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Waste-to-Energy in the Danube Strategy Region: Challenges and Prospects

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List of Abbreviations

Abbreviation	Term
AD	Anaerobic digestion
BiH	Bosnia and Herzegovina
CEWEP	Confederation of European Waste-to-Energy Plants
DSR	Danube Strategy Region
EC	European Commission
EU	European Union
GHG	Greenhouse gas
LFG	Landfill gas
MSW	Municipal solid waste
NGO	Nongovernmental organization
PPP	Public–private partnership
RES	Renewable energy source
WtE	Waste-to-energy
WFD	Waste Framework Directive

1. Introduction

This report presents the current state and main challenges for the development of the waste-to-energy (WtE) industry in the countries of the Danube Strategy Region (DSR). In general, waste-to-energy systems constitute a broad range of technologies for converting various types of waste either directly into electricity and/or heat or into a fuel for subsequent use. These technologies, furthermore, are dependent on complementary systems and services, in particular waste management. WtE is thus a complex topic overlapping with other prominent issues within the broader European context, such as renewable energy, sustainability, resource security, and the circular economy.

In order to present such a complex topic, the report is divided into five chapters each with increasing specificity. First, a general overview of WtE technologies and associated systems is provided. A cursory look at relevant EU legislation and statistics is also presented for context. Next, the main challenges facing the development of WtE projects are detailed based on a literature review. Such challenges fall into five categories: political/legislative, economic, infrastructural, technological/environmental and social. An overview of the situation in the DSR countries is then presented to shed light on how these countries approach WtE and waste management. In order to identify best practices, a case study of a selected successful project is then presented. Finally, the report concludes with an executive summary and recommendations.

1.1 WtE in a European context

As commonly acknowledged in literature dealing with this topic in a European context (Malek 2012, Sommer and Ragossnig 2011, Wolf Theiss 2016), initiatives and legislation at the EU level are of significance. This can be said for both the EU members and non-members within the DSR, given that those countries in the latter group are either EU applicants or members of other groups such as the Energy Community. As EU applicants, Bosnia & Herzegovina (BiH), Montenegro and Serbia all face significant impetus to bring national legislation in line with EU legislation as part of the accession and application process. The two other non-EU members, Moldova and Ukraine, are part of broader European initiatives such as the Energy Community and the EU's European Neighbourhood Policy. As part of the latter, the EU has association agreements with both countries. These agreements deal with such matters as waste management in an effort to support efforts to bring national legislation and practice in line with the rest of the EU (European Commission [EC] 2018a, 2018b). Thus it is worth reflecting on EU legislation and initiatives relevant for WtE.

The EU waste acquis is comprised of several directives. Those of most relevance to WtE are the Waste Framework Directive (2008/98/EC), Landfill Directive (1999/31/EC), and the Waste Incineration Directive (2000/76/EC). First and foremost, Directive 2008/98/EC on Waste (WFD) stipulates proper waste management and disposal practices to be followed by all Member States as well as states intending to join the EU. Furthermore, it provides formal definitions of the various waste types and management and disposal practices. Together with the Waste Incineration Directive, it also stipulates criteria according to which the processes of recovery and disposal may be distinguished. For example, in order to be considered a recovery operation waste incineration must meet certain efficiency criteria. For plants in operation or permitted before 2009, the benchmark is 60% efficiency; for newer plants it is 65% (EC 2016). If this criteria is met, the operation is classified as R1 - incineration with energy recovery; if not, it is classified as D10 – incineration without energy recovery. Nevertheless, typically all incineration operations recover energy, whether in the form of electricity or heat (Saveyn et al. 2016).

The most recent iteration of the WFD also sets out the so-called waste hierarchy. This hierarchy is part of a broader move at the EU level to push towards a circular economy in which resources are kept within the economy for as long as possible (see Figures 1 & 2). Waste should therefore no longer be regarded as a burden to be disposed of but a resource to be used in other processes. The relevance of the hierarchy for WtE is that such treatment of waste is now considered a viable option only where the given waste cannot be first prevented, reused or recycled. Nevertheless, WtE is still regarded as preferable both environmentally and economically to landfilling, which is seen as the least desirable option (European Parliamentary Research Service 2017).

In terms of landfilling, Council Directive 1999/31/EC on the landfill of waste is the main EU legislation in this area. In particular, it addresses the need to reduce the amount of biodegradable waste sent to landfill due to environmental considerations. It also sets specific targets for landfilling rates for Member States, exemption conditions, and penalties for failure to comply. The most recent target is to reduce the amount of municipal waste sent to landfill to a maximum of 10% of total municipal waste generated by 2035.

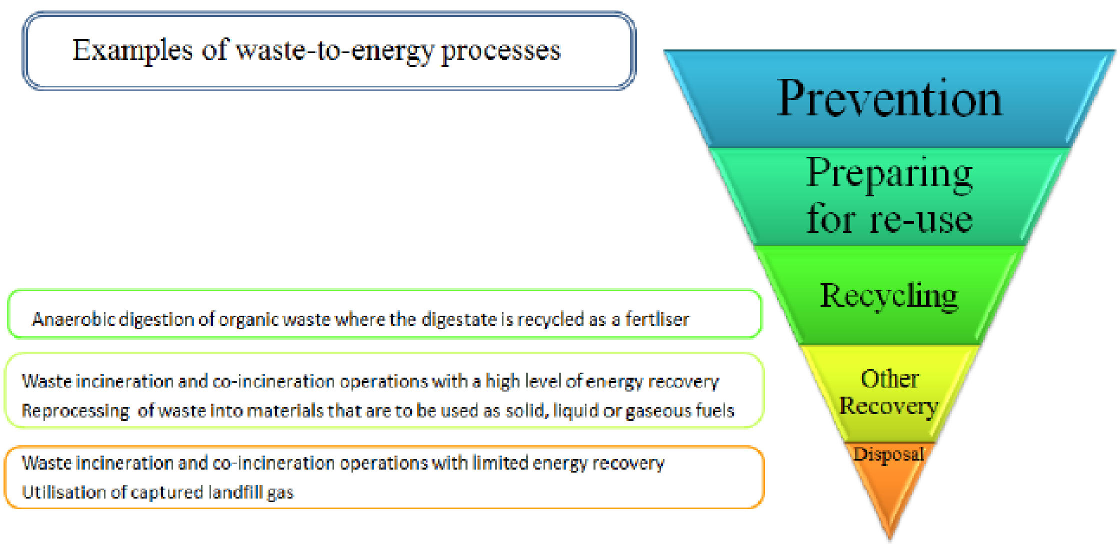

Figure 1. WtE processes in relation to the waste hierarchy (EC 2017b)

As is evident, the issue of waste in a European context concerns not only energy but also the environment and the economy. Thus, WtE plays a potential role in several critical areas of EU policy. In its Energy Union Package (EC 2015), the Commission notes the need to create synergies between energy efficiency, resource efficiency, and the circular economy. WtE can play a role in all three areas. Moreover, given that some waste streams may be regarded as renewable sources, WtE is also relevant for the energy transition. The Renewable Energy Directive (2009/28/CE), for example, addresses the topic of biomass and biofuels, both of which may use biodegradable waste as a feedstock. According to the Wolf Theiss report (2016), the new RES target set by the European Council in October 2014 (27% by 2030) and broader plans for an Energy Union will necessitate a new Renewable Energy Directive. In this context, the EC identified the following measures of potential relevance to WtE: reducing emissions in the heating and cooling sector, facilitating market entry for RES, and increasing the use of RES in transport. Once again, WtE could play a role in all three.

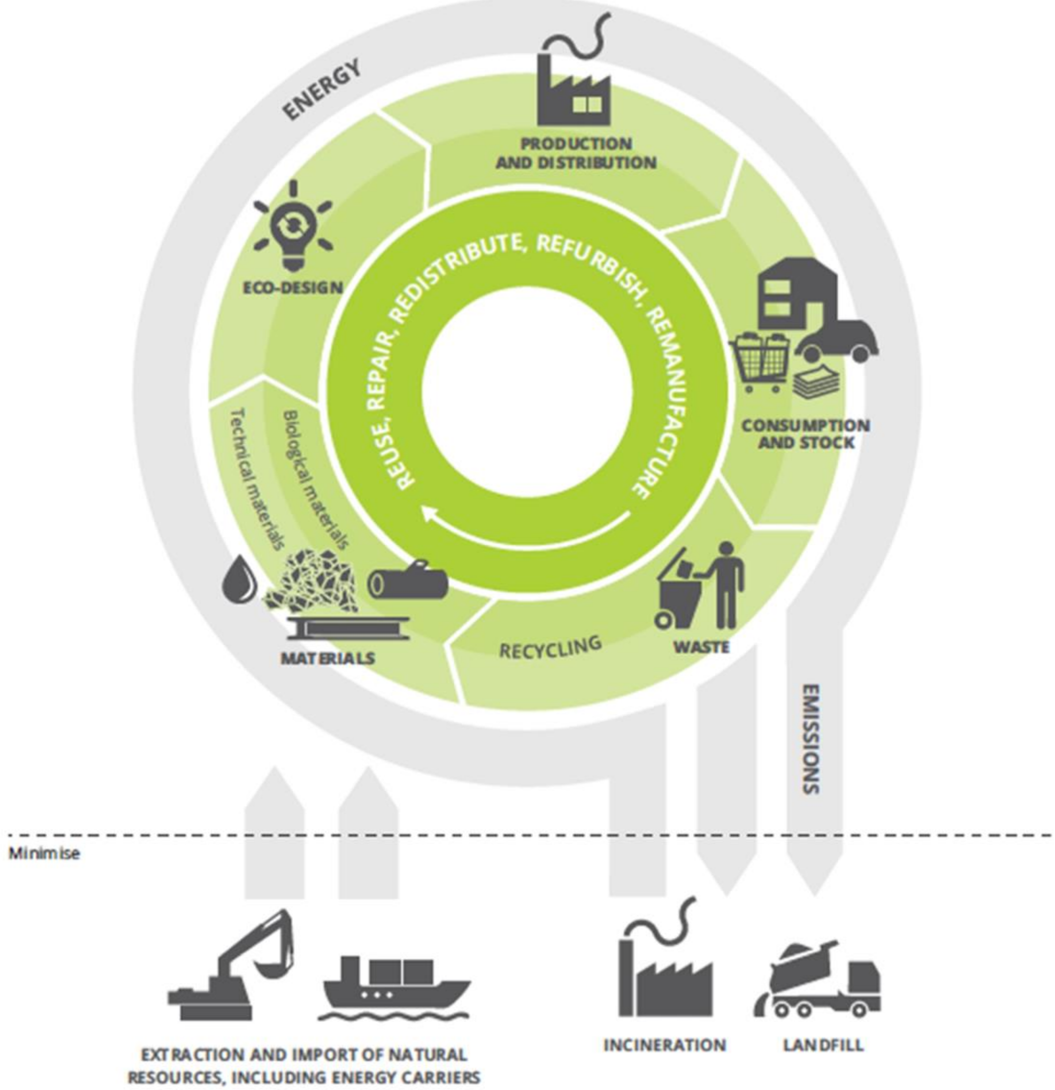

Figure 2. Circular economy diagram (EEA 2015)

The above discussion of WtE in the European context highlights its significance across several critical areas of European policy in general. The same can be said for the Danube Strategy Region, for which WtE may perhaps be even more important. Thus the next section presents the DSR and the significance of WtE for the region.

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1.2 WtE & the DSR

The European Union Strategy for the Danube Region covers 14 countries, including 9 EU member states, 3 accession countries, and 2 neighbourhood countries. The EU MS are Austria, Bulgaria, Czech Republic, Germany, Hungary, Romania, Slovakia and Slovenia. The other five countries are BiH, Montenegro, Serbia, Moldova and Ukraine. The first three are accession countries, while all five are members of the Energy Community and included in the Energy Union initiative. As part of the Danube Strategy Region (DSR), these countries cooperate on 4 key pillar issues encompassing 12 priority areas. Of relevance to the topic of waste to energy, the DSR countries cooperate on initiatives relating to sustainable energy and environmental protection.

The region is generally characterized by relatively high energy prices and reliance on imports (Banja et al. 2014). Thus, energy security is of particular relevance to the region, especially in terms of supply and affordability. On the other hand, the region boasts significant potential for domestic alternative sources of energy, such as waste and biomass (Banja et al. 2014). Both sources can help these countries to address supply security issues while also helping them to meet renewable energy and efficiency targets. Thus the significance of the DSR region and of WtE within this region is evident.

1.3 Waste streams & WtE technologies

In the context of WtE, not all wastes are created equal. Some forms of waste are more suitable for generating energy than others; some not at all. Moreover, those waste streams that may be used to generate energy may be more appropriate for a certain WtE technology. Thus to discuss WtE it is first necessary to present what types of waste are relevant and for what technologies.

A report by the EC's Joint Research Centre (Saveyn et al. 2016) identifies 13 waste streams and 5 waste-derived fuels which are of the most significance for WtE with regard to their energy content. Of those 18, the report then specifies 15 for which reliable data was available (see Table 1 below). The 6 highlighted in blue account for 83% of the total energy embedded in wastes sent to incineration (with and without energy recovery) and 93% of the total energy embedded in wastes sent to landfill. As the report notes, this is significant especially for WtE because "any changes in waste management practices for the six waste types…, and in particular for household and similar wastes (HSW) and sorting residues, would be likely to have the largest impacts on the waste-to-energy landscape in the EU-28" (p. 5).

Table 1. Waste-embedded energy sent to incineration or landfill/disposal in 2012 in the EU-28

Type of waste	Incineration (D10+R1 in PJ)[3]		Landfill/disposal (D1-D7-D12 in PJ)[3]	
Wood wastes	375	21%	7	0%
Plastic wastes	61	3%	51	4%
Paper & cardboard wastes	6	0%	3	0%
Textile wastes	2	0%	3	0%
Waste tyres	35	2%	2	0%
Spent solvents	29	2%	0	0%
Waste oils	32	2%	0	0%
Chemical wastes	93	5%	31	2%
Household & similar wastes (HSW)	470	26%	616	44%
Mixed & undifferentiated materials	149	8%	120	9%
Sorting residues	334	18%	489	35%
Animal & vegetal wastes[1]	70	4%	80	6%
Dried municipal sewage sludge[1]	22	1%	7	0%
Waste-derived biogas[2]	108	6%	0	0%
Waste-derived biodiesel[2]	19	1%	0	0%
Total	**1,805**	**100%**	**1,409**	**100%**

[1] For "Animal & vegetal wastes" and "Municipal sewage sludge", energy recovered from anaerobic digestion is taken into account within "waste-derived biogas".
[2] Biogas and biodiesel are used only for energy purposes, so data for "Incineration…" is the same as the amount of waste-derived biofuel produced.
[3] Data in PJ is calculated by multiplying the amount of waste sent to incineration or landfill by its average lower heating value.
Source: Saveyn et al. 2016

Wastes may also be characterized by their point of origin and method of collection. Figure 3 below depicts a general categorization along these two dimensions. From the figure, it is also evident why many studies on waste to energy and waste management focus on municipal solid waste (MSW). MSW encompasses a great many waste streams. It is also of critical importance within the EU policy framework on waste due to its complexity, despite representing only 7–10% of total EU waste by weight (Malinauskaite et al. 2017). While this report does not focus exclusively on MSW, some related statistics are presented in order to provide a general picture of waste management practices in the DSR.

