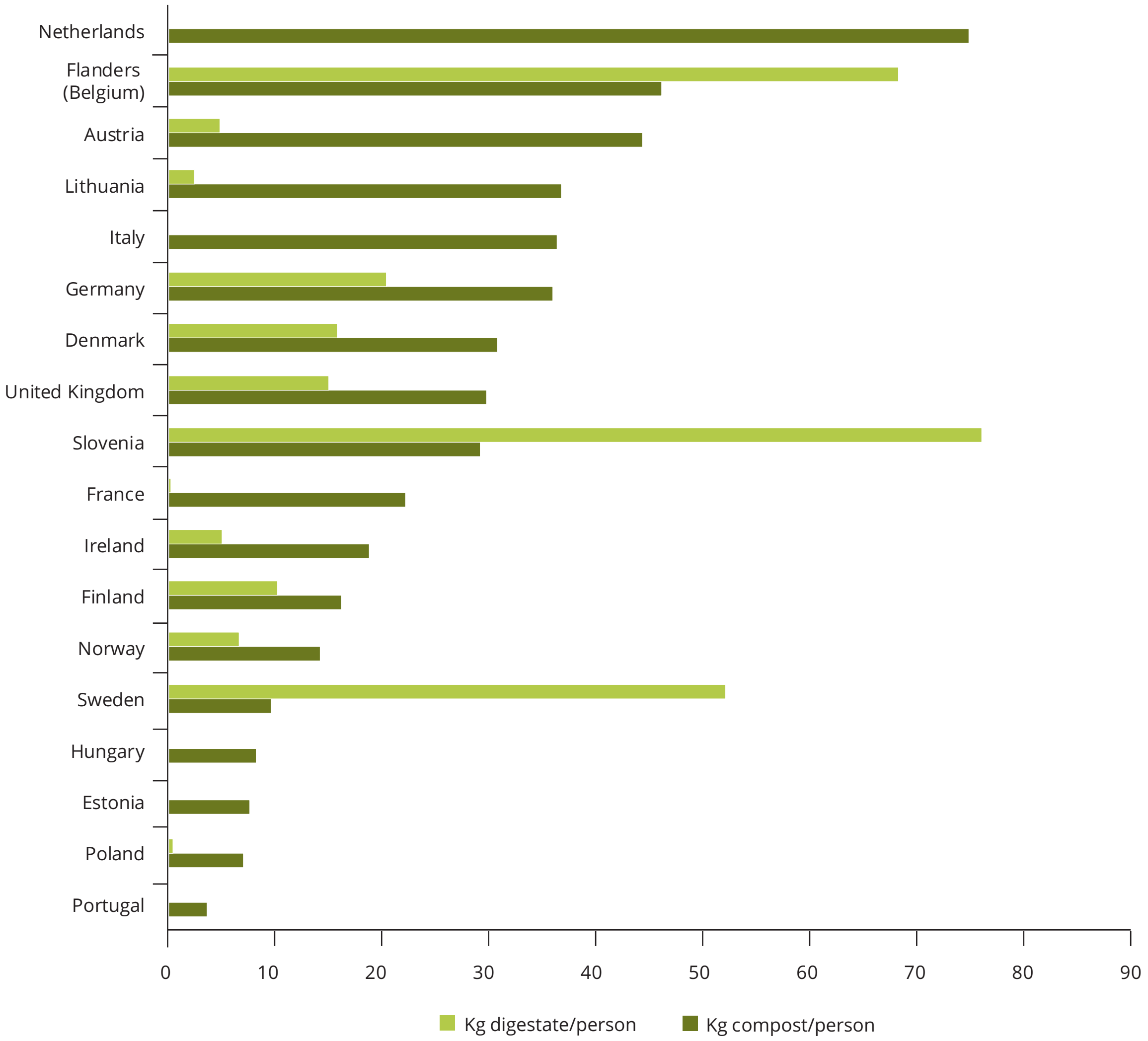
Some countries have no separate data on the amount of digestate produced from bio-waste. In the Netherlands and Italy, for example, the digestate from municipal bio-waste is composted and only the final amounts of compost produced are recorded (ECN, 2019).

Anaerobic (co-)digestion of bio-waste delivers around 4.14 million tonnes of digestate in Europe, and there are big differences in the amounts countries produce per person (Figure 5.1).

