WASTE-TO-ENERGY STRATEGY CONCEPT FOR A COAL-FIRING POWER PLANT IN THE CZECH REPUBLIC: PART A – WASTE CO-INCINERATION APPROACH

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ABSTRACT

The Czech Republic has committed to ending or significantly reducing landfilling of waste by 2030. At the same time, not only in the energy sector, the emphasis is on sustainability, involving the abandonment of fossil fuels. The new concept of the Opatovice coal-firing power plant is trying to counter these two factors. The presented concept considers energy utilisation of waste in two different major ways. The first is combustion, adapting the mechanical-biological treatment, while the second is gasification, dealt with in Part B of this study. In this part, the issue of regional waste management is viewed from a broad scale. The production of waste in the Czech Republic and in a specific region and the legislation associated with it are discussed, along with the use of outputs from the mechano-biological treatment of the fuel, the outputs of which include retained and passing fractions. The ratio of their mutual production depends on the composition of the waste, which is variable during the year. The retained fraction reaches a calorific value higher than 17 $MJ \cdot kg^{-1}$, which requires modification of the classic incinerator for the waste-to-energy (WtE) approach. The passing fraction usually ends up in landfills, conditionally, if the lower heating value and oxygen content do not exceed 6.5 $MJ \cdot kg^{-1}$ and 10 mg per 1 g of dry fraction, respectively. The production of such a fuel, which is very strict for biological activity but at the same time environmentally beneficial due to the legislative restriction of waste disposal in landfills, appears to be the most promising use of the passing fraction. The gasification part, as well as environmental impact and the entire evaluation of the concept of the Opatovice WtE power plant are included in Part B of this study.

Keywords: mechanical-biological treatment, waste, waste to energy, landfilling, legislation, incineration, calorific value, environment.

1 INTRODUCTION

Reducing CO_2 emissions is one of the core commitments of the European Union. As a result, it is necessary to change the source fuel used in most coal-fired power plants in EU countries, especially in the central and eastern parts of the continent. The restructuring process also affects the brown coal burning Opatovice power plant, even though the ecology rate of its operation has been intensively upgraded in recent years. The Opatovice power plant, located in the Czech Republic, supplies the surrounding cities of Hradec Králové, Pardubice, Chrudim, and others with heat and at the same time produces electricity. Since the capacity of coal-replacing natural gas for the production of heat and electricity is not sufficient, it is not possible to completely replace this source with a gas source. Therefore, it is advisable to replace part of the production of heat and electricity with another source, such as the production of energy from waste. This approach is suitable above all for its stability and the possibility of maintaining a central heat supply with a positive environmental impact in the form of reducing the amount of landfilled waste.

The limits of the construction of capacity facilities for the waste-to-energy (WtE) applications above 100 kt are mainly due to the limiting capacity of the central heat supply. In the case of the coal source replacement with equipment for the energy utilisation of waste, EU support under the HEAT subsidy program can be expected in the amount of up to €$20 \cdot 10^9$.

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Because landfilling in the Czech Republic is to be significantly reduced by 2030, the replacement of the current coal source by WtE would serve this purpose.

Fig. 1 shows the currently existing and planned WtE on the territory of the Czech Republic.

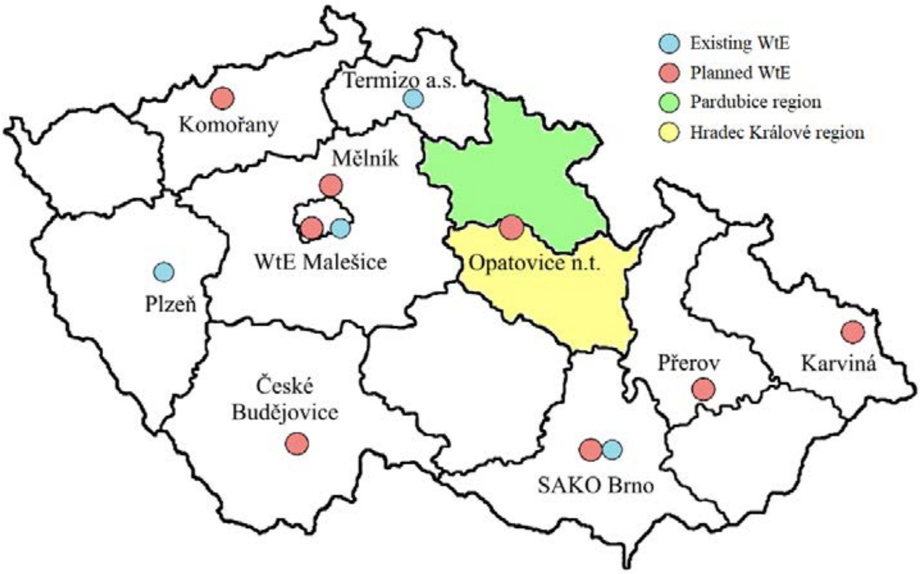

Figure 1: WtE in the Czech Republic.