Figure 3. Waste origin and method of collection (Saveyn et al. 2016)

As regards WtE technologies, they can be categorized according to the physiochemical process of converting the given waste into energy. Three broad categories can thus be identified: thermal, biological and sanitary landfilling (see Figure 4). The first two may be further subdivided, and all categories have their respective technological features and specifications.

Thermal conversion processes include incineration, pyrolysis, gasification, and refuse derived fuels. These processes use various forms of thermal treatment to convert organic material derived from waste into heat energy, fuel oil or gas. These processes are typically applied to waste with relatively low levels of moisture and high content of non-biodegradable organic matter (Kumar and Samadder 2017).

Incineration is the most common of these methods and can be used to produce heat, electricity or both. Furthermore, as was the historical stimulus for this technology's implementation, it has the advantage of considerably reducing waste mass and volume. The generated heat can be used in particular in district heating systems but also in industrial applications. In this case, proximity to the area of use is important. Such is not the case for electricity production, though in this case grid issues are relevant. The process also produces various by-products which can then be used in other industrial applications, such as road construction and cement production. Various gaseous pollutants are also produced by this process, and thus any incineration plant must also include a flue-gas cleaning system in order to meet environmental regulations, as specified in the Waste Incineration Directive. Various incineration plant constructions are possible, but the most common in the EU is grate combustion. To ascertain the most appropriate technology it is essential to first evaluate the composition and characteristics of the respective waste stream. Pre-treatment of waste, for example, by means of sorting, may be done to improve the relevant characteristics of the waste stream for the given plant. Such pre-treatment can also be used to create refuse derived fuel, which contains high calorific value and is suitable for incineration (Kumar and Samadder 2017).

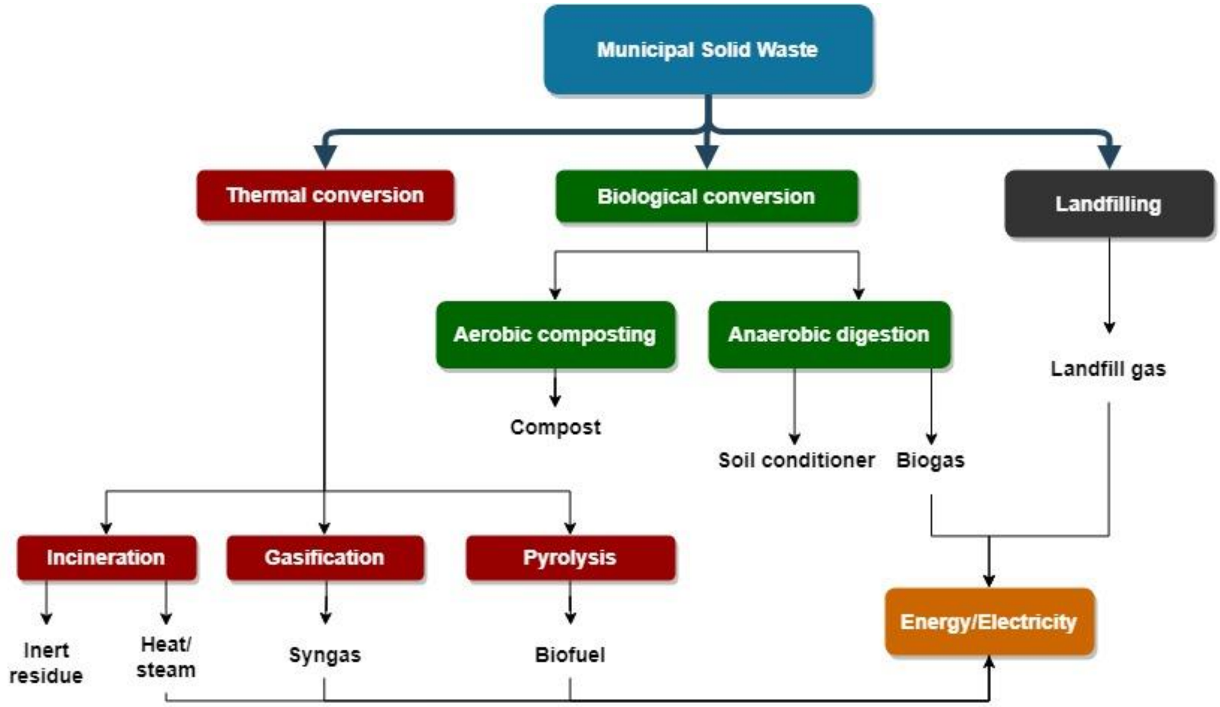

Figure 4. Municipal solid waste treatment techniques and their products (Kumar and Samadder 2017)

Pyrolysis and gasification are less common due to their weaker commercial viability at larger scales as compared to incineration. In the case of pyrolysis, the resulting products are in general pyrolysis gas, oil and char; however, the specific products and their respective yields and qualities depend on the specifics of the process (e.g. heating rate, temperature) and of the waste (e.g. composition, particle size). Furthermore, certain types of waste are most suitable for pyrolysis, including plastic, tires, waste electrical and electronic equipment, and wood waste. Although relatively less common, commercially operating pyrolysis plants have been built, for example, in Burgau and Hamm, Germany (Kumar and Samadder 2017). The Burgau plant, however, is no longer in operation, having shut down at the turn of 2015/2016 (Bayerisches Landesamt für Umwelt 2018). Thus the commercial viability of this technology remains in doubt.

Gasification is the process of converting organic waste into so-called syngas under controlled atmospheric conditions (i.e. oxygen levels) and at high temperatures. The resulting syngas can then be combusted to produce energy or be used as a feedstock for chemicals and liquid fuel. Like pyrolysis, its use tends to be limited to smaller scale processing of MSW. The smaller economies of scale of these two technologies can be seen as a weakness relative to incineration. On the other hand, both have been reported to be more advantageous in terms of environmental impact and energy recovery. Both also offer the benefit of waste volume reduction, while neither requires the same level of flue-gas cleaning as does incineration (Kumar and Samadder 2017).

Biological conversion uses microbes to decompose organic fractions of waste streams and thereby produce biogas. The primary technology currently in use for this process is anaerobic digestion (AD). Appropriate waste for this process is characterized by high moisture content and high percentage of organic biodegradable material. The specifications of the process and waste stream determine the quality of the resulting biogas. In addition to biogas, the other by-product is sludge, which may have additional applications, for example, in agriculture. The process of AD proceeds through a series of stages ultimately converting the biodegradable waste primarily into methane and carbon dioxide. Factors influencing the end product include the type of reactor (single or multi stage) and process (wet or dry), and the choice between each pair of options depends on the characteristics of the available feedstock and the desired final product. The resulting biogas is further treated to remove the carbon dioxide (and other gases) in order to produce biomethane for use in transportation or as a substitute for natural gas in various domestic and industrial applications. While this form of WtE treatment is regarded as economically and environmentally viable, its major disadvantage is the necessary duration of the process (20–40 days) (Kumar and Samadder 2017).

The final form of WtE introduced above is sanitary landfilling. As opposed to standard landfilling, this process incorporates systems for the recovery of landfill gas (LFG) and management of leachate. LFG is a natural product of the complex biological and chemical processes that affect landfilled waste. As with other WtE technologies, the characteristics and rate of production of this gas depend on various factors, including type of landfill, waste composition, climate conditions and moisture content. LFG is mostly comprised of methane. Successful implementation of sanitary landfilling depends first on proper estimation of a given landfill's LFG production. Various models exist for this purpose, including several developed in a European context. Nevertheless, given the EU's current efforts towards a circular economy and reduced landfilling, this WtE technology is likely the least prospective and thus not a key focus in this report (Kumar and Samadder 2017).

As is evident from the above discussion of WtE technologies, various solutions exist for implementing WtE systems. What is also evident is that successful implementation depends on other factors, including, but not limited to, the quantity and characteristics of the given waste streams, presence of necessary infrastructure, desired energetic output, available financial resources, and complementary waste management systems. These factors may vary according to additional factors, such as geographic location, demographics, and level of economic development. Effective implementation of WtE technologies thus requires a comprehensive overview of all these related issues in order to ensure environmental and economic viability and longevity.

1.4 Conclusion

Waste to energy is a topic that touches on several critical areas within the broader EU policy context. Use of such technologies can play a role in waste management, energy transition, energy security and the circular economy. Indeed, the future development of WtE will depend on developments in those key areas and will need to take into consideration the inherent synergies.

The following chapter will address the specific challenges and opportunities facing WtE projects in general. Thereafter the current situation in the countries of the Danube Strategy Region will be presented, with particular focus on the prospects for WtE. A case study is then presented to shed further light on this topic. Finally, an executive summary with recommendations concludes the report.

2. Drivers & Barriers to WtE Development

Despite its advantages, WtE technology is not widespread throughout the DSR. The aim of this chapter is to answer the following question: What explains the shortcomings in the more rapid dissemination of WtE technologies in the states of the Danube region? To do so, the following text will analyse the political/legislative, economic, infrastructural, technical/environmental and social barriers restraining the development and dissemination of WtE technologies in the region.

The key contribution of the chapter is to identify the main challenges and obstacles that these new technologies face. Addressing these issues within the analysed countries may contribute to their energy, environmental and waste-management needs. Wider use of WtE technologies also can create several opportunities untapped in this region – such as local job creation, a healthier environment and land savings. For EU Member States and candidate countries, WtE can also help to fulfil European ecological obligations, such as the binding landfill target to reduce landfilling to a maximum of 10% of municipal waste by 2035 (EC 2017b, 2018c).

2.1 Political & legislative

Political support for WtE technologies varies throughout the countries of the Danube region. In general, on one side are states with a long tradition of supporting these projects and distancing themselves from landfilling of waste. On the other side are countries where WtE projects are not politically or legislatively supported and where landfills still play an important role in waste management (Malek 2012). A handful of countries represent a sort of middle ground. Furthermore, the WtE sector is part of mainly two jurisdictions—waste and energy policies. Therefore, these legislative debates encompass broad topics related to waste treatment, including everything from failing recycling goals and other waste-related objectives to poor legislative coverage of WtE, lack of interest from the public, and derelictions in introducing effective landfill fees. The results of these multi-layered and interconnected debates have deep implications for WtE projects (Stengler 2008).

Firstly, the issue of supranational support of WtE technologies needs to be discussed. Based on the goal of achieving a circular economy (see section 1.1 above), the European Union is setting new rules in order to become a front-runner in waste management and recycling. Although WtE technologies are part of this concept, the EU has decided that for now it will focus (both politically and financially) on achieving greater recycling rates of waste and preventing WtE overcapacities. For example, EU institutions have set a target to reduce landfilled MSW to a maximum of 10% and to increase the amount of recycled MSW to 65% by 2035. Depending on the technology and its efficiency, WtE may be considered a recycling, recovery or disposal operation. This legislation may therefore favour certain WtE technologies over others, and these obligatory targets can make a significant difference in waste management practices for the majority of DSR countries (EC 2017b, 2018c). For those DSR countries outside the EU framework, this supranational pressure would be less influential, which situation could itself prove to be another challenge to the dissemination of WtE technologies.

Secondly, for most DSR states, WtE plants are not clearly defined by national law and are subjected to a wider range of legislative acts. In BiH, Romania, Serbia, Slovakia and Ukraine, for example, national legislation offers no definition of WtE projects (Wolf Theiss 2016). Furthermore, local politicians are not interested in discussing the waste management topic because implementing advanced WtE technologies results in an increase in waste management fees for citizens. The cost of improving waste management systems for populations with lower incomes, such as in Bulgaria, Moldova, Romania, and Ukraine, is the reason why the political focus lies elsewhere. Insufficient legislative support and lack of political will create an unpredictable market environment, which is not very attractive for investors (Briese and Westholm 2012).

Additional problems regarding some EU member states stem from the lack of implementation of existing waste policies transposed from EU law. These could potentially create tens of thousands of jobs and generate billions in turnover if full implementation were achieved. This could open the way to greater recycling rates as well as sorted residual waste that could be treated thermally. States like Bulgaria, Croatia, Hungary and Romania are in slightly different positions regarding the state of their waste management systems. However, the latest country reports prepared by the EC suggest one common problem—implementation of waste management policies remains a challenge. As a result, several sectoral targets have not been met in these states. In the case of Romania in particular, problems with compliance with EU legislation are prevalent (EC 2017a).

Thirdly, weak regulation of landfilling plays an important role in the DSR countries. Only Germany and Austria have extensive landfill bans. According to Eurostat, the worst situation is in Bulgaria and Serbia where more than 80% of waste (excluding major mineral wastes)[1] ends in landfills. Croatia, Hungary, Romania and Slovakia, all with landfilling rates above 45%, are also above the EU average (Eurostat 2014). This situation suggests that the landfilling industry is a competitor with WtE for waste streams. These high levels of landfilling can be attributed to the relatively lower prices for disposing of waste at landfills. With such landfilling option, many municipalities choose to dispose of their waste at landfills instead of WtE facilities, thus removing the incentive for WtE. Such situation also creates lock-in and path dependency whereby both landfilling companies and municipalities oppose the rise of landfill fees, which would result in WtE becoming more competitive (Tramba 2018).

[1] Mineral wastes are inert waste streams with high volume and mass but no energy applications and minimal recycling potential.

While the EU previously supported the development of new waste incineration plants, more recent waste policies have adopted a more holistic approach to waste management based on the duel concepts of circular economy and waste hierarchy. Nevertheless, WtE continues to be a legitimate element of waste management practice and regions with underdeveloped WtE capacities have the option to develop these facilities as needed. This need is likely to be limited by the new focus on waste prevention, improved recycling, sorting of biodegradable waste, and improvements in the recyclability of plastics. There is therefore also a risk that newly built incineration plants planned without taking these factors into account will be left underused or abandoned. On the other hand, waste management practise in most DSR countries is characterized by significant landfilling and lower levels of recycling. The shift away from landfilling could present opportunities for both recycling and WtE. Indeed, those states with more developed waste management systems indicate that the two can coexist. The risk for those countries is whether existing WtE capacities will restrict efforts to move further up the waste hierarchy. Another option for some states will be to negotiate exceptions or pay fines for missing recycling and landfilling targets. However, such approach results in a situation where building WtE facilities may not be attractive to private investors despite apparent need.

2.2 Economic

Economic challenges are associated mostly with a lack of economic instruments to support the dissemination of WtE projects, whether in terms of heat/electricity pricing, cost structure, ownership or return on investment (Pan et al. 2015). Such instruments could include direct support of WtE technologies in the form of subsidies or loan guarantees or indirect support in the form of the landfill taxes.[2] It is not so common in the Danube region to subsidize or economically promote WtE technologies as it is not a political priority (see section 2.1 above).