5.1.3 Nutrient recycling and soil improvers

It is estimated that, through the production of digestate and compost from 47.5 million tonnes of separately collected bio-waste, over 129 000 tonnes of nitrogen, 42 000 tonnes of phosphate and 3.5 million tonnes of organic carbon were recycled in the 18 European

Figure 5.1 Production of compost and digestate from bio-waste by country, 2016



Source: EEA, based on theoretical estimated amounts of compost and digestate generated as documented in country fact sheets in ECN (2019).

countries/regions for which data were available, as shown in Figure 5.1 (ECN, 2019). This estimate is based on the following assumptions on the nutrient content in fresh compost/digestate (WRAP (2016):

- Nitrogen: 9.25 kg per tonne compost (mean of garden waste and garden/food waste compost), 5 kg per tonne food waste digestate.
- Phosphate (P_2O_5): 3.4 kg per tonne compost, 0.5 kg per tonne food waste digestate.

The European Compost Network calculated that the amount of nitrogen in the digestate and compost produced is equivalent to 1.5 % of the total inorganic nitrogen and 4.3 % of inorganic phosphate consumed by the 18 European countries shown in Figure 5.1 (ECN, 2019). Applying the same assumptions on nutrient content to the around 50 million tonnes of municipal bio-waste that is currently collected within mixed municipal waste in the EU-28 (28 EU Member States) suggests that a potential 134 000 tonnes of nitrogen and 44 000 tonnes of phosphate is currently wasted.

The market for high-quality compost from bio-waste could be further developed, for example for organic farming where the use of mineral fertilisers is not allowed (Raussen et al., 2019). Long-term experiments on agricultural management practices across Europe and China have shown that applying compost increases soil organic matter levels, the number of earthworms, crop yield and other parameters (Bai et al., 2018).

5.2 Market for compost and composted digestate

Compost is mostly used as an organic fertiliser and soil improver (ECN, 2019). Figure 5.2 shows the different market sectors for compost from municipal bio-waste for those countries that have quantified information: agriculture and horticulture seem to be the main markets, and this is also assumed to be the case in countries that do not have quantified market data.

Around 50 % of the compost goes to agriculture and horticulture in Europe; in Switzerland more than 90 % is used in agriculture. Around 30 % of the compost, often mixed with other components, is used as a soil improver in parks, private gardens and for landscaping in Flanders, Germany and Italy (Figure 5.2).

Across Europe there is also growing awareness of the negative effects of peat extraction and its use in horticultural growing media. High-quality mature compost can be used at a share of 20-40 % in growing media mixes. In Flanders, Germany, Ireland and the Netherlands (Figure 5.2) this is actually a valuable market opportunity for compost manufacturers. Norway has recently set a national target to phase out the use of peat in growing media for amateur users by 2025 and in professional horticulture by 2030 (ECN, 2019).

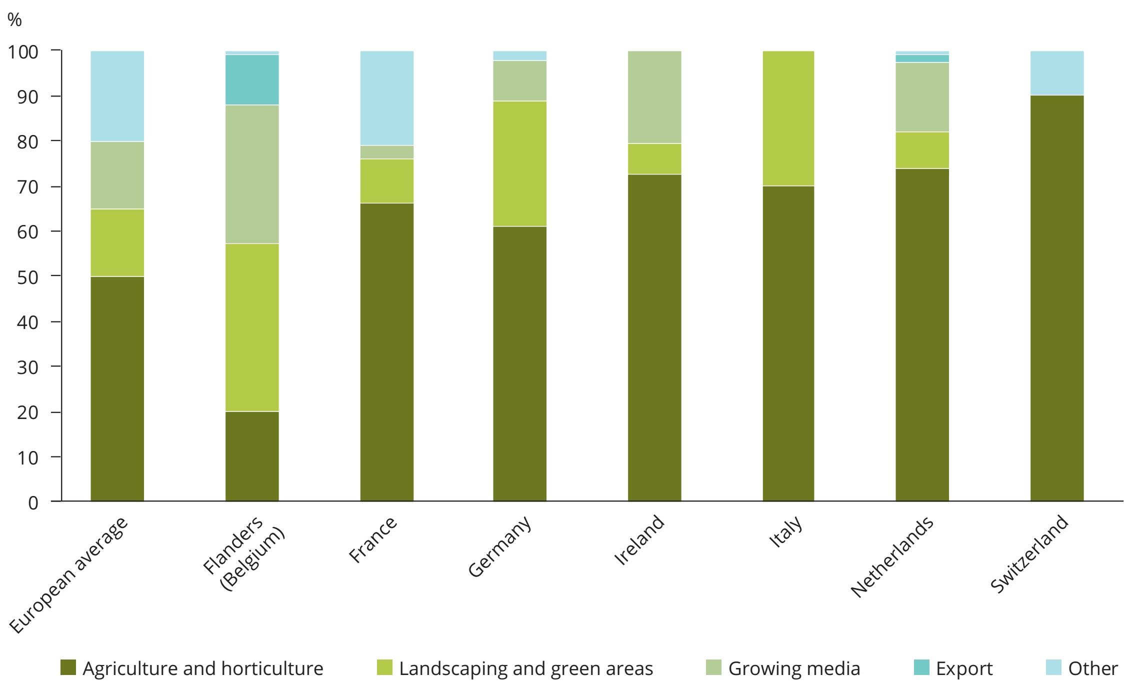
Agriculture is the largest receiving sector for digestate, as it is considered to be a useful organic fertiliser because the nutrients are present in a form that is readily available for uptake by plants.

5.2.1 Impact of compost on soil and the environment

Organic matter is a key component of soil, controlling many vital functions. It has been estimated that 45 % of European soils have a very low organic matter content. This is particularly the case in the soils of many southern European countries, but also in parts of Belgium, France, Germany, Norway and the United Kingdom (JRC, 2012). Repeated applications of good-quality compost can improve the soil's ability to retain water and nutrients and to store carbon, as well as raising its fertility. In some regions, compost is competing with other organic fertilisers such as manure or digestate (e.g. in Belgium and the Netherlands), leading to an oversupply of organic fertilisers.

Using good-quality compost to replace inorganic N P K fertiliser, as well as peat in growing media, has environmental benefits because the production of mineral fertilisers and the harvesting of peat are avoided. Finally, compost is of value for growing media because of its microbial diversity.

Figure 5.2 Market for compost from bio-waste in selected countries/regions, 2018



Sources: Data for France, Ireland, Italy, Netherlands from ETC/WMGE (2019a), for the European average from ECN (2019), for Germany from BGK (2018), for Flanders from VLACO (2019), and for Switzerland from Fuchs (2016).

5.2.2 *Impact of the EU Fertilising Products Regulation*

The EU Fertilising Products Regulation (EU, 2019b) is intended to create a policy framework to encourage the use of organic fertilisers and soil improvers, thereby decreasing the EU's dependency on imports of mineral fertilisers and contributing to a circular economy for nutrients. By fulfilling the requirements of the regulation, compost and digestate-based fertilising products (organic fertiliser, soil improver and growing media) can be placed on the European market. National rules for fertilisers and soil improvers may continue to exist and, where there is bilateral recognition of these rules, Member States may still export materials that comply with national product requirements.

The regulation builds upon three pillars:

1. Product function categories, for example organic soil improvers and growing media, with specified standards. These materials are made up of one or a combination of component material categories.

2. Component material categories, for example compost and digestate.

3. Modules for the conformity assessment: for compost and digestate-based fertilising products, the conformity procedure envisages external control by a notified conformity assessment body auditing the production process and the product quality.

Working groups still have to decide on many questions that arise from the regulation. Its rules will affect companies in EU Member States that want to export compost or soil improvers, fertilisers and growing media based on compost or dried digestate to other EU Member States. From 16 July 2020 onwards, exporting producers need certification (CE marking) of their products. Some criteria for this certification are very clear. For example, bio-waste that is not collected separately, sewage sludge and industrial sludge are not allowed as input materials.

In some countries/regions, including Flanders (Belgium), existing national standards are more stringent than the EU soil improver standards for compost based on bio-waste and garden waste. The conformity assessment requires a good quality management and assurance system covering the production and the products, as already implemented in 11 European countries/regions (Section 5.4). Finally, compost and digestate are exempt from registration under the EU Regulation on registration, evaluation, authorisation and restriction of chemicals (EU, 2006).

5.3 Quality of compost and digestate

Of the countries surveyed, 24 have national standards for compost quality, which are either set in legislation, standalone standards or under development (Table 5.1).

The quality standards for heavy metals and impurities and the limits on application doses to soil vary between countries/regions, as they are mostly dependent on the specific situation, for example the soil structure, background concentrations of pollutants, agricultural practices, and lack or presence of other soil improvers/fertilisers (Saveyn and Eder, 2014).

Compost quality is best in countries with separate collection of municipal bio-waste, where the type and quality of the input material is regulated. Countries/regions where sewage sludge is not allowed to be co-treated with bio-waste and a risk assessment is obligatory for all input materials face few problems in achieving the product quality standards (Saveyn and Eder, 2014).

Pollution with plastics is an important aspect when putting compost on the market, and several countries mention plastics as a key contaminant to be addressed (Eionet, 2019). The EU Fertilising Products Regulation allows up to 2.5 g plastics per kilogram compost (dry matter); however, several countries apply more stringent limits. The quality standards for impurities, including plastics, have recently been strengthened in the quality assurance systems in Flanders and Germany, and these standards are expressed in terms of not only weight but also surface area. Analyses of quality-assured compost in Germany revealed, on average, 0.3 g plastics per kilogram compost (dry matter), but with considerable variation (Kehres, 2018).