Indirect support for WtE in the form of taxes imposed on landfilling are the most common. By making landfilling an uneconomical solution for disposing of recyclable or untreated waste, such taxes indirectly support WtE. Austria, for example, gradually raised the landfill tax to the current 87 euro per ton for low calorific waste, while high calorific combustible waste is banned from landfills. Except for Germany, the rest of the Danube region is characterized by low taxes for landfilling (e.g. 26 euro per ton in Romania, 20 euro in Czech Republic, and 5–10 euro in Slovakia). For most of these states, the tax is supposed to increase significantly over the next few years (CEWEP 2017). With a high enough landfill tax, more waste would be pushed higher up the waste hierarchy, whether through recovery or recycling.

The dissemination of WtE technologies also depends on the given ownership model. Generally, three kinds of ownership structures can be distinguished: public, private, and public–private partnership (PPP). Public ownership enables a municipality to include a plant into the local waste management system regardless of short-term profits. The downside of public ownership is the risk that a facility operates with negative profit and therefore has to be covered by public resources. The primary motivation for private ownership is to generate a profit, and therefore return on investment is a crucial criterion for project development. Private projects tend to operate more efficiently, but if a plant is facing long-term unprofitability investors will step away from such project and the local waste management system would be deeply affected. The last form of ownership is PPP, wherein the private sector invests in public projects. While sharing risks, costs

[2] A landfill tax is part of the final price for landfilling. The price includes a fee for waste disposal, the landfill tax, and possibly a recultivation fee.

and benefits, PPP attracts funding from the private sector to ensure public infrastructure and services. Moreover, resource efficiency is improved through shorter construction time together with lower capital and operating costs (Rogoff and Screve 2011b, Arbulú et al. 2017).

Because WtE technologies are expensive not only during the building phase but also during the phase of operation, return on investment is also crucial. In this regard, a project's cost structure should be carefully considered, both in terms of capital and operating costs. On the one hand, capital costs consist of expenditures for land, facility construction, technology equipment, engineering, installation, permitting and implementation. On the other hand, operating costs are influenced by labour costs, costs of chemicals and utilities, maintenance and repair expenses, emissions testing and ash disposal (Rogoff and Screve 2011b, Arbulú et al. 2017). Additional factors such as heat/electricity pricing and disposal also have a significant impact on ROI. This is especially true in the case of private ownership, for which profitability is absolutely critical.

A WtE plant should also run continuously because swift heating and cooling can damage the units and increase the operating and maintenance costs (Rogoff and Screve 2011a). To ensure regular operation of the facility, some states with overcapacities have to import waste from other countries. For example, Austria imports waste mainly from Italy and Slovenia and Germany from Italy, Switzerland, Ireland, Britain and others. The impending problem is that European states with WtE overcapacities cannot import waste from countries with insufficient incineration capacities (i.e. in Central and Eastern Europe) because the price that municipalities pay for local waste disposal is significantly lower than the price of incineration abroad; thus, there is no incentive (The Wall Street Journal 2015, Wilts and von Gries 2014). The economic challenge, in this case, arises when states are pushed to import waste from more distant places than from neighbouring countries. Importing waste from one side of Europe to another is expensive, unecological and impractical.

WtE are capital-intensive projects requiring supporting economic instruments for their faster dissemination. Such instruments include direct tools, such as subsidies, grants and loan guarantees, as well as indirect measures, such as high landfill taxes. Implementation of such measures improves the competitiveness of WtE technologies and helps to address the economic issues discussed above. Nevertheless, the risk of stranded assets must be taken seriously and therefore proper evaluation of the economic viability of any given WtE project is crucial.

2.3 Infrastructural

The most common energy outputs from WtE projects are heat and electricity. Because different WtE plants have various requirements for complementary infrastructure, this section presents the infrastructural challenges to successful implementation of WtE technologies.

Within this context, WtE projects can face problems such as insufficient grid interconnection and associated infrastructure or occurrence of technical and capacity problems within the site. For plants generating heat, the facilities also need to be in close proximity to consumers in order to avoid relative heat loss caused by long transmission (over 30%). Such plants are thus primarily built near larger municipalities, while district heating systems are especially beneficial (Masatin et al. 2016, Persson and Münster 2016). Furthermore, access to infrastructure in comparison to other producers of heat or electricity is also of relevance. Relative access mainly depends on the ownership of the competing plants and the authority deciding about access issues.

The problems mentioned above can appear within a wide scale of WtE projects. Specifically, the problem with access to infrastructure in comparison to other energy producers can be found, for example, in the case of the Czech incineration facility in Brno. As the municipal authority in Brno is the owner of both the incineration plant and heating plant, the authority decides on the participation of both producers in Brno's district heating system. The current situation shows poor optimization, whereby the gas-powered plant for district heating has priority access over heat generated by the WtE facility, thus lowering the plant's efficiency and energy output. The owner primarily uses the WtE plant for waste disposal, but not harnessing its energy output indicates poor implementation of this technology. In such cases where competitors are given preferential access, WtE plants do not have sufficient opportunity to fulfil their capacity (Suzova 2018).

As the challenge is the use of the generated heat, the plant's siting process must navigate between optimal location in terms of the waste supply chain and optimal location in terms of heat delivery, i.e. close to industrial facilities or large municipalities with significant heat requirements. That is why WtE facilities are often placed near capital cities, such as Budapest, Prague, Vienna or

Zagreb. Close cooperation with existing infrastructure (local thermal plants, coal-burning plants) can also generate innovative technical solutions. As an example, the Zwentendorf power plant in Austria sends steam to a nearby thermal plant for the purpose of generating electricity. Thus, no generator need be installed at the WtE complex (Alfons 2018).

Existing infrastructure is considerably influenced by past choices concerning energy and waste management needs. Such choices often reflect a country's natural resources (COOLSWEEP 2014). Thus, a country with significant domestic coal resources, for example, is likely to have an electricity sector characterized by large coal-fuelled thermal plants and the appropriate supporting infrastructure. Similar to the political and legislative landscape, infrastructure is thus affected by lock-in and path dependency. The state of existing infrastructure can also have economic impacts on WtE projects given the high capital costs discussed above. Any WtE project should therefore give careful consideration to this issue.

Choosing the best possible location has a crucial impact on a WtE project. Selecting the most viable site with good connection to heat/electricity transmission and waste delivery infrastructure is as important as the technology itself. Efficient planning of infrastructure connections is therefore key to the successful operation of both existing and planned projects (Department for Environment, Food and Rural Affairs 2014).

2.4 Technical & environmental

Generally, technical and environmental challenges are understood to include the difficulty of choosing cost-effective technologies suitable for local conditions and potential negative environmental impacts (Pan et al. 2015). The primary technical challenge concerns the composition of the waste itself, while the main environmental impact regards associated emissions. Various tools exist for addressing these issues.

One of the key technical problems relates to waste composition. The composition of waste may vary from year to year and region to region, and WtE technology needs to adjust accordingly. For WtE facilities, the primary concern is the calorific value of the waste stream being used. Too low or too high a calorific value can have negative technical impacts on a facility, while specific types of waste may also cause physiochemical damage, thus impacting operating costs. Furthermore, a shift towards recycling can impact the calorific value of collected MSW due to separate collection of different types of waste, in some cases resulting in lower calorific values for MSW at the point of collection. On the other hand, not all waste collected for recycling is actually recyclable and waste sent to WtE facilities from separation and sorting facilities has high calorific value especially because of the presence of unrecyclable plastics (Suzova 2018).[3] Careful consideration of the available waste stream is therefore critical for any WtE project.

The second challenging aspect of this technology is its environmental impact, specifically the production of greenhouse gas (GHG) emissions and dioxins.[4] Waste incinerators used to be one of the major contributors of dioxins and other emissions until the late 1990s when the toxic effects of dioxins were discovered and steps were taken to reduce their emissions through a system of filters and barriers (Psomopoulos et al. 2009). Although WtE is therefore no longer a significant source of dioxins, WtE facilities are still subject to strict emissions limits. The challenge in this regard is to accurately measure all emissions, with which WtE facilities tend to struggle because the deviation of analysers is often larger than the strictly defined limits (Suzova 2018). On

[3] Plastic content can be maximally 3%, which is a very low amount that is hard to mix well with other waste.
[4] Dioxins are highly toxic and ubiquitous compounds that are persistent, bioaccumulative and cause a wide scale of reproductive, developmental, hormonal or immune system problems. They are products of chemical processes, such as incineration, but there are also natural sources, such as volcanic eruptions and forest fires (WTO 2016).

the other hand, given that WtE is often discussed as an alternative to landfilling, in that context it is seen as a more environmentally friendly option which facilitates the avoidance of GHG emissions from landfills.

Various tools exist to deal with both technical and environmental challenges. At a regulatory level, there is a requirement to have a universally valid technical standard for WtE facilities and standardized European measurement requirements for emissions in order to create a stable environment for new project development. The production of dioxin emissions is limited by both prevention during the incineration process and removal of dioxins from combustion products using a combination of filters and barriers. These preventative measures are now standard practice. The issue of dioxin emissions is therefore rather a technical challenge than an environmental one, and any new WtE facility must meet strict emissions regulations (Ferdan 2008).

Given the above technological and environmental challenges, decision-makers should take into account several factors when planning a WtE project. Not only the volume but also the composition of waste become increasingly important when waste is shifted from landfills to WtE plants. While emissions of dioxins and other by-products are not an issue for current incineration technology, the challenge is to use the technology well and follow existing standards and best practices accompanied with rigorous emissions monitoring.

2.5 Social

In addition to the challenges presented above, the development of WtE facilities is also highly dependent on public acceptance of proposed projects in a particular locality. More specifically, three dimensions of social acceptance can be distinguished: socio-political, community and market acceptance. Socio-political acceptance is related mainly to the embracing of technologies and policies by the public, key stakeholders and policymakers. The second dimension, community acceptance, is based on procedural justice, distributive justice and trust. In that regard, the participation of local communities in decision-making processes is crucial; otherwise, protests may become a factor. From the market point of view, the key problem is market adoption and the diffusion of innovation, reflecting acceptance by investors, companies and consumers (Wüstenhagen et al. 2007).

The main reason why WtE technologies often lack public support is that people perceive them as highly polluting, imposing risks not only to the environment but also to public health and safety. Social rejection of such projects is often connected with the NIMBY (Not In My Back Yard) or BANANA (Build Absolutely Nothing Anywhere Near Anyone) phenomena, which imply that geography and distance matter (Achillas et al. 2011). Among newer theories explaining local opposition is the concept of place attachment. Emerging from social and environmental psychology, this concept proves that people tend to take place-protective actions when their pre-existing emotional attachments are disrupted by new technology or other elements introduced into their environment (Devine-Wright 2009).

When citizens decide to express their disagreement with new plans by the city or private investors to build a WtE plant, they will most likely take the following steps. Citizens or NGOs will lodge a complaint with the mayor, municipal authority or district council. People then begin to organize themselves into groups with common interests, file petitions, organize protests, and create or join NGOs. The last step involves giving their actions legitimacy, media presence, and an overall better position to oppose the project. Social opposition can be observed in number of cases around the region. For example, petitions were filed against a WtE project in Varna, Bulgaria and a number of public protests were held against incineration plants in Croatia, Czech Republic and Slovakia (European Parliament - Directorate General for Internal Policies 2011, iDnes.cz 2016, Klimant 2014, Pavlic 2016). These efforts are often organized by local or subdivisions of international NGOs.[5]

There are several ways to deal with potential social challenges to WtE projects. Firstly, participation in national level discussions on WtE, wherein authorities should clearly explain why the change is needed within the given timeframe, is essential to gaining acceptance. Secondly, community engagement and education play an important role. To gain approval, for example, it is helpful to involve the community in the planning process and to emphasize benefits to the local community, such as job creation and skills training. Additional community outreach can take the form of dissemination of proper information about the given technology and project or organizing of workshops, seminars or discussions with experts. Thirdly, a dialogue between communities and authorities (or other involved parties) should be maintained, facilitating compromises such as additional environmental controls, establishment of a supervising authority, or financial compensation to local communities for imposed risks (Achillas et al. 2011, Davison 2012).

Social acceptance/rejection of WtE technologies is the rational outcome of psychological, social and economic factors. These can be addressed through careful management within all phases of a project. Every project is more or less endangered by all three dimensions of social rejection, but the key issue for authorities is to learn how to work with social aspects in favour of the given project.

[5] In the area of Danube region, those are for example HuMuSz (Hungary), Zelena Akcija (Croatia), Ecologists without borders (Slovenia) or Za Zemiata – Friends of the Earth Bulgaria or subdivisions of Greenpeace.

2.6 Conclusion

WtE technologies face a number of challenges, and every new project needs to overcome each of them. The challenges presented above fall into five categories: political, economic, technical and environmental, infrastructural, and social. Addressing each of them separately, however, is not optimal, as there is much overlap between them. These issues should therefore be addressed through a more holistic approach.

Firstly, political challenges also impact economic challenges at the same time. Political support and planning is necessary to introduce economically stable waste management systems, creating a market system where WtE plants are competitive. Gradually introducing landfill taxes is a political solution that is proven to work in channelling waste streams higher up the waste hierarchy towards recycling and recovery operations. Having stable political support and a sustainable market environment also attracts investors to such projects. DSR countries can draw on the experiences of other European states, including Austria, Germany and Slovenia, to effectively implement such taxes and other rules and thereby support WtE technology while also avoiding excess capacities. Political challenges are therefore impossible to separate from economic issues.

Secondly, there is considerable overlap among infrastructural, technical and environmental challenges. These issues can also have knock-on effects for economic issues and social acceptance. For example, waste deliveries by trucks increase the production of emissions and traffic situation within the region, thus presenting both an environmental and social hurdle. The technical requirements of WtE facilities are closely connected with infrastructural conditions, such as connection to the electricity grid or district heating network. In turn, these issues can impact both the capital and operating costs of the given facility.

Lastly, the social acceptance issue has strong linkages to all other challenges. For example, adopting the best available technology can not only solve ecological challenges but in turn help to gain social acceptance due to the decreased local emissions. Likewise, having a clearly communicated political agenda and laws setting forth the justifications for building WtE plants, including environmental benefits and job creation, makes the social acceptance issue less complicated. Finally, having all the above in place at the outset and involving local communities in planning processes can in the long run help to avoid cost overruns for such projects.

The challenges presented above all have overlapping implications. Successful implementation of any WtE project therefore necessitates a holistic strategy for dealing with them. No one-size-fits-all strategy exists. Careful consideration of local, national and even supranational conditions impacting all the aforementioned areas is crucial.

3. WtE & waste management in the DSR

This chapter presents the current situation in the DSR countries in terms of WtE development and waste management practices. Rather than focusing on each country individually, however, each subsection addresses key indicators relevant for WtE and waste management. Statistical information for these indicators is used to present the current situation in the DSR countries. The future potential of WtE and its respective benefits are also assessed in the context of the transition toward a circular economy.

In addition to waste-related data, relevant energy sector statistics are also presented. In particular, the role of renewables and WtE in the electricity, heating/cooling and transport sectors are relevant here. Also relevant are the countries respective targets in these areas and their performance in achieving those targets. Analysing this data helps to identify areas where WtE could yield particular advantages.