Policies that aim to increase the share of bio-waste captured from municipal waste might increase the risk of contamination (van der Zee and Molenveld, 2020), requiring additional measures to reduce contamination of bio-waste with plastics during collection. Avoiding contamination with plastics at source is the most effective and efficient approach, as removing plastic contamination from bio-waste during treatment is both expensive and limited in its effect (Kehres, 2017). Overall, more attention needs to be given to avoiding contamination of bio-waste and compost with plastics.

Some countries/regions, including Denmark, Flanders, Germany, Sweden and the United Kingdom, have developed quality standards for digestate as well. In many cases digestate may be applied directly onto agricultural land.

5.4 Quality management system

An efficient quality management system enables the production of high-quality compost, ensures reliability and trust, and facilitates the creation of a compost market. Developing and controlling product quality standards for compost and digestate is just one step. A quality management system, however, includes several steps: composting and anaerobic digestion plants are audited throughout the entire production chain, from input to output and application of the products. Compost and digestate samples are taken on a regular basis, and an automatic control system, laid down in a quality manual, is part of the quality management system in each treatment plant. If there is a problem in an individual plant, an action plan is developed to find the external source of pollution and take measures to improve quality.

Currently, 11 countries have developed and implemented compost quality management and assurance schemes (Table 5.1), which are mainly based on the European Compost Network's quality assurance scheme (Figure 5.3). In the Netherlands, compost is certified under a voluntary industry initiative that covers process requirements, time and temperature, and contaminant limit values.

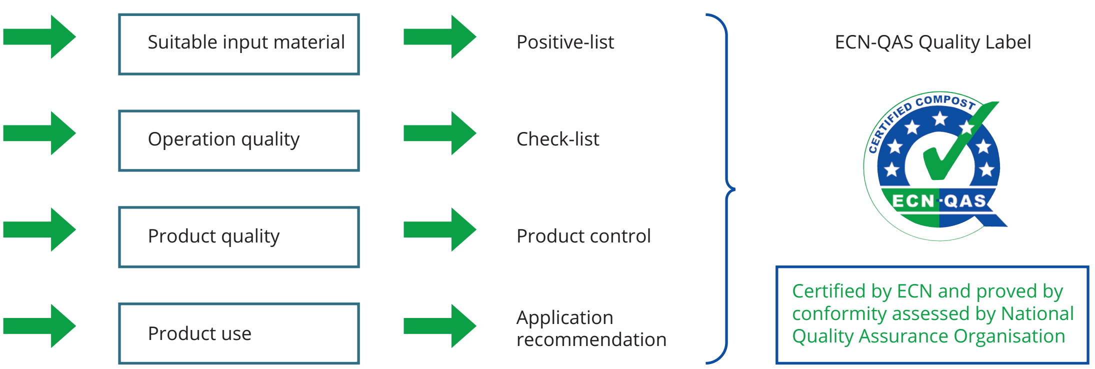
Applying a proper quality management system and producing high-quality compost and digestate opens the door to higher added value markets such as growing media, as can be seen, for example, in Flanders, Germany, Ireland and the Netherlands (Figure 5.2).

Quality management systems can also help avoid instances of misapplication of low-quality compost or digestate, which can potentially put a country's whole bio-waste management system at risk. An EU-wide requirement to introduce quality management systems for the whole bio-waste management system might therefore help support both optimal use of bio-waste as a resource and a high level of environmental protection.

Table 5.1 gives an overview of the status of separate collection of municipal bio-waste, national standards for the quality of compost and the quality management system in each country. There are differences in the maturity of these systems. Eleven countries already report that they have implemented a quality management system, the final step following the national rollout of separate collections of bio-waste and embedding standards for the quality of compost in national legislation.

In Flanders (Belgium), Germany, Sweden and the United Kingdom quality management systems exist for the production of digestate and digestate-based products derived from operating bio-waste co-digested with energy crops or manure. These quality systems are also based on the European Compost Network's quality assurance scheme (Figure 5.3).

Figure 5.3 The essential elements of the European Compost Network's quality management and assurance scheme



Source: ECN (2018b).

Table 5.1 Quality management systems for the production of compost from bio-waste for selected European countries and regions, 2016-2018

	Separate bio-waste collection	National standards for compost quality	Quality management system
Albania	-	-	-
Austria	+++	+++	+++
Belgium	+++	+++	+++
Bosnia and Herzegovina	-	-	-
Bulgaria	-	-	-
Croatia	+	+	-
Cyprus	-	-	-
Czechia	++	++	++
Denmark	++	+	-
Estonia	+	+++	+++
Finland	+++	+++	+++
France	+	+++	+++
Germany	+++	+++	+++
Greece	-	-	-
Hungary	+	+	-
Iceland	+	-	-
Ireland	+++	+++	+++
Italy	+++	+++	+++
Kosovo*	-	-	-
Latvia	-	-	-
Liechtenstein	-	-	-
Lithuania	+	+	-
Luxembourg	+	+++	-
Malta	+++	-	-
Montenegro	-	-	-
Netherlands	+++	+++	+++
North Macedonia	-	-	-
Norway	+++	+	-
Poland	++	++	-
Portugal	+	++	-
Romania	-	-	-
Serbia	-	-	-
Slovakia	-	-	-
Slovenia	+++	+++	-
Spain	+	+++	-
Sweden	+++	+++	+++
Switzerland	+	++	-
Turkey	+	+	+
United Kingdom	+++	++	+++

*Under UN Security Council Resolution 1244/99.

Note: +++ a mature system embedded in national legislation; ++ part way between starting out and reaching maturity; + just starting out or on a voluntary basis or developing local/regional or national standards; - not started.

Sources: ECN (2018a, 2019). Information for Spain from Puyuelo et al. (2019). Information for Croatia, Czechia, Estonia, Lithuania, Malta, Poland, Portugal, Slovenia and Turkey provided during Eionet review.

6 Innovation and future developments

Keeping the value of products and materials in the economy is one of the key principles of a circular economy. Bio-waste is a potential source of chemicals, products and energy. Innovation plays a key part in valorising bio-waste. Currently, composting is the most common method of municipal bio-waste treatment in Europe, and anaerobic digestion is the most advanced treatment method that is commonly used. In addition to these treatment methods, however, there are various emerging technologies aimed at valorising bio-waste as a source of products or energy. Currently, most of the more advanced technologies are more suitable for and applied to bio-waste from food processing and agriculture, as these bio-waste streams are better defined and cleaner. This chapter reviews potential alternative technologies for bio-waste management in Europe.

6.1 Creating new materials and products from bio-waste

In recent years, various new concepts for creating new materials and products from biomass, including bio-waste, have received significant attention. Processing facilities in which biomass is converted into valuable products such as chemicals, biofuels, food and feed ingredients, biomaterials or fibres are called biorefineries (Fava et al., 2015; Vea et al., 2018; Parisi et al., 2018). Integrated biorefineries combine the production of bio-based products and energy from biomass. Biorefineries use different types of organic feedstocks, including bio-waste. There are 803 biorefineries in Europe, 136 of which report taking in waste streams (Parisi et al., 2018).

The most common bio-waste valorisation processes are the production of fuels, ethanol, methane and hydrogen and the extraction of organic acids from volatile fatty acids (VFAs) (Matsakas et al., 2017; Vea et al., 2018). Converting bio-waste from municipal sources into products in a biorefinery is challenging because of the mixed nature and complex composition of this type of waste. Existing full-scale waste-based biorefineries mainly use homogeneous waste streams from agriculture and food processing as feedstock. Biorefineries using the organic fraction of municipal waste as feedstock are a promising opportunity for a future circular bioeconomy and they would help us to move up the waste hierarchy (Vea et al., 2018). Further research and development are needed to move to large-scale commercial biorefineries that are both environmentally and economically sustainable.

6.1.1 Ethanol fermentation

Ethanol is commonly produced by fermenting biological material and it is considered one of the most important liquid biofuels (Matsakas et al., 2017). Ethanol can be blended with petrol to produce fuels such as E5 and E10 (Matsakas et al., 2017; Bhatia et al., 2018). In the ethanol fermentation processes, the carbohydrate fraction of municipal waste, including glucose, fructose, starch and cellulose, is converted into ethanol (Matsakas et al., 2017). Currently, bioethanol is often produced from maize- or sugarcane-derived feedstocks. Producing bioethanol from edible feedstock has raised concerns because of its competition with food and feed. Non-edible feedstock, also known as second-generation feedstock, derived from waste streams, has been suggested as a sustainable alternative for bioethanol production (Lohri et al., 2017). The feasibility of this concept has been proven in Finland (Box 6.1).