Wherever possible, Eurostat data are used in order to ensure a certain level of consistency. However, such data is not always available for all DSR countries, especially some of the non-EU members. In such cases, supplemental sources may be used, but with the obvious caveat that comparability will be limited. Even within the EU, definitions of various waste streams can vary from country to country, thus potentially compromising comparability. This is true also for municipal solid waste, the main waste stream considered in this chapter. Even within a single country, divergent data may be available, as exemplified by the discussion of Czech Republic below. Using Eurostat data nevertheless offers the greatest level of consistency and comparability.

3.1 Current MSW management & potential gaps

Waste management practices vary significantly across Europe. The countries of the DSR are no different, and indeed represent the full spectrum of practices at the broader European level. Nevertheless, the push towards a circular economy as discussed above will have a considerable impact on such practices across Europe. The targets for landfilling and recycling proposed in the WFD and the Circular Economy Package are especially important in this regard. By 2035, landfilling should account for no more than 10% of MSW treatment while 65% of MSW should be recycled, thus leaving at least 25% for energy recovery.

Figure 5 shows the distribution of MSW treatment by operation in the DSR countries as of 2016.[6] The first thing to point out is the level of landfilling. Three states (Austria, Germany and Slovenia) landfill less than 10% of all MSW and at the same time recycle over 50% of MSW, thus meeting the target set forth in the WFD for 2020. Also interesting is that these same three countries have the highest levels of overall incineration (with and without energy recovery). There is then a significant jump with Czech Republic, Hungary, Bulgaria, Slovakia and Romania sending 50–70% of MSW to landfill. The first three recycle over 30% of MSW, while Slovakia recycles approximately 23% and Romania 13%. These countries are slightly more varied in terms of energy recovery, ranging from 4% to 16% of MSW treatment. The remaining countries are all characterized by exceptionally high landfilling rates (nearly 80% and above), zero or negligible energy recovery (with the exception of Ukraine) and very low recycling rates (with the exception of Croatia).

[6] Comparable statistics were not available for Moldova.

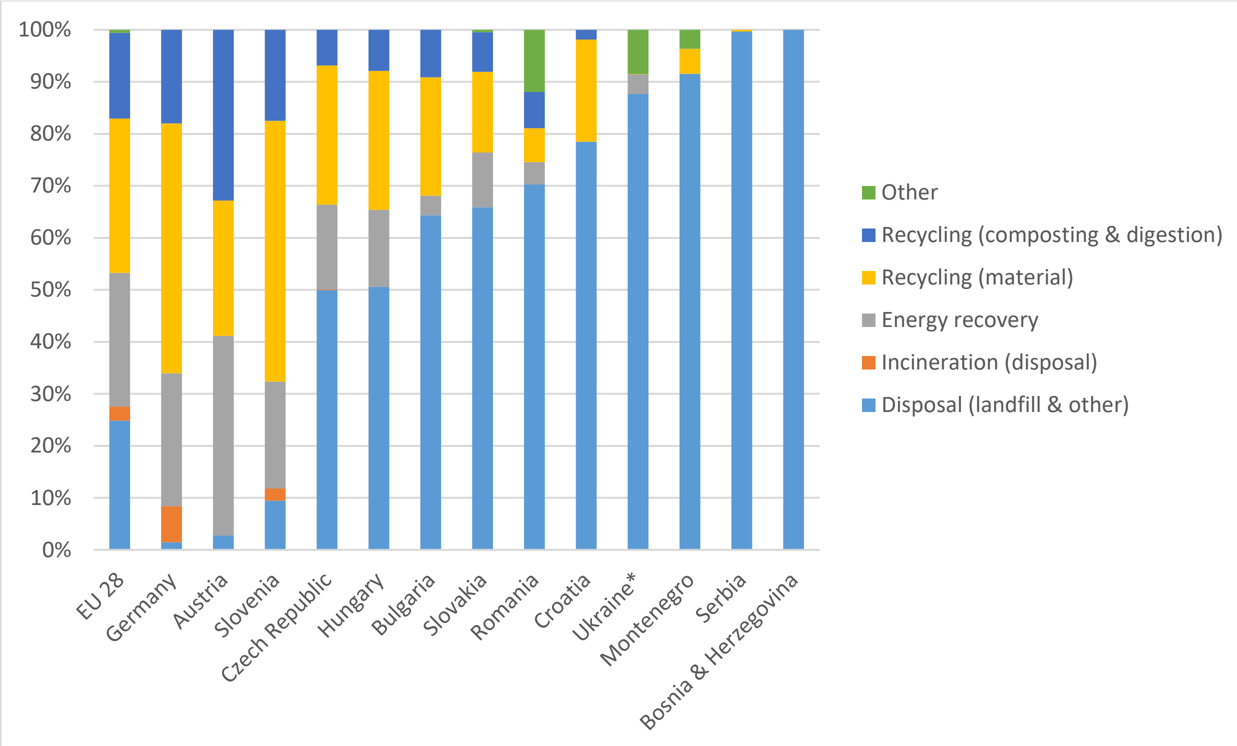

Figure 5. *Distribution of MSW by treatment type, 2016 (Eurostat 2018a; * based on own calculations using data from the State Statistics Service of Ukraine [Ukrstat.org 2018])*

What is apparent from this data is that the DSR countries are generally characterized by underdeveloped WtE sectors and rather high levels of landfilling. Most countries in the DSR are thus a rather long way from achieving the circular economy goals. The question then is what role WtE could play in helping these countries to move towards a circular economy. To answer that question, it is also necessary to consider some broader data in waste generation and waste management.

Table 2 below presents some overall descriptive statistics regarding waste generation and waste management in the DSR countries. Based on these data, an estimate of the potential for WtE development is calculated as the gap between current WtE capacity and the theoretically necessary capacity to meet the circular economy goals, representing 25% of generated MSW in 2035. Because exact data on current WtE capacity exclusively for MSW is not available from Eurostat, this figure also had to be estimated. For Austria, Czech Republic, Germany, Hungary and Slovakia, however, the respective capacities were taken from the Confederation of European Waste-to-Energy Plants (CEWEP).

Table 2. Estimated capacity gap as indicator of future potential for WtE development (2016, thousand tonnes)[1]

	Total waste[2]	MSW	% MSW	Total R1 capacity	R1 MSW cap. est.	CEWEP capacity[3]	25% MSW	Capacity gap
EU 28	910,960	246,515	27.06	145,920	39,487	:	61,629	**22,141**
Austria	16,482	4,928	29.90	5,110	1,528	2,367	1,232	**(1,135)**
BiH[4]	4,070	1,303	32.01	:	0	:	326	**326**
Bulgaria	18,012	2,881	15.99	1,214	194	:	720	**526**
Croatia	3,457	1,680	48.60	214	104	:	420	**316**
Czech Rep.[5]	12,829	3,580	27.91	2,616	730	726	895	**169**
Germany	156,206	51,633	33.05	63,702	21,056	24,710	12,908	**(11,802)**
Hungary	10,956	3,721	33.96	1,999	679	382	930	**548**
Montenegro	728	322	44.23	0	0	:	81	**80**
Romania	21,355	5,136	24.05	6,190	1,489	:	1,284	**(205)**
Serbia	9,728	1,890	19.43	:	0	:	473	**473**
Slovakia	7,925	1,890	23.85	1,006	240	285	473	**188**
Slovenia	3,032	963	31.76	284	90	:	241	**151**

[1] Own calculations using data from Eurostat (2018a,f,g), unless indicated otherwise. Arithmetic errors due to rounding.
[2] Excluding major mineral waste.
[3] CEWEP 2018b.
[4] Data for BiH from 2012.
[5] Eurostat data for Czech Republic comes from the Czech Statistical Office. This data is widely considered within the Czech Republic to be inaccurate, as discussed in more detail below.
: = "Not available"
() = negative.

The first step was to calculate the percentage of *Total waste* (excluding major mineral waste) comprised by *MSW* (*% MSW*, column 4) based on Eurostat data. Then, again based on Eurostat data, an estimate was made for WtE capacity for MSW by multiplying the *% MSW* by the *Total R1 capacity* for total waste (excluding major mineral waste) to yield the figure *R1 MSW cap. est*. Next, *25% MSW* was calculated, representing the amount of waste available for energy recovery while meeting the 10% landfill and 65% recycling targets set for 2035. Finally, the *Estimated capacity gap* was calculated as the difference between the *25% MSW* figure and the *R1 MSW cap. est*. What this calculation reveals is that the majority of DSR countries appear to face significant capacity shortages for WtE in a circular economy context and therefore considerable potential for development in this area.

Furthermore, this calculation can be regarded as rather conservative because of the method employed and certain underlying assumptions. Firstly, the calculation of the estimated current WtE capacity for MSW relies on the assumption that the proportion of MSW represented in *Total waste* also applies to WtE capacity. For those five countries mentioned above for which CEWEP data was available, this figure was used instead. Comparing the CEWEP figures with the estimates provides some interesting insights. For three of the countries (Czech Republic, Germany, Slovakia), the estimates are relatively close to the CEWEP figure. For Austria the estimate is considerably lower, while for Hungary it is considerably higher. What this suggests is that while the estimate is suitable for giving a preliminary picture regarding the capacity gap, ultimately it would be necessary to apply the actual current capacity of WtE plants using MSW, as done with the CEWEP data.

The calculation of the capacity gap also assumes that waste generation will remain stable through 2035. Given the oft-cited connection between waste generation and economic development, however, it would certainly be expected that the absolute amount of MSW generated in each country would increase over time. On the other hand, waste prevention efforts implemented as part of the circular economy would have the opposite effect. Overall, however, this assumption would also appear to make the resulting estimate rather conservative. Trends in waste generation are discussed further below.

The calculation may also be considered conservative due to the assumptions regarding the circular economy targets themselves. Firstly, looking at MSW management throughout the EU 28 + Iceland, Norway and Switzerland, it is apparent that those countries who have already achieved the landfilling target in fact have even lower levels of landfilling. Switzerland has 0%, while five countries, including Germany, have a landfill rate of 1%. Austria and Finland each landfill 3% of MSW, while Norway has a rate of 4% (Eurostat 2018a). This circumstance would suggest that where effective landfilling legislation is in place levels even lower than 10% are achieved and thus the potential for WtE could be more than 25%. Similarly, the recycling target is measured as the percentage of MSW that is separately collected for recycling purposes. However, not all separately collected waste is ultimately recyclable. A conservative estimate by CEWEP and the European Commission states that 8% of separately collected waste is ultimately sent to recovery operations and 2% to landfill (Stengler 2016). Thus, once again, the proportion of MSW available for energy recovery would increase beyond 25%. Indeed, the net effect could be significant. In the case of Romania, for example, the estimated gap in Table 2 is negative, suggesting an overcapacity. However, given its relatively high level of MSW generation, these additional inputs would likely result in a positive gap, indicating additional required capacity.

Finally, it is worth once again pointing out that the choice of Eurostat data was made in order to maintain a certain level of comparability and reliability. Nevertheless, as discussed above, the definition and method of measurement for some figures may vary across countries. To that end the EU-level initiatives in this area also strongly aim at achieving homogenization with regard to definitions and measurements. The Czech Republic offers a clear example of the necessity of such efforts. Eurostat relies on MSW data from the Czech Statistical Office despite the fact that the competent authority in the country is the Ministry of Environment (Czech Statistical Office 2016). The former provides an estimated figure of 3.58 million tonnes of MSW in 2016, while the latter cites a figure of 5.612 million tonnes based on its collected data (Ministry of the Environment of the Czech Republic 2018). Long-standing discussions between the two authorities are likely to resolve this discrepancy, but in the meantime it is worth considering both sets of data (Czech Statistical Office 2016). Using the MZP figure, a capacity gap of 677,000 tonnes is calculated, which may be regarded as a more realistic estimate in the case of Czech Republic. Once again, this highlights the conservativeness of the estimated gaps in Table 2 and the need for each country to conduct a more thorough individual evaluation.

What is clear from Table 2 is that overall there appears to be significant room for further development of WtE technologies while respecting the goals of the circular economy. For countries such as BiH, Montenegro and Serbia with currently no energy recovery, the situation is rather clear in that a capacity of some 25% of MSW in 2035 is missing. For other countries, the picture is a little less clear given the assumptions outlined above. Ultimately each country should conduct a similar assessment using the most current and precise data available while also taking into account planned developments in MSW management practices, including already planned prevention schemes and additional recycling and recovery capacities, in order to identify the potential gap in capacity toward the 2035 targets. Forecasted developments in waste generation and waste intensity could also be taken into account. Furthermore, the above discussion concerns only MSW and additional capacities may also be appropriate for handling commercial and industrial wastes. Absolutely critical is to take a long-term, holistic perspective when planning developments in this area.

3.2 Waste generation & intensity

Implementation of WtE processes of course necessitates the availability of the required feedstock. In calculating the estimated gap in WtE capacities in the DSR countries in the previous section, it was assumed that waste generation would remain stable through 2035. As discussed above, however, the validity of such assumption is impacted by various factors. In this section we present some basic data regarding waste generation in order to get a better picture of developments in the DSR countries in this area.

Looking at the absolute values of MSW generated in individual countries over a 10-year period from 2007 to 2016 (see Figure 6) a generally stable trend is apparent in most countries. There are, of course, exceptions. Both Hungary and Romania showed a significant decline until 2011 after which point MSW generation has relatively stabilized, while Serbia shows almost the opposite trend, with MSW generation increasing until 2011 and declining thereafter. Bulgaria, on the other hand, is characterized by a clear and consistent declining trend over the full period. The remaining countries display rather flat and stable trends, with Czech Republic, Germany[7] and Slovakia showing moderate growth.

[7] Germany has significantly higher absolute levels of waste generation (nearly six times more than Romania) and was therefore not included in the figure as doing so would have skewed the graph drastically. Likewise, while using $\log_{10}$ would have resolved this issue, the trend lines would also have been skewed in such a way to make them less representative.

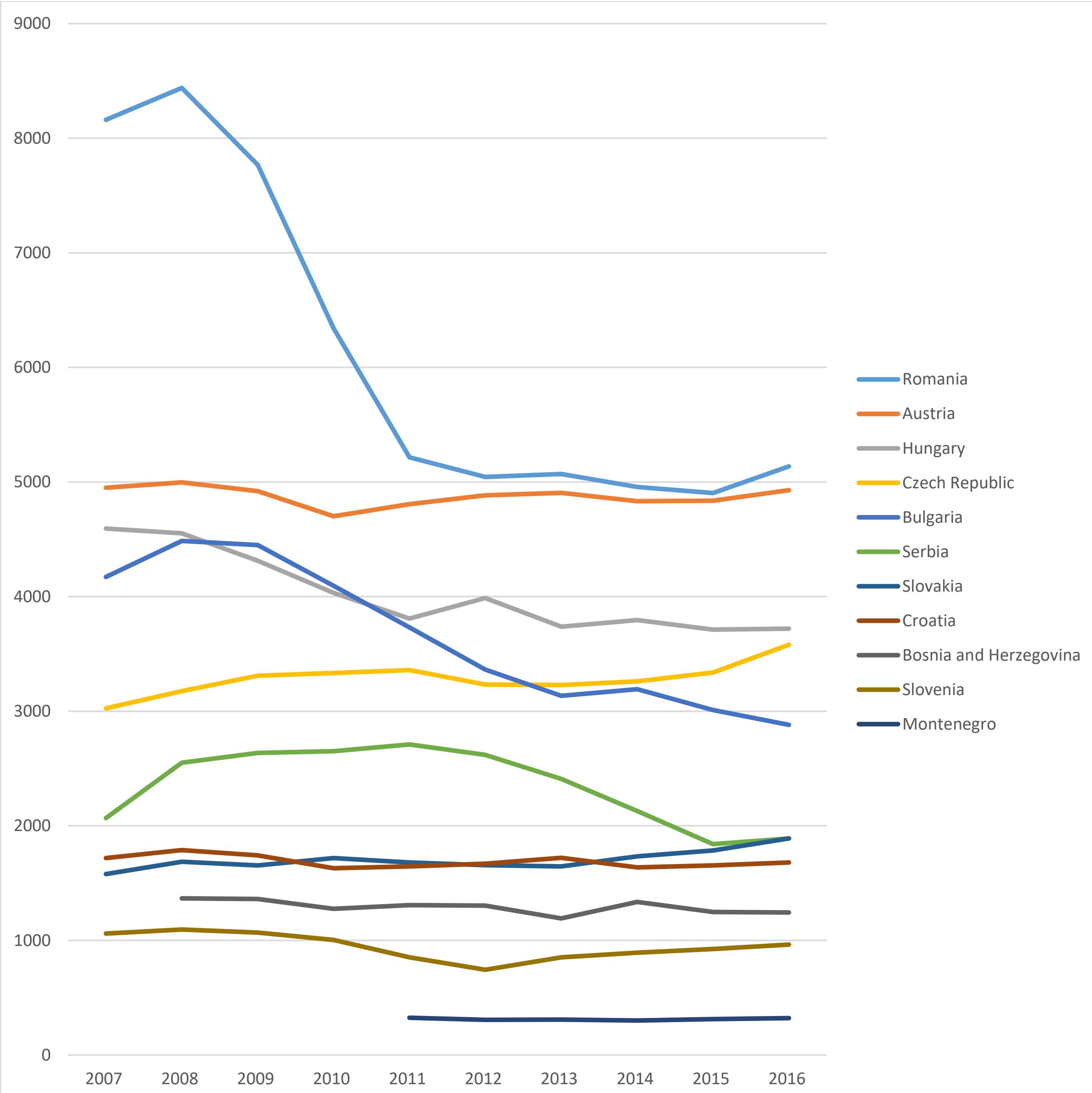

Figure 6. Development in MSW generation, 2007–2016 (Eurostat 2018a)

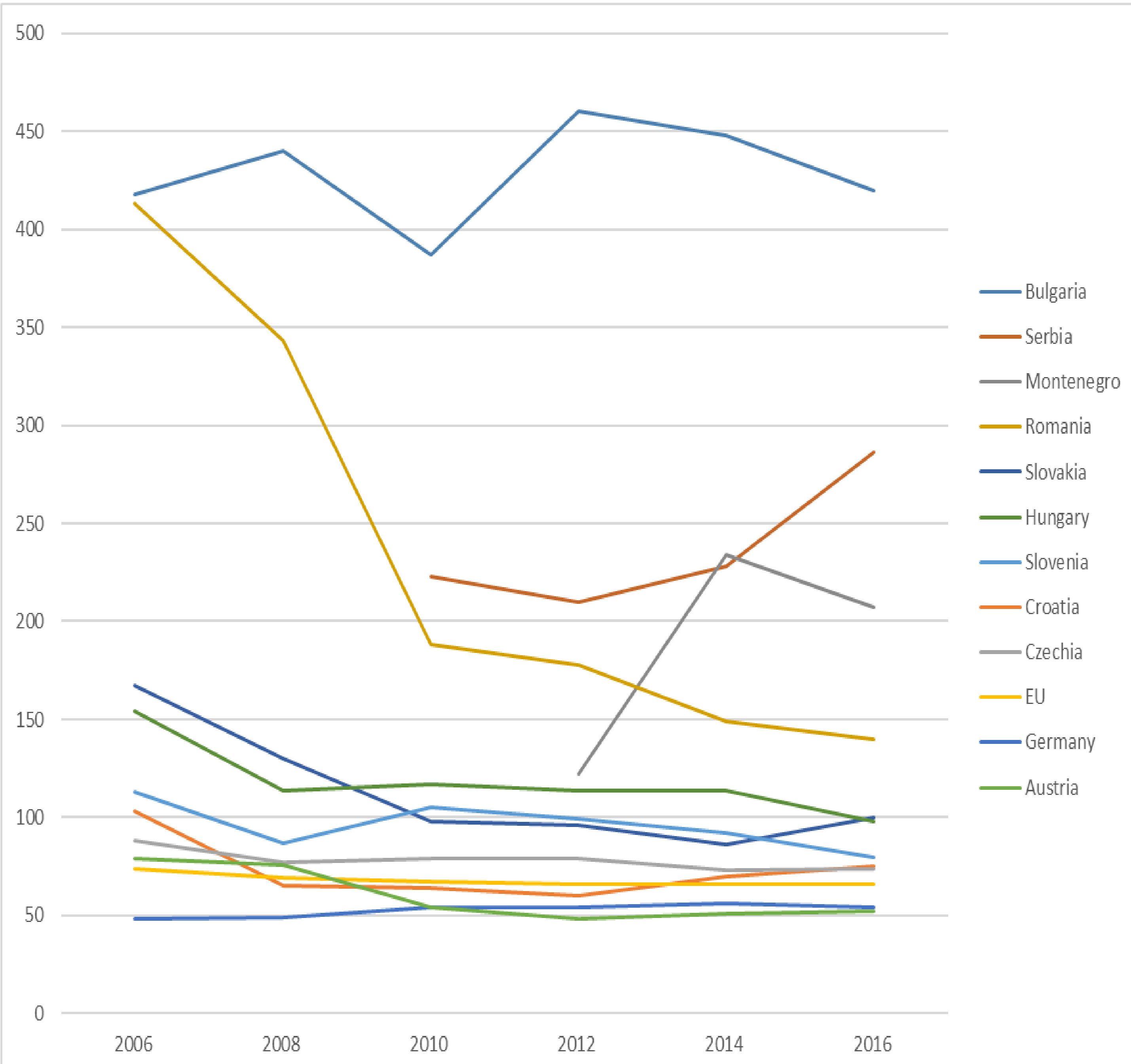

Figure 7. Waste intensity (kg per thousand euro, 2010 chain-linked volumes) (Eurostat 2018h)

Figure 7 shows the trend lines for waste intensity in the DSR countries over an 11-year period from 2006 to 2016. Waste intensity measures the amount of waste generated[8] per unit of GDP. In this case, the trend lines indicate an overall downward trend for most DSR countries. In many cases the slope is rather gentle, but in the case of Romania a drastic decrease is apparent, especially from 2006 to 2010. Montenegro and Serbia are the only two countries with clearly upward trends. Bulgaria and Germany also show a slight increase over the 11-year period, though with greater fluctuation in the case of Bulgaria. The general trend in the DSR therefore appears to be a decoupling of economic growth and waste generation.

Taken together, the above data suggests an overall stable situation in terms of waste generation in the DSR countries. For the most part, growth in total generation of MSW is rather stable year to year. Furthermore, the general trend in waste intensity indicates a decoupling of economic growth and waste generation. Of course, there could be certain economic factors and developments underlying these trends that are not evidenced by this data. Likewise, economic development may affect total waste (excl. major mineral waste) differently than municipal solid waste, as economies transition towards more services and household income rises. Nevertheless, the picture appears stable in this area. It would seem, therefore, that the assumption of stable MSW generation made in the capacity gap calculation in the previous section is not so unrealistic. When planning new WtE developments it is critical that each country think also about the long-term availability of the required feedstock. Looking at trends in MSW generation and waste intensity provides one piece of the puzzle. However, additional factors, such as broader plans in waste management especially in the areas of prevention and recycling, also must be taken into consideration. With this information each individual country can then make a more informed decision regarding the potentially required capacities for individual waste management operations, including energy recovery.

[8] Total waste excluding major mineral wastes.

3.3 WtE as an alternative fuel source

As discussed in previous chapters, WtE is often mentioned as an alternative fuel source enabling reduction of GHG emissions. In some cases, it may even be regarded as a renewable source of energy. It would therefore seem beneficial to look at the current situation in the DSR countries in these relevant areas.

Perhaps contrary to expectations, the countries of the DSR region generally perform rather well in terms of renewables development as measured against their respective 2020 targets (see Figure 8). Germany, Slovenia and Serbia are the only countries with a gap towards the 2020 target greater than that for the EU 28 as a whole (3.2%, 3.7% and 6.3% vs. 3.0%, respectively), while Austria and Slovakia have smaller gaps (0.5% and 2.0%, respectively). The remaining countries have all already met their targets.

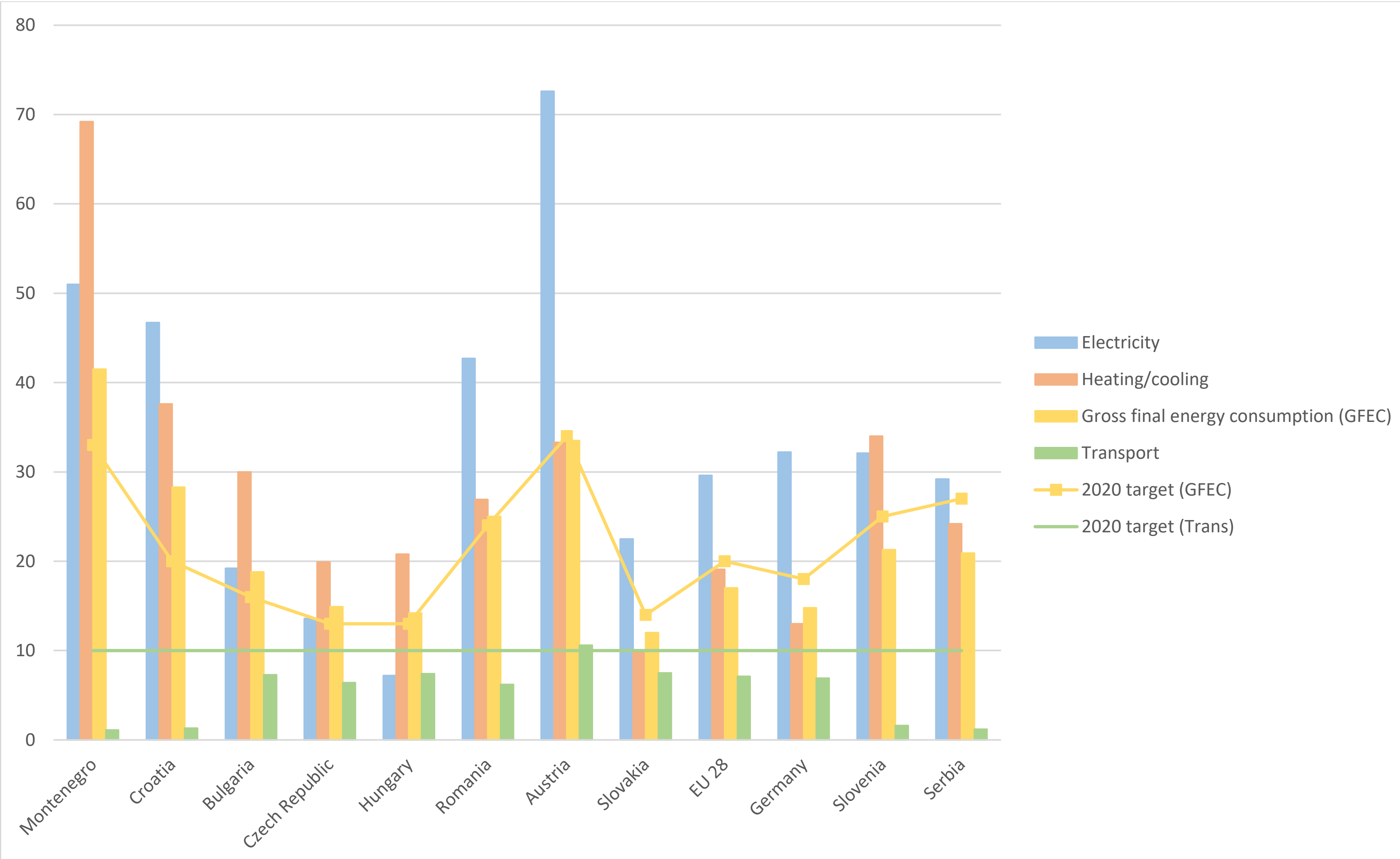

Figure 8. Share of RES by sector and in total (%, 2016) (Eurostat 2018d)

Looking at the electricity sector, most countries have a share of RES over 20%. Half have shares greater than the EU 28 average. Thus, the situation in the electricity sector also looks rather strong already. Nevertheless, WtE might be regarded as an option for further improvement in this sector not only as a potential renewable source but as an alternative to other fuels, especially coal and gas. To consider WtE's potential in this area, it is useful to look at current exploitation of WtE for electricity.

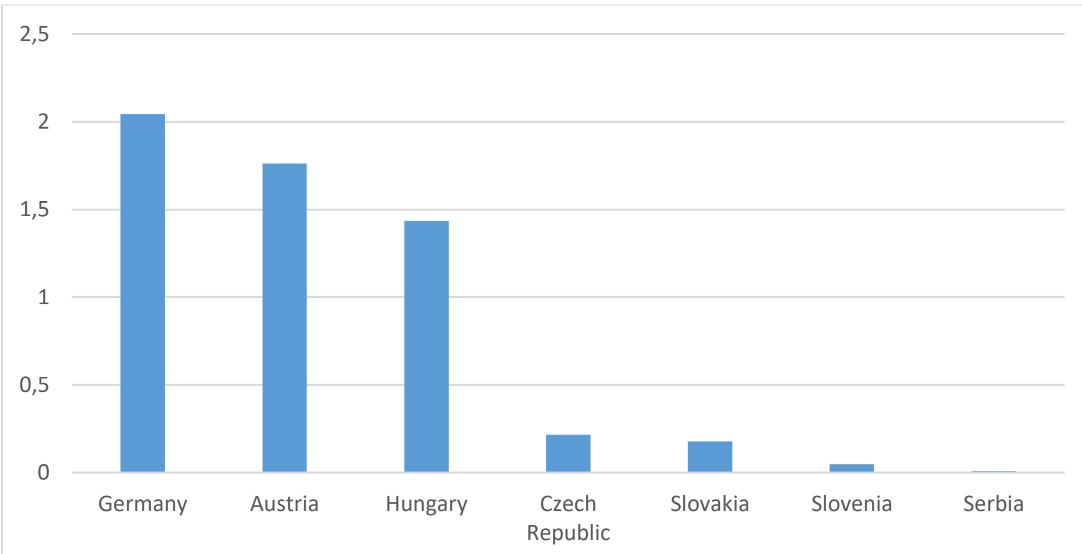

Figure 9. % of gross electricity production from waste (Eurostat 2018b)

Figures 9 and 10 provide an overview of the use of WtE for electricity in selected DSR countries. The percentage of electricity produced from waste in DSR countries ranges from 2.04% in Germany to a negligible 0.01% in Serbia (see Figure 9 above). The remaining countries produce no electricity from waste. Looking at Figure 10 below, we can further break down WtE electricity production according to the waste source (MSW vs. industrial) and whether it is regarded as renewable. With the exceptions of Slovakia and Slovenia, which produce electricity exclusively from industrial waste, MSW accounts for most of the electricity produced from waste, ranging from 56% in Austria to 92% in Czech Republic. Furthermore, for most countries the renewable portion of MSW is dominant. The two exceptions are Germany, where the split is 50-50, and Austria, where only 40% of the MSW fraction is considered renewable. Nevertheless, the general conclusion to be drawn from this data is that waste does not account for a high percentage of electricity production in any one country. Therefore, the potential for WtE to significantly contribute to RES development or as an alternative to other fuels appears limited to rather incremental contributions.