6.1.2 Production of volatile fatty acids

VFAs are short-chain fatty acids that are used in various applications, for example in the production of biofuels or bio-based plastics and in the biological removal of nutrients from waste water. At present, VFAs are mainly derived from fossil fuels through chemical synthesis, but in recent years there has been growing interest in bio-based VFA production from such waste streams as food waste, the organic fraction of municipal waste and industrial waste water (Lee et al., 2014; Strazzera et al., 2018). Food waste contains high levels of organic matter, high nitrogen and phosphorous concentrations and nutrients for the metabolic pathway of microorganisms, making food waste an optimal substrate for VFA production (Strazzera et al., 2018). VFAs are produced as an intermediate product of anaerobic digestion of such waste streams as food waste or waste-activated sludge

Box 6.1 St1's Etanolix and Bionolix processes

The Finnish energy company St1 has developed a process called Etanolix that uses locally generated waste and process residues. During the multi-phase process, the feedstock is hydrolysed and fermented into alcohol that is then recovered and dehydrated to fuel grade. The end product is fuel-grade ethanol, which is ready for use in high-blend ethanol fuels or as the bio-component in low blends. The process also generates stillage that can be used as high-protein animal feed or as a feedstock in biogas plants for producing renewable electricity and heat.

St1's Etanolix concept refines waste and residues rich in starch and sugar, for example bio-waste from bakeries, breweries and beverage production as well as retail waste including surplus bread and sorted bio-waste. The annual production capacity varies between 1 and 9 million litres. St1 has also developed the Bionolix biorefining concept that produces ethanol from municipal and commercial bio-waste. The Bionolix process uses packaged and unpackaged municipal and retail food waste as feedstock to produce ethanol that can be used in various applications. The Bionolix technology has been tested and now operates in Hämeenlinna, Finland. The plant is integrated with a biogas plant and has an annual production capacity of 1 million litres of advanced ethanol (St1, 2018).

(Atasoy et al., 2018). Compared with methane, VFAs have many possibilities for high value, non-energy-related end uses. However, producing VFAs through anaerobic digestion is still in the upscaling phase and its full-scale production has been tested with only a narrow spectrum of types of biomass, for example sewage sludge (Liu et al., 2018). Further developments are required to enable sustainable and economically feasible production and recovery of VFAs from bio-waste at market scale. The most important challenges are optimising the operational parameters for VFA production and the cost-effective separation of VFAs from digestate (Atasoy et al., 2018; Tampio et al., 2019).

6.1.3 Production of biohydrogen

Bio-waste can also be used to produce hydrogen (H_2), valuable as a source of clean energy, for which demand has increased considerably in recent years. Conventional methods for the production of H_2 are expensive because of the high energy requirements. There are also biological methods for producing H_2, in which bio-waste can be used as feedstock. Dark fermentation and photo-fermentation are biological processes that have been widely studied for H_2 production (Sabarathinam et al., 2016; Schüch et al., 2019). There are still major barriers for industrial-scale H_2 fermentation technologies, such as low substrate conversion efficiency and low yield (Sabarathinam et al., 2016). Another option is H_2 production from waste-derived VFAs (Lee et al., 2014).

6.1.4 Nutrient recovery from bio-waste

Recovery of nutrients from bio-waste is increasingly relevant, and recovery of phosphorus is increasingly recognised because of concerns over the depletion of this non-renewable resource. The European Commission has included phosphate rock on its list of critical raw materials (EC et al., 2017). Phosphate rock is the original source of phosphorus used in fertilisers and industrial applications. Secondary sources of phosphorus are unevenly distributed, and therefore demand from agriculture and the amounts of secondary nutrients available might not match in each region. When used in fertilisers, phosphorus ultimately ends up in solid bio-wastes, such as food waste, animal manures, sewage sludges and crop biomass, and therefore efficient recovery of phosphorus from bio-waste could not only reduce dependency on non-renewable resources but also reduce the run-off of phosphorus and eutrophication of water (Huang et al., 2017).

There are two strategies for its recovery from solid bio-wastes: (1) direct application of phosphorus-rich products as fertilisers; and (2) its recovery as pure compounds (Huang et al., 2017). Anaerobic digestion of bio-waste produces digestate that contains all the nutrients from the food waste feedstock and can be used as an agricultural fertiliser. There might be obstacles related to the direct application of digestate and therefore it sometimes needs further processing to concentrate and recover the nutrients as high-quality end products. A range of technologies has been developed that can be applied to digestate processing. The best available ones for nutrient recovery are struvite precipitation and crystallisation, ammonia stripping and absorption, and acidic air scrubbing; they have already been implemented at full-scale and have the ability to produce marketable end products. However, these technologies require further technical development to minimise operational costs and improve the quality and predictability of the fertilisers produced. Vibrating membrane filtration is also a potential nutrient recovery technology, but its technical and economic performance at full-scale has yet to be demonstrated (Vaneeckhaute et al., 2017).