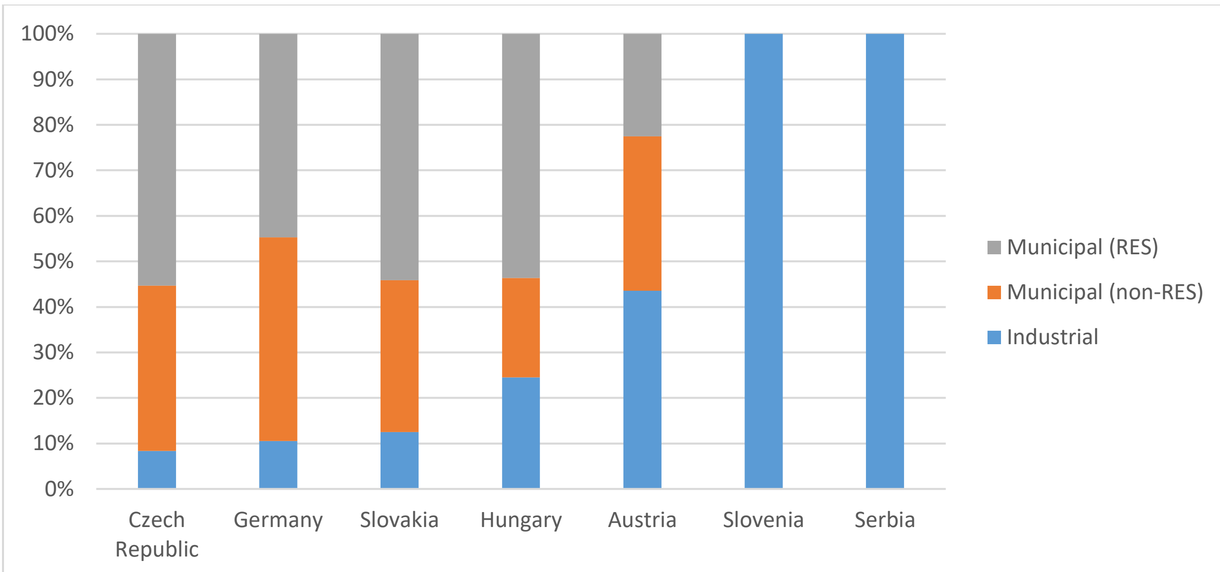

Figure 10. Distribution of electricity produced from waste by source (Eurostat 2018b)

Regarding heat production, overall there appears to be greater usage of waste. In this case, the portion of heat produced from waste in DSR countries ranges from a significant 14.56% in Germany to a negligible 0.05% in Romania (see Figure 11 below). Once again, those countries not represented in the figure produce no heat from waste. As with electricity, these figures can then be further broken down according to the specific waste source (MSW vs. industrial) and, in the case of MSW, whether it is regarded as renewable (see Figure 12 below). Once again, MSW is the predominant source for most countries, with the exceptions of Slovenia and Romania, both of which produce heat exclusively from industrial waste. As regards the split between renewable and non-renewable MSW, only Austria relies more on non-renewable MSW to generate heat.

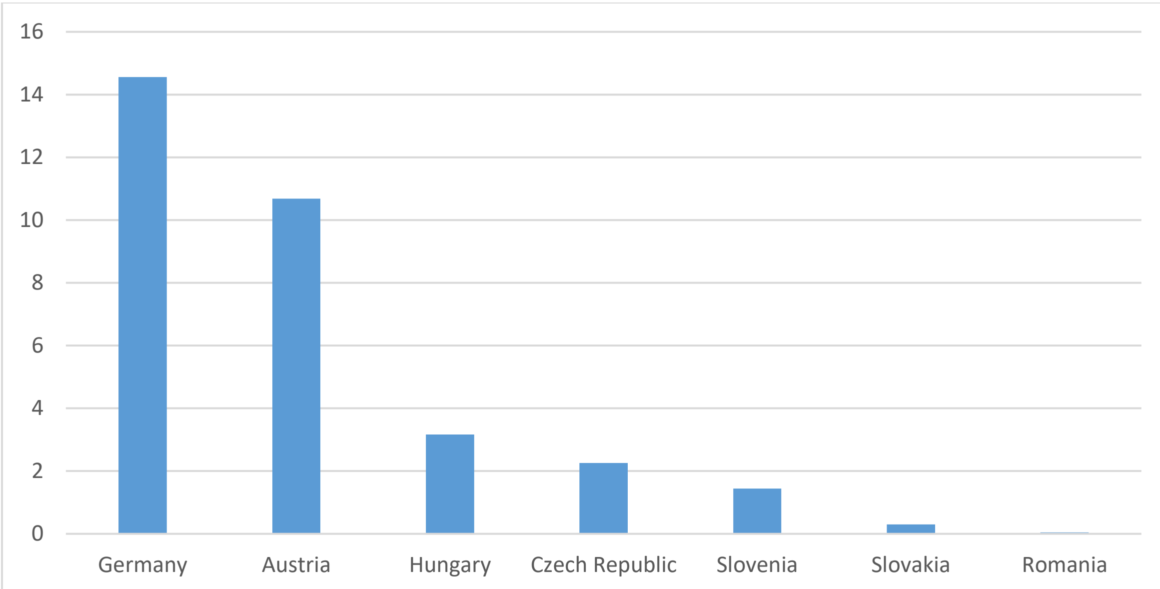

Figure 11. % of gross heat production from waste (Eurostat 2018c)

WtE would thus seem to have much greater potential in the heating/cooling sector than in the electricity sector. In this regard, some waste streams may contribute to increasing the share of RES but more generally waste can be used as an alternative to other fuel sources, especially fossil fuels. As discussed above, in combination with the diversion of the used waste from landfilling such use of WtE thus contributes to the reduction of GHGs on two fronts. Individual countries would want to take additional considerations into account here, including heating/cooling demand, use of district heating, and heat produced by other fuels.

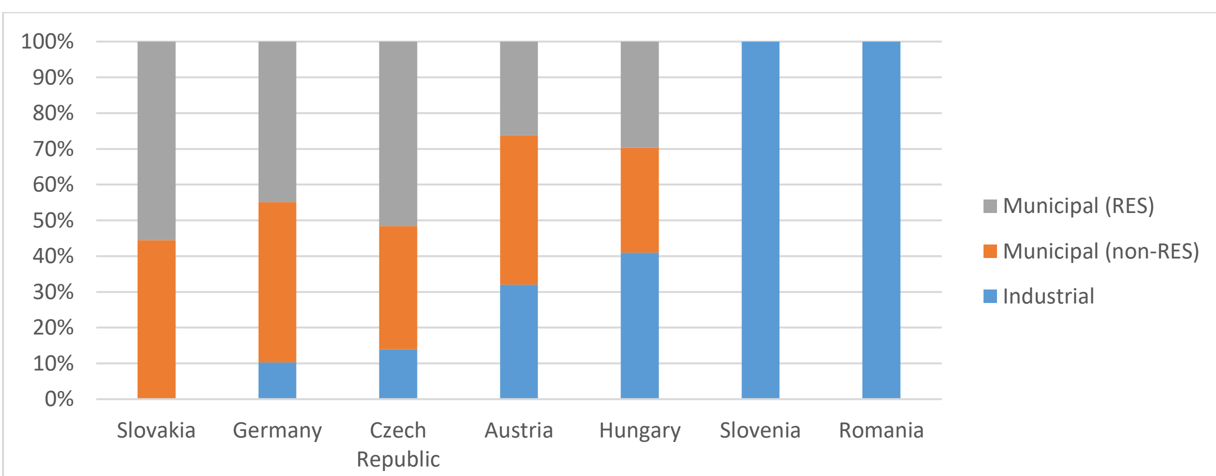

Figure 12. Distribution of heat produced from waste by source (Eurostat 2018c)

In the case of transportation, a common target of 10% by 2020 is set for all EU member states. As can be seen in Figure 8 above, Austria is the sole country which has already met the 2020 target. Among the remaining states, two groups can be identified. The first, comprised of Slovakia, Hungary, Bulgaria, Germany, Czech Republic and Romania, are all within 4% of the target. Finally, Slovenia, Croatia, Serbia and Montenegro face the greatest challenge, all with an over 8% gap.

In addition to the target, the EU Renewable Energy Directive sets sustainability criteria pursuant to which biofuels and bioliquids may be regarded as RES transport fuel. Biofuels and bioliquids from wastes and residues,[9] however, have an apparent advantage as they only have to fulfil the GHG emission savings criteria.[10] Thus, biodegradable waste could prove a highly valuable source of RES in transportation for those countries yet to meet the 2020 target. In this respect, AD would appear to be a promising area for development in nearly all DSR countries. Not only can AD help in achieving renewables targets in transportation, it can also help in achieving higher recycling rates.

Overall, the case for WtE as an alternative fuel appears most promising in the heating/cooling and transport sectors. To some extent, WtE can help to achieve renewables targets but the greatest overall benefit is the potential combined reduction in GHG emissions by replacing landfilling in the waste management sector and fossil fuels in the respective energy sectors.

[9] With the exception of residues from agriculture, fisheries and forestry.
[10] As of 1 January 2018, 60% savings as compared to the reference fossil fuel.

3.4 Summary

Based on current waste management practices and the established circular economy targets, the potential for WtE development in the DSR appears significant. In this context, at minimum 25% of MSW generated in 2035 can be expected to be available for energy recovery. Looking at current capacities, the majority of countries seem to have significant gaps in WtE capacities to fulfil even this conservative target. The overall drive for WtE development would therefore appear to stem from its crucial role in the waste management sector. Additional advantages are also evident in the energy sector. While the potential for WtE to contribute to electricity generation appears more limited, it seems to have more significant potential in heating/cooling and transportation. Regardless of the particular sector, WtE as an alternative fuel source can yield benefits in terms of increased use of RES, reduced GHG emissions, improved energy efficiency and even energy security. Overall, greater development of WtE thus appears advisable throughout the DSR, offering several important benefits.

4. Case Study: Thermal Waste Utilization Plant in Zwentendorf

The following is an inductive case study, the aim of which is to explain as many aspects of the case and their interconnections as possible (Levy 2008). The case is presented as a pivot amongst waste-to-energy projects. The EVN Abfallverwertung NÖ in Zwentendorf is considered to be the most advanced operating thermal waste utilization plant in Europe. Thus, it can provide us with important insights into the tools, incentives and legislative setting which precede best possible outcomes (EVN Abfallverwertung 2018c).

The case study presents a detailed analysis of this successful project focused on the main challenges (as discussed in chapter 2) and measures taken to overcome them. Based on this analysis, we identify best practices to support the wider dissemination of WtE projects in the DSR countries.

4.1 Zwentendorf plant design

The Zwentendorf thermal waste utilization plant is located in Lower Austria, less than 40 kilometres from Vienna. The plant was completed in 2003 with operation beginning in January 2004. After expansion in 2010, the plant's annual capacity was increased to approximately 525,000 tons of residual waste, making it the largest of its kind in Austria. Furthermore, as will be described below, the energetic interplay between the Zwentendorf plant and neighbouring industrial facilities also make it one of the most advanced.

Waste is delivered mainly from nearby municipalities in the Lower Austria region by rail and truck. Some waste is also imported from neighbouring countries Italy and Slovenia. Steam generated by the Zwentendorf plant is directed to the Dürnrohr thermal power station, where it is used to generate electricity (1.4 GWh per year) for 170,000 households; to the district heating networks for Zwentendorf and St. Pölten; and to the AGRANA bioethanol plant. The unique system whereby water steam is transferred directly to the steam system of the Dürnrohr coal and gas power plant enables savings of about 100,000 tons of coal as well as 10 million m^3 of natural gas every year (EVN Abfallverwertung 2018b).

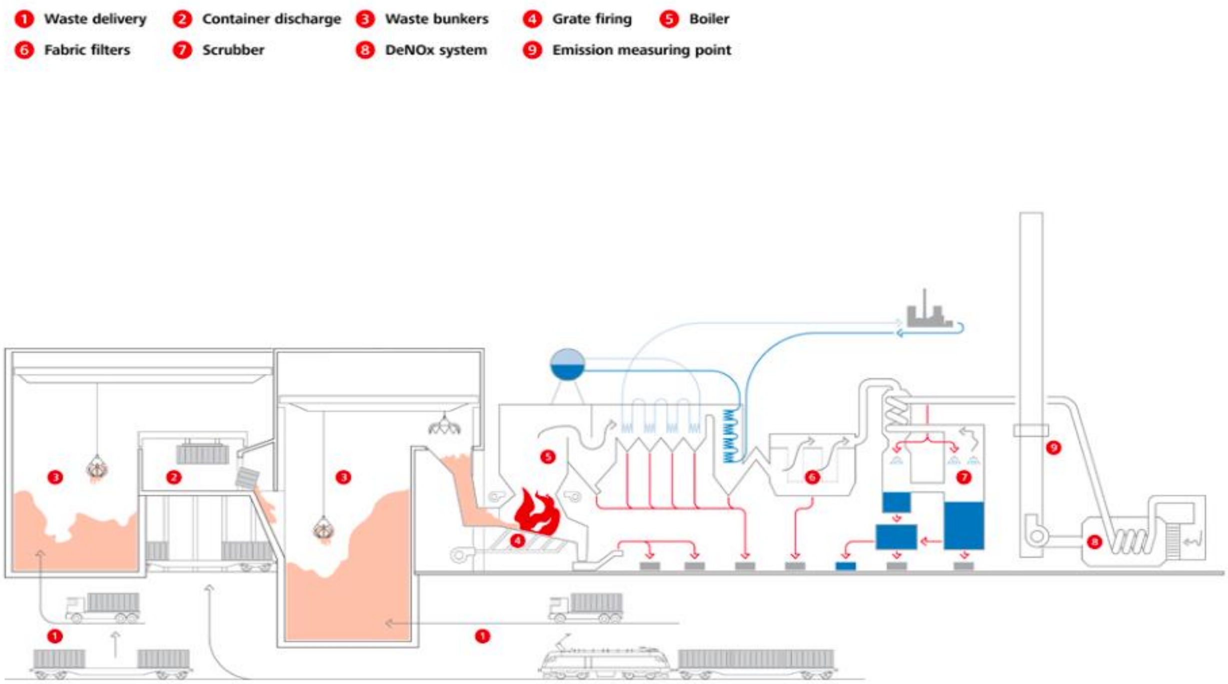

Figure 13. Zwentendorf plant technology scheme (EVN Abfallverwertung 2018a)

A basic schematic of the plant is presented in Figure 13 above. Most important are the grate firing and boiler sections, representing the heart of the plant, and the three cleaning stages, namely the fabric filters, scrubber and DeNOx system (EVN Abfallverwertung 2018a).

In the first step, waste is delivered to the plant mostly by rail. In Lower Austria alone there exist ten reloading stations where waste is collected, pressed and loaded into containers. The plant is equipped to handle waste deliveries by truck as well. Waste is transported in special designed airtight containers, each of which can hold up to 14 tons of waste. Approximately 250 of these containers are delivered daily from the Lower Austria region and from Italy (EVN Abfallverwertung 2015).

Two unloading stations equipped with cranes lift and discharge the containers with waste directly into the storage bunkers. Zwentendorf is endowed with the largest waste capacity in Austria, consisting of two bunkers with a combined capacity of 40,000 m^3. The larger of the two has a capacity of 30,000 m^3 and is connected to the smaller one by a bridge. The bunkers also serve as the location where the delivered waste is mixed by three clamshell cranes, each of which can haul up to 10 m^3 of waste. From here, waste is fed to the grates in three incineration lines (EVN Abfallverwertung 2015).

Natural gas is used within the start-up phase to achieve the initial temperature for grate firing (850 °C). The waste is then burned on its own at a temperature over 1,000 °C, during which most of the pollutants are destroyed. The products of the combustion process are flue gas,[11] ash, and an inert, rock-like slag. The grate is built from movable bars set in an overlapping arrangement enabling garbage to move slowly across the grate until everything is burned. Throughout this process, air is injected through the grate bars to promote incineration (EVN Abfallverwertung 2015).

During the fifth phase, flue gas generated during the grate firing phase is processed in the waste heat recovery boiler, equipped with gas-tight tubing walls designed for constant circulation of water. The flue gas transfers its heat to the circulating water, generating approximately 260 tonnes of steam per hour. This steam is delivered to the nearby Dürnrohr power plant where it is used for electricity production. The flue gas is also cooled to 170 °C during this process, after which it is ready to be cleaned (EVN Abfallverwertung 2015).

The last step consists of three cleaning stages: fabric filters, scrubber, and DeNOx system. The first constitutes a dry cleaning stage using fabric filters to extract dust particles and separate heavy metals together with dioxins and furans. The filtered ash is stored in silos and later deposited to landfill. The next stage is wet cleaning wherein hydrogen chloride and sulphur dioxide are scrubbed from the flue gas by adding a limestone suspension. The resulting wastewater is subsequently cleaned and discharged into the Danube. The filter cake is deposited, and the resulting gypsum can be later used in the construction industry. The last cleaning stage, the DeNOx system, converts NOx gases to steam and nitrogen (two normal compounds in the air) by adding an ammonium solution. Before the gas is released, it passes through several measuring points where continuous measurements are taken for dust, hydrogen chloride, sulphur dioxide, carbon monoxide, carbon dioxide, nitrogen oxides, mercury and mercury compounds together with total organic carbon (EVN Abfallverwertung 2015).

[11] Combustion exhaust gas produced from combustible elements of waste.

Incineration of one ton of waste produces 250 kg of slag, which can be either landfilled or reused, for example, in road construction (as is allowed in Germany). Additionally, about 25 kg of scrap iron can be recycled, whereby it is extracted and sold to the metal industry. Approximately 20 kg of boiler ash, 30 kg of filter ash and 1 kg of filter cake are solidified and then landfilled. The process also produces about 4 kg of gypsum, a valuable raw material typically sold to the construction industry (EVN Abfallverwertung 2015).

Zwentendorf WtE plant is equipped with state-of-the-art technology carrying out the aforementioned processes to guarantee the most efficient operation and lowest possible emissions. Its construction was enabled thanks to long-term political efforts in waste management both regionally and nationally, overcoming a number of legislative, technical, economic, infrastructural and social challenges. These challenges and the ways which they were addressed are examined in detail in the following sections.

4.2 Political & legislative challenges

Political support and a clear legislative framework with fixed goals are an effective way to develop the WtE sector. Common challenges in the DSR include poor implementation of EU waste policies, insufficient support in national politics, poor legislative coverage of WtE, ongoing debates concerning landfilling laws, and postponement of laws coming into force. In the case of Austria, however, such impediments are not present, as indicated by its management of MSW. Austria already landfills less than the EU target of 10% of municipal waste (3% in 2016) and recycles 59%, while the remaining 38% is used for energy recovery (European Parliament 2018). This is the result of policies with roots in Austria's Waste Management Guidelines from the year 1988 (CEWEP 2018a; Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015).

Austrian efforts to develop WtE were motivated by two factors. Landfills and waste treatment generally were recognized as unecological in the 1980s, and a working solution was already observable in neighbouring Germany, where legislative and practical efforts started ten years earlier. As a result, the Austrian Ministry of the Environment, Youth and Family introduced in 1988 the Guidelines for Waste Management in Austria, which were based on Swiss Guidelines for Waste Management. In addition to supporting environmental compatibility and resource efficiency, the aim was to minimize the landfilling of untreated waste over the next 10–15 years (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015; Ossberger 1997).

Debates about subsidies for WtE systems were prominent between 1988 and 1996. Ultimately, the decision was made not to subsidize WtE projects. This outcome was largely due to a lack of consensus regarding which waste treatment technologies were optimal for resolving the waste problem. Nevertheless, the Waste Management Act of 1990 established a waste hierarchy as a guiding principle for waste management and introduced economic instruments such as the deposit refund system. Although further reduction in landfilling was promoted, the rules introduced by the Act were gradual and kept restrictions and limits to a minimum in order to give citizens and the economy time to adapt (OECD 2017, Ossberger 1997).

A landfill tax (ALSAG fee) was introduced in 1989. The first objective was to raise capital for the cleaning of contaminated landfill sites. From 1996, the Landfill Ordinance created differentiated progressive landfill tax rates. Different tax brackets were stipulated according to the technical standard of existing landfills and types of waste. The Landfill Ordinance also established a future ban on landfilling and stipulated that all waste with a calorific value higher than 6,600 kJ/kg must be thermally treated. Total compliance with this law was set for 2004, with local exceptions until the end of 2008. This step was a significant hit to landfilling companies and thus encountered considerable resistance. The situation led to increased competition and a reduction in prices for landfilling. Landfill owners were forced to take such action for economic reasons, but this step ran counter to the intended effect of the ordinance (Bartelings et al. 2005; Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015).

A successor law to the 1990 Waste Management Act was approved in 2002. The Waste Management Act 2002 implements the EU Waste Framework Directive, establishing goals together with principles and defining waste. It also established rules for handling, storage and shipment of waste. A 2010 amendment updated the Act to reflect the new EU Waste Framework Directive, Directive 2008/98/EC. Since 2017, the overall waste management agenda is addressed in the Federal Waste Management Plan (the *Bundes-Abfallwirtschaftsplan*). Generally, the legal basis for Zwentendorf's operation is provided by the following legislative acts (Austrian Court of Audit 2017; Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015; Office of the Federal State Government of Niederösterreich 2016):

- EU Waste Framework Directive (2008/98/EC);
- Waste Management Act 2002 - AWG 2002, BGBl. I Nr. 102;
- Federal Waste Management Plan 2017;
- Lower Austrian Waste Management Act 1992 (NÖ AWG 1992), LGBl. Nr. 8240-0;
- Lower Austria Waste Management Plan 2016–2020.

In February 1994, the Lower Austrian Provincial Diet decided to employ thermal waste utilization as part of its waste management system. As a result, 558 of 573 communities in Lower Austria started to work together to form 22 waste associations, which together established the associated company for waste management and environmental protection BAWU[12] in 1996. Around the same time, the initial plans for building Zwentendorf were made. In June 1994, the company EVN Abfallverwertung NÖ (co-owned by the Lower Austria government and company EVN [50% each]) was founded to begin work on the project. After 7 years of technical planning, siting and environmental impact assessment, approval for construction was granted in 2001 and two years later in 2003 the Zwentendorf plant began operations (Alfons 2018).

As is evident, in deciding about its waste management practices Austria built upon its neighbours' earlier experience. Moreover, laws were introduced slowly in order to avoid resistance among people and industries. The foundations for the legal framework for the construction of WtE plants had already been established with landfill bans and other rules. Austria has thus been generally successful in implementing WtE, though current and future challenges are to prevent WtE overcapacities while focusing on greater rates of recycling and waste prevention.

[12] NÖ Beteiligungsgesellschaft für Abfallwirtschaft und Umweltschutz Ges.m.b.H.

4.3 Economic challenges

Generally, WtE projects are exposed to several economic challenges, such as unpredictable electricity and heat wholesale pricing, financially demanding construction and infrastructure costs, lack of economic instruments to support WtE, and the implications of ownership models, all of which affect profitability and return on investments. The Zwentendorf plant in particular faces several of these issues. Firstly, the government of Austria decided to not provide any direct financial subsidies for new WtE projects. Secondly, in order to be profitable and to fulfil its commitments (e.g. for district heating), the plant faces pressure to secure its waste supply even by importing waste from neighbouring countries. The necessity to transport waste also presents a challenge for operating costs.

As of now, the government of Austria does not offer economic mechanisms, such as government subsidies or insurance of investments, to support WtE projects directly. The only economic instrument in place to encourage the use of thermal treatment of waste are landfill taxes, known as "ALSAG". Introduced in 1990, the tax gradually rose to approximately 87 euro per tonne of waste in 2006, depending on waste composition and landfill standards. This long process of implementing a *de facto* ban on landfill disposal was met with considerable resistance as landfill operators offered their remaining landfill space at dumping prices before the actual ban on untreated waste took place. Such situation complicated the implementation of waste management policy, but the introduction of ALSAG provided financial security for long-term development and investments in the waste management system (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015).

As an indirect result of the ALSAG policy and the plant's ownership structure, the Zwentendorf plant was built without financial aid from the government. The ownership structure also helped with other economic challenges. The plant is fully owned by Austrian multi-utility group EVN AG, the majority stakeholder (51%) of which is NÖ Landes-Beteiligungsholding GmbH, a subsidiary of the province of Lower Austria (EVN 2018). Being partially publicly owned, the incinerator could be integrated into the publicly managed waste management system without having to worry about short-term profits.

Even though Zwentendorf is majority publically owned, it remains important for the company to be profitable. Generally, the source of income is split into three categories: 79% of income comes from the incineration fee, 20% from sales of heat and electricity, and 1% from sales of recovered metals (Netoliczka 2018). Electricity is sold through EVN AG group, supplemented by long-term contracts for energy, such as providing industrial process steam to the AGRANA bioethanol plant (Alfons 2018).

Given the plant’s dependence on waste incineration as a source of income and its commitments to the district heating networks in St. Pölten and Zwentendorf, the constant influx of waste into the plant must be ensured (EVN Abfallverwertung 2018d). Zwentendorf obtains its fuel waste through two main channels. Long-term contracts with municipalities ensured through BAWU contribute approximately 40% of waste, while the remaining 60% is obtained on the market (Austrian Court of Audit 2017). Most of the waste material is from Austria, and nearly half of the material (250,000 tons/year) comes from Lower Austria. Nevertheless, the waste available in Austria is insufficient to meet the plant’s capacity, and thus it is necessary to import waste in order to keep operations profitable. Because neighbouring countries such as Czech Republic and Slovakia have neither high landfill fees nor landfill bans, municipalities in these countries have no economic incentive to send waste to Austria for treatment. The Zwentendorf plant thus imports some 70,000 tons of waste (13% of capacity) mainly from Rome, which suffers from full landfills (Bell 2017). When importing waste from abroad, both the incineration fee and transport costs are borne by the client of the WtE plant. The fee paid for incineration is in accordance with domestic market prices (Netoliczka 2018).

The means of transport is an important consideration in the process of waste acquisition. The feasibility of long-distance land-based transportation (1,000 km from Rome to Zwentendorf) is dependent on the availability of low-cost rail connections. Fortunately for the Zwentendorf plant, it is able to import waste from Italy by rail. While rail transport is beneficial for longer distances, shorter distances within Austria are served more economically by truck. Originally the Zwentendorf plant aimed to obtain 90% of waste by train and 10% by truck, but this proportion changed in 2015 to 73% by train and 27% by truck in order to improve competitiveness with other WtE plants within the waste market (Austrian Court of Audit 2017).

Austria's long-term waste management plan and landfill taxes system imposed in ALSAG have created a stable legal and economic framework for investment in WtE facilities. As a result, Zwentendorf and other WtE plants in Austria can operate confidently within a transparent waste market. Zwentendorf is unique for its focus on railway transport, resulting in a situation where long-distance deliveries of waste are beneficial from an economic point of view. On the other hand, the focus on rail can also create a competitive disadvantage to other WtE plants on the national waste market, where truck transportation is less costly (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015).

4.4 Infrastructural challenges

Generally, the infrastructural challenges faced by WtE facilities include the need to ensure sufficient interconnection and capacity of the site as well as access to infrastructure and the requirement to locate the plant near an urban area. The Zwentendorf waste utilization plant has developed a unique system to address such challenges. This system is one of the most significant reasons why the plant is considered to be a showcase project in environmental engineering without equal in the world.

The Zwentendorf plant is located near the capital city of Vienna, a major waste-generating urban area, but provides district heating primarily to communities in its vicinity, namely Zwentendorf and St. Pölten. In terms of infrastructure access, the plant takes advantage of existing infrastructure by virtue of its location near coal and gas power stations. This system of energetic interplay enables the plant to transfer its produced steam from the incineration plant to the steam systems of adjacent power stations for the purpose of generating electricity (EVN Abfallverwertung 2018a).

A major challenge is to manage the infrastructure for waste delivery by train and truck. The original agreement with the local government was to receive 90% by rail and 10% by truck with a maximum of 50 trucks per day in order to avoid additional emissions from road transport and maintain traffic levels. Currently, however, due to the economic reasons discussed above, trucks now deliver 27% of waste, primarily from local areas. With the increase in truck deliveries, the upper limit of 50 truckloads per day was easily reached and thus the challenge to comply with the rules of the agreement has arisen. The solution has been to use more trucks with trailers (Austrian Court of Audit 2017). Moreover, to overcome infrastructural restrictions and short-term supply fluctuations during weekends and holidays, Zwentendorf has built the largest waste storage capacity in Austria. The storage capacity of 40,000 m^3 allows the plant to maintain operations for a maximum of 10 days without additional waste delivery (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015).

Despite the greater share of road delivery than planned, the Zwentendorf plant continues to rely on the well-developed regional railway infrastructure for the majority of its waste deliveries.