6.2 Innovation related to energy recovery from bio-waste

In addition to biogas production through anaerobic digestion, ethanol fermentation and incineration, there are other technologies that can be used to convert bio-waste to energy. These methods include pyrolysis, gasification and hydrothermal carbonisation (HTC).

Pyrolysis is the thermochemical process in which biomass is decomposed at high temperature in the absence of oxygen, producing solid, liquid and gaseous products (Lohri et al., 2017). Pyrolysis allows the transformation of low-energy-density materials into high-energy-density biofuels and the recovery of higher value chemicals. One of its advantages is that many types of raw material can be used, including industrial and domestic residues, but making pyrolysis economically viable remains challenging. Work is needed to take the latest developments into a pilot phase and then to an industrial scale (Czajczyńska et al., 2017).

Gasification is a thermal treatment method that converts organic material into syngas ([1]) at high temperature. The gas produced can be used as a fuel or for producing chemicals. Gasification is considered a promising technology for bio-waste treatment because it produces minimal emissions and is a flexible technology that can be adapted to treat various materials (Watson et al., 2018). In addition, there is the possibility of coupling the operating conditions and features of a specific reactor to obtain a syngas suitable for different applications (Pham et al., 2015). Currently, large-scale commercial implementation of gasification is limited to municipal waste and agricultural residues. The economics of bio-waste gasification depend on the gate fees charged by gasification plants for accepting bio-waste, the capacity to generate electricity and the efficiency of the gasifier (Watson et al., 2018).

HTC is a thermochemical process involving pressurised water at relatively low temperatures (between 180 °C and 250 °C) at or above saturated pressure that converts bio-waste into hydrochar, which can be used as a solid fuel or soil improver or be further processed into activated carbon (Heidenreich et al., 2016). The end product of the process is a sterile and energy-rich resource that can be easily stored and transported. HTC is especially applicable to bio-waste with a high water content (Li et al., 2013; Pham et al., 2015; Bhatia et al., 2018). It has advantages over other energy conversion technologies, including greater reductions in waste volume and a short reaction time of only a few hours (Li et al., 2013; Pham et al., 2015). Another benefit associated with HTC is the potential for the recovery of nutrients from the liquids (Li et al., 2013). HTC is an attractive option for bio-waste management, but there are still some challenges that have to be resolved as well as the need for a techno-economic analysis to study the feasibility of using HTC in a large-scale operation (Pham et al., 2015).

6.3 Animal feed production

Certain types of food waste, especially from the food industry, can be turned into animal feed; however, EU food safety legislation creates a number of barriers. Broeze and Luyckx (2019) found that there are opportunities for safe pathways to increase the valorising of food waste into animal feed that still meet the intended food safety standards. One technology already available and in principle suitable for municipal bio-waste is using the waste to produce insect protein using black soldier fly larvae, a simple method potentially suitable for decentralised conditions in defined environments (Dortmans et al., 2017; Lohri et al., 2017; Gold et al., 2018). Black soldier fly larvae consume the bio-waste converting it into larval biomass and a compost-like residue. The larval biomass contains 32–58 % proteins and 15–39 % lipids and can be used as a raw material for animal feed production (Gold et al., 2018). The potential options for applying such approaches were explored with stakeholders in the Flemish Strategic Platform for Insects (Eionet, 2019). Although this technology is currently not allowed according to EU food safety regulations, this might change in the coming years (Lohri et al., 2017).

6.4 Opportunities and challenges for innovations

Bio-waste can be a valuable resource for recycling and energy generation. Currently there is much ongoing research looking at valorising bio-waste as bio-products and biofuels, although there are still many challenges that need to be tackled. Emerging technologies in bio-waste management and their main opportunities and challenges are listed in Table 6.1. Apart from the

([1]) A gas mixture consisting primarily of hydrogen, carbon monoxide and often some carbon dioxide.

Table 6.1 Emerging technologies in bio-waste management: main opportunities and challenges