Thus it is still able to keep emissions from road traffic to a minimum and to keep the traffic situation in the region under control (Alfons 2018). The main potential challenge for railway transportation is train scheduling as the railroads are generally more utilized than roads. According to Commercial Director Franz Netoliczka, however, the plant has no problems concerning railway deliveries. The deliveries are organized by the contracted railway company according to the planned time schedule considering peak and off-peak railway hours. Generally, rail deliveries of waste are scheduled three times per day, Monday to Friday. Domestic deliveries are organized either by EVN or the client depending on the agreed contractual conditions. In the case of imports, the client is responsible for transport organization and costs (Netoliczka 2018).

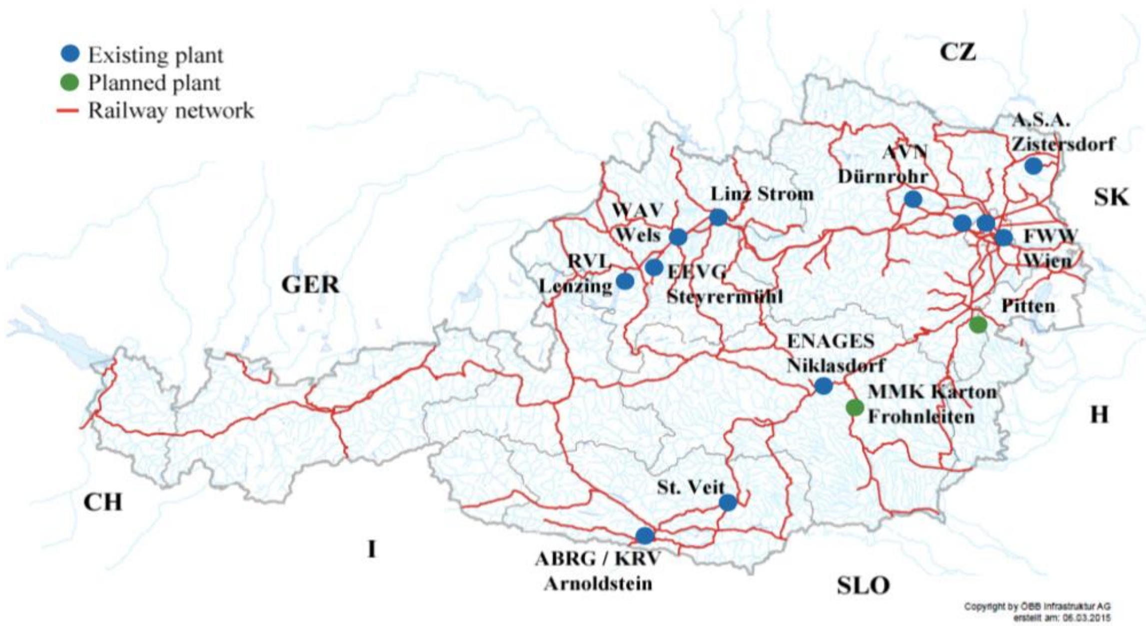

Figure 14. Thermal waste treatment plants and railway network in Austria (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2015)

The Zwentendorf plant addresses the infrastructural challenge of energy output through its unique system of energetic interplay with neighbouring facilities. While located near Vienna, the plant is connected to the more local district heating systems of Zwentendorf and St. Pölten. The produced steam is also sent to the nearby power plant for the purpose of generating electricity. On the input side, the underlying waste transportation infrastructure continues to develop. While the share of waste delivered by train has declined over the years, train deliveries prove to be beneficial especially for deliveries from longer distances. The shift toward a higher share of deliveries by truck, however, is due rather to economic concerns regarding competitiveness than to infrastructural issues.

4.5 Technical & environmental challenges

Technical and environmental challenges are embedded in technological solutions. Optimal use of the technology best suited for a given location and waste composition is key for achieving high levels of efficiency and the lowest possible emissions. As mentioned above, the unique system of energetic interplay in place at Zwentendorf enables the plant to address these technical and environmental obstacles.

This energetic interplay means that the plant primarily generates steam which is then sent to a near-by coal and gas power station. The incinerated waste thus serves as a substitute for fossil fuels, saving about 100,000 tons of coal and 10 million m^3 of the natural gas annually. The energetic interplay system is also highly energy efficient, operating within the range of 0.84–0.88 efficiency (EVN Abfallverwertung 2018a). Thus the plant easily meets the R1 energy efficiency criteria set out in the Waste Framework Directive (see section 1.1 above; EC 2016). The Zwentendorf plant thereby helps reduce emissions and carbon footprint on two fronts—by avoiding landfilling and the burning of fossil fuels.

Regarding the issue of waste composition, in order to maintain a certain level of quality and a steady caloric value the waste received at the plant is mixed using a system of cranes. This arrangement was established especially because of the different types of plastics (PET, PP, PE etc.) coming into the plant from sorting facilities (Alfons 2018). Furthermore, waste from different countries can have different compositions resulting in higher or lower calorific values. In the case of Zwentendorf, waste from Italy is chosen for import because its composition is very close to the waste in Austria. Specifically, the calorific value requirements are between 7 and 13 MJ/kg, independent of the origin of the waste. Nevertheless, imported waste is randomly inspected to check for inconsistencies and verify the calorific value (Netoliczka 2018).

Looking more closely at emissions, Zwentendorf clearly surpasses the already strict emission limits in place in Austria. Thanks to its advanced technology and system of filters, Zwentendorf has managed to reduce almost all emissions by 50% or more as compared to the levels permitted under the plant's licence. In Austria, emissions produced by WtE plants are subject to various limits set in independent processes. For instance, while statutory limits for NO_X

emissions are established by EU Directive at 400mg/m^3, the limits set by the Austrian Ordinance Governing the Incineration of Waste are even stricter at 100 mg/m^3. The emission level permitted under the plant's operation licence is 70 mg/m^3, while actual emissions of NO_X are 50 mg/m^3 (29% below the permitted level). The licenced and actual emissions in the Zwentendorf plant as well as the legislated limits at EU and state level are presented in Table 8 below.

Table 3. Emissions of Zwentendorf WtE plant

Pollutant	**Unit**	**Statutory limits under EU Directive**	**Statutory limits Austria**	**Approved values (licence)**	**Average operating values**	**Reduction vs. licence values**
NO_x	mg/m^3	400	100	70	50	–29%
Dust	mg/m^3	30	10	8	1	–88%
CO	mg/m^3	100	100	50	20	–60%
SO_2	mg/m^3	200	50	50	20	–60%
$C_{organic}$	mg/m^3	20	10	8	1	–88%
HCl	mg/m^3	60	10	7	< 1	–86%
Heavy metals	mg/m^3	0.5	0.5	0.5	<0.1	–80%
Hg	mg/m^3	0.05	0.05	0.05	<0.01	–80%
HF	mg/m^3	4	0.7	0.3	<0.1	–67%
Cd + Tl	mg/m^3	0.05	0.05	0.02	<0.01	–50%
Dioxins	ng TE/m^3	0.1	0.1	0.1	<0.05	–50%

Source: EVN Abfallverwertung 2015

To conclude, Zwentendorf benefits from well-chosen technology optimized for the best use of waste energy at the site of operation. The energetic interplay with neighbouring industries guarantees very high efficiency of operations, while strict emissions limits push the technology to achieve very low levels of emissions.

4.6 Social acceptance

Generally, the problem with social acceptance/rejection is driven by psychological, social and economic factors. According to Davison (2012) three steps are crucial to gaining public support for a WtE project. First, the project must be situated within a bigger picture by explaining national policy with a clear goal and predictable setting and giving people time to adapt to changes. The next step is to engage the local community and support them with all necessary information and to involve them in the planning process in order to address their needs. Stressing community benefits such as employment opportunities can be key. Thirdly, an open dialogue must be established amongst all parties concerned, wherein their interests can be presented and compromises achieved.

Firstly, national policy should be introduced and explained to citizens, offering them a clear image of the situation where change is needed. As mentioned under section 4.2 above, the first national initiatives in Austria in this area started at the end of the 1980s and gradually introduced changes in the waste management system. Citizens were thereby convinced of the importance of reducing the amount of generated waste and fulfilling the potential of creating energy from waste at the same time. Moreover, the history of the Lower Austria region had a positive impact on social acceptance. Industrial plants have a long history in the region, beginning with coal in the early 20th century and continuing with chemical plants and oil refineries for the aircraft industry during the interwar period (Alfons 2018). As regards Zwentendorg, to be assured of local citizens' support a consultative referendum[13] was organized in June 1997 before the environmental impact assessment procedure and technical planning started. Voter turnout was 72%, and the result was that 74% of voters expressed agreement with the decision to build the plant (EVN 2010, Niederösterreichische Landesregierung Stabstelle Öffentlichkeitsarbeit und Pressedienst 2004).

Secondly, the important role of community engagement and education is also confirmed in the case of Zwentendorf. The main benefit for Zwentendorf and the surrounding area was the promise of qualified jobs for locals. As a result of this project, 75 new jobs were created on site

[13] This particular kind of referendum was non-binding. Without the binding function, the referendum serves as an orientation aid for politics. Nevertheless, according to the statistics, no legislator in Austria has yet ignored the result of a referendum (Martinovsky 2012).

and 60 jobs indirectly in the region. Around 85% of the workforce comes from the immediate area. Hiring locals has other benefits too. Hiring local staff one year prior to the start of operations and providing them all necessary training not only results in highly qualified and motivated staff, but local staff also act as spokespeople by ensuring fellow citizens about proper management and efficient operation with respect to environmental standards (Alfons 2018, EVN 2010).

Based on a policy of transparent dissemination of information, the company set up an information office from the start of the project planning phase. The company also organized workshops, discussions with the experts, and other public events to raise awareness about WtE technologies and their impact. For example, a newsletter for local residents called "Bürger-info" was regularly published. Moreover, to ensure easy access to information, the company created a website where the public can find not only basic information about the plant and its technology but also about its environmental impact, such as regularly updated and detailed information about emissions production. To emphasize the transparency of all procedures, the company even offers the option to visit and observe the facility's daily operations (EVN Abfallverwertung 2015, 2018e).

A high level of social acceptance was also achieved thanks to economic benefits for local services (such as hotels and restaurants) stemming from the employed workforce and plant visitors (about 38,000 visitors in the past five years). In addition, EVN supports the local kindergarten, various clubs and associations, and local activities such as the Zwentendorfer Hauskalender (EVN 2010). Last but not least, ownership plays an important role in community engagement. Citizens perceive a level of stability due to the local government being the majority stakeholder. Moreover, locals, employees and other interested parties have the possibility to purchase free float shares. Currently, the free float accounts for 17.96% of shares, including shares held by employees (Alfons 2018, EVN 2018).

Thirdly, this case shows the immanent importance of communication. Thanks to previous experience with WtE technologies in Austria, the discussions with citizens, local authorities and the national government were not exacting, but rather fruitful. A citizens' council has accompanied the plant during all phases of the project since 1994. This citizens' council creates the foundations for open dialogue in two directions: information from EVN reaches residents as soon as possible and the questions and wishes of residents are quickly passed on to EVN. The results of this measure can be seen in agreements made between the citizens' council and EVN, including the online publication of emissions and the limit of 50 trucks per day for bringing waste to Zwentendorf (Alfons 2018, Austrian Court of Audit 2017, EVN Abfallverwertung 2015).

As detailed above, a series of steps were taken to achieve greater social acceptance for this project and to assure that locals' questions and issues were fully addressed. A well-defined national policy supported by an information campaign promoting new waste policies also likely contributed to the high level of local citizens' acceptance and thus also to the realization of the Zwentendorf WtE plant.

4.7 Conclusion & identified best practices

As challenges occur during all phases of a WtE project, looking into a specific case can reveal some general patterns of best practices that could be relevant beyond the individual case. While examining the Zwentendorf case, several steps were tracked to uncover the best practises ensuring successful completion of the project leading to the facility's current operations.

Firstly, national waste management policy was created after years of discussion and taking into consideration best practices in Switzerland and Germany. Key pieces of legislation were gradually introduced with long enough timeframes for both citizens and industries to adapt. Support for these efforts came not only from law but also through several economic tools such as subsidies, insurance of investments, and the establishment of higher landfill taxes (Alfons 2018). These tools created an environment where investment in WtE was stable and appealing.

The local government of Lower Austria also played an important role in fulfilling new national waste management goals. To improve waste management in the region, the decision to build a WtE plant was made very early in 1994 under the public–private partnership company EVN Abfallverwertung NÖ. The initiative was then driven by both the private company and the regional government with the aim to improve waste management for local citizens. Thanks to the synergy of political will and the company's knowhow, the plant was finished in 18 months upon receiving all necessary approvals.

Secondly, the operation of the plant is highly efficient due to the idea of energetic interplay, wherein the WtE plant is interconnected to an adjacent power plant thereby reducing the burning of fossil fuels and decreasing emissions. The plant is also connected to local district heating systems in St. Pölten and Zwentendorf and to a nearby bioethanol plant. Furthermore, Zwentendorf's continual operation is guaranteed by the delivery of waste by both rail and truck both domestically and internationally. The rail connection in particular allows the plant to import waste from long distances and thereby benefit from waste management imbalances in neighbouring countries such as Italy. Such synergies should certainly be considered when developing any new WtE project.

Thirdly, Zwentendorf achieved unusually high public support levels in a referendum held prior to facility construction. Despite the generally recognized complexity of gaining social acceptance, convincing the local citizens in Zwentendorf appears not to have been problematic. Several measures seem to have been key. First, national waste management policies and the necessary steps for implementation, such as the building of WtE plants, were explained to citizens through open dialogue. Furthermore, possible conflicts were settled through compromises, such as in the case of road transport limits. Finally, the potential positive impact on the region and local communities was promoted and ultimately achieved by hiring and training mostly locals, who also then act as spokespeople for the plant within the broader community.

Last but not least, Zwentendorf is recognized as a successful project not only among locals but also in the broader WtE industry. The know-how acquired during the planning and operation of the thermal utilization plant in Zwentendorf was applied in the EVN MSZ 3 project in Moscow, which has been operating since 2007 and is considered to be a success. EVN is also involved in an advisory role on more plants currently in the planning stages across Europe (EVN Abfallverwertung 2017). Such sharing of knowledge and experience with WtE technologies is both possible and highly desirable.

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Waste-to-Energy in the Danube Strategy Region: Challenges and Prospects

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This study presents the current state and main challenges for the development of the waste-to-energy (WtE) industry in the countries of the Danube Strategy Region (DSR). Waste-to-energy systems constitute a broad range of technologies for converting various types of waste either directly into electricity or heat or into a fuel for subsequent use. These technologies, furthermore, are dependent on complementary systems and services, in particular waste management. WtE is thus a complex topic overlapping with other prominent issues, such as sustainability, resource security, and the circular economy. The study provides a general overview of WtE technologies and associated systems, presents a cursory look at relevant EU legislation and statistics, details the main challenges facing the development of WtE projects, outlines the situation in the DSR countries, and, finally, presents a case study of a selected successful project.

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