Technology	Opportunities	Challenges
Bioethanol production	Bio-waste can serve as a sustainable alternative feedstock for the production of bioethanol — an important liquid biofuel.	High processing costs and the heterogeneous nature of bio-waste create challenges for industrial-scale bioethanol production.
Producing volatile fatty acids (VFAs) through anaerobic digestion of bio-waste	VFAs have a wide range of possible high-value end uses. Extraction of VFAs from bio-waste can be more sustainable than the conventional approach of deriving VFAs from fossil fuels through chemical synthesis.	The most important challenges include optimising the operational parameters for VFA production and cost-effective separation of VFAs from digestate.
Production of biohydrogen	Hydrogen demand is increasing and there is a need for sustainable methods for producing it.	Low substrate conversion efficiency and low yield.
Recovery of phosphorus	Efficient recovery of phosphorus from bio-waste can reduce the dependence on limited geological resources.	Further technical development is needed to minimise operational costs and improve the quality and predictability of the fertilisers produced.
Pyrolysis	Pyrolysis provides the possibility of transforming low-energy-density materials into high-energy-density biofuels.	Making pyrolysis economically viable remains a challenge.
Gasification	A flexible technology that can be adapted to treat various materials. The gas produced can be used as a fuel or for producing chemicals.	The main challenges are finding solutions to deal with heterogeneous feedstocks, maximising syngas yield, optimising gas quality and process efficiency and decreasing production costs.
Hydrothermal carbonisation	Converts bio-waste into hydrochar that can be used as a solid fuel or soil improver or be further processed into activated carbon.	Further technical development is needed for industrial-scale applications.
Production of animal feed	Direct use as animal feed, or potential small-scale bio-waste treatment methods to turn bio-waste into insect protein and lipids.	Legal barriers hinder the development of valorising bio-waste as animal feed, for example black soldier fly larvae technology.

Source: ETC/WMGE's own compilation.

technological aspects, economic, environmental and social aspects will also have to be considered before new solutions can be implemented. The cost of bringing new technologies on line, for example, is often high and the complexity and varying nature of bio-waste can necessitate costly separation processes and purification (Fava et al., 2015). As there is often a gap between laboratory research and its transfer to industrial-scale commercial application, improving the uptake and application of research findings needs collaboration between researchers, industries and governments (Bhatia et al., 2018). Integrating different technologies at the same site is an opportunity to enhance energy efficiency and decrease operational costs (Fava et al., 2015; Bhatia et al., 2018). The separation of bio-waste at source is a basic condition for high-quality recycling of bio-waste (Schüch et al., 2019).

Abbreviations

CO_2	Carbon dioxide
EEA	European Environment Agency
Eionet	European Environment Information and Observation Network
ETC/WMGE	European Topic Centre on Waste and Materials in a Green Economy
EU	European Union
EU-28	The 28 EU Member States for the period 2013-2020
EUR	Euro (European monetary unit)
FAO	Food and Agriculture Organization of the United Nations
HTC	Hydrothermal carbonisation
NGO	Non-governmental organisation
NRC	National reference centre
SDG	Sustainable Development Goal
UN	United Nations
VAT	Value-added tax
VFA	Volatile fatty acid
WFD	Waste Framework Directive

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Annex 1 Countries that responded to the survey

The following countries/regions provided data and information through an EEA and ETC/WMGE survey:

Albania, Austria, Bosnia and Herzegovina, Brussels Capital Region (Belgium), Croatia, Czechia, Denmark, Estonia, Finland, Flanders (Belgium), France, Germany, Greece, Hungary, Iceland, Ireland, Kosovo under UN Security Council Resolution 1244/99, Latvia, Luxembourg, Montenegro, Netherlands, North Macedonia, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey.

Lithuania provided data during the Eionet review of the report.

Survey questions

Relevance of bio-waste

- Can you provide links to national or regional studies on the economic and social impacts of bio-waste?

Food waste prevention

- Has your country introduced new measures related to food waste prevention?

Quality standards and markets

- If you have separate collection of bio-waste/food waste/garden waste from households and/or services, which quality standards do you have for the different types of compost and digestate generated from this waste?
- Which are the most critical parameters (e.g. cadmium, plastics, hazardous substances, …) to achieve the product quality standards for compost and digestate? Why?
- According to your knowledge/experience, what are the main drivers (e.g. mandatory use, low organic matter content in agricultural soil, …) and barriers for the use of compost? (e.g. legislation, competition with other fertilisers, …)
- If there are currently no quality management systems for biowaste in your country, are there plans for the development of these kind of programs?
- What market applications exist for compost in your country, and what share of compost is used in agriculture, viticulture, landscaping, horticulture, …?

Innovations and case-studies

- Are you aware of promising innovations in bio-waste collection and management in your country?
- We invite you to share a case study from your country on the collection and/or management of bio-waste/food waste/garden waste that would be interesting for other countries. What were the lessons learnt? This can be everything from a particularly successful process of introducing separate collection, experiences with food waste prevention measures or other experiences from projects and pilot cases.

Data on bio-waste

- Municipal waste composition and share of food waste, garden waste and other bio-waste in municipal waste
- Amount of separately collected food waste, garden waste and other bio-waste
- Existing and planned bio-waste treatment infrastructure

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