Waste management through thermochemical conversion processes is possible in several ways. Apart from conventional incineration in specially designed furnaces [1], combustion of biomass waste [2]–[5], non-biomass waste [6], [7] and sewage sludge [8], [9] is possible. Waste combustion processes must be often followed by advanced technologies for flue gas treatment such as catalytical treatment [10]–[13] or electrostatic precipitation [14]–[16]. Simultaneously, gasification [17], [18] and pyrolysis [19], [20] can be also applied, offering different, interesting benefits, such as production of sustainable syngas [21], [22], pyrolysis oil [23], high specific surface sorbent [24]–[26] or liquid fuel [27]–[29] from both biomass and non-biomass waste fractions, involving numerous feedstock variations.

As part of this study, an assessment of many options for the energy use of mixed municipal waste (MMW) is carried out. The approach is based in ideology of choosing a proven technology, both in the Czech Republic and abroad, which is the direct energy use of MMW. Such approach would eliminate issues of advanced, yet industrially undeveloped strategies for waste management.

The considered variants of direct energy use of MMW are:

1. Combustion of solid recovered fuel (SRF) derived from MMW by mechanical-biological treatment (MBT) technological concept (Part A of this study).
2. Gasification technology (Part B of this study).

These scenarios were also chosen with respect to the existing technologies and transition possibilities of Opatovice WtE.

2 ENVIRONMENTAL AND LEGISLATIVE CONSIDERATIONS

As landfilled municipal waste accounts for up to 50% of the biodegradable component, the Czech Republic is committed to reducing it, specifically by 75% since 1995. More than 2 million tons of landfilled municipal waste in 2021, testify to the non-fulfilment of the given obligation [30]. Energy utilisation of these wastes supports the fulfilment of this goal. Act No. 541/2020 Coll., on waste, which was applied on 1 January 2021 prohibits or significantly limits landfilling from 2030. To fulfil the interests in the abovementioned law, many secondary steps are linked, such as an increase in storage fees or a ban on the storage of energetically usable waste. Such waste includes materials with calorific value higher than 6.5 $MJ \cdot kg^{-1}$, which can be purposefully recycled, or which exceeds the limit value of the biological stability parameter AT4. At the same time, the goal of the Ministry of the Environment of the Czech Republic is to limit landfilling to 10% of municipal waste produced in the Czech Republic by 2035. Fig. 2 shows the increase in fees for usable, residual, dangerous technological and rehabilitation wastes. Increasing the fees will motivate entities depositing waste at the landfill to reduce waste production.

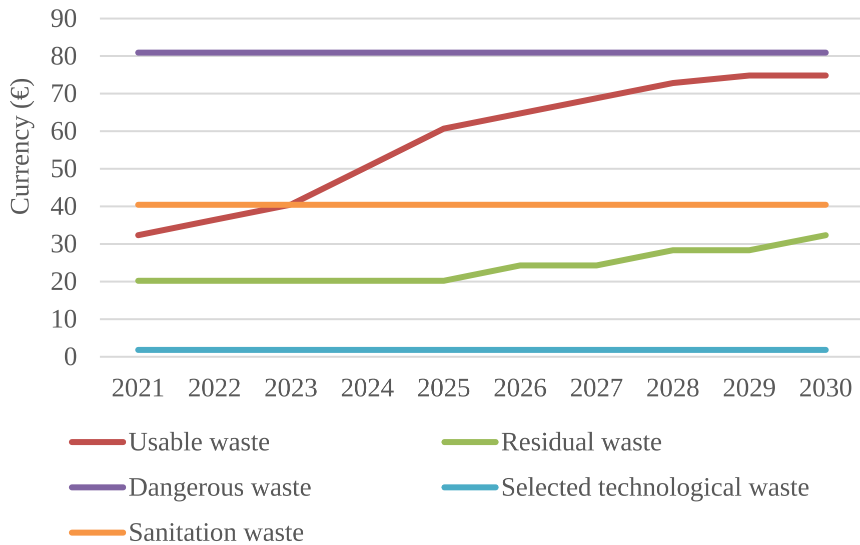

Figure 2: Increase in prices of stored residual and usable waste in 2021–2030.

3 WTE COMBUSTION APPROACHES

3.1 SRF combustion with MBT

Combustion of municipal waste for energy purposes on industrial scale is the only approach which has references in the EU. As example we can talk about companies such as Veolia Environment, Covanta, E. ON, FCC Environment or Suet. Veolia is a multinational company that provides environmental services, including waste management and energy recovery. They operate several WtE plants across Europe. Covanta is a U.S.-based company with operations in Europe. They specialise in WtE facilities, converting MSW into electricity and heat. E. ON, a major energy company, has invested in WtE projects. They focus on sustainable energy solutions, including waste incineration. There is new WtE combustion plant in Czech Republic in Přerov. Germany leads in WtE capacity, with approximately 1,023 MW installed across the country in 2023 [31].

Specific large-scale plants include those in cities like Hamburg, Bremen, and Munich. Sweden is known for its efficient WtE facilities. The city of Västerås hosts one of the largest WtE plants in the world, producing both electricity and heat [32]. A similar concept of SRF combustion with MBT does not yet work in the Czech Republic. This method of energy utilisation of SRF is with the need to comply with the emission limits of the incinerator as is the case with MMW WtE plants. The difference is the higher calorific value of SRF reaching up to 25 $MJ \cdot kg^{-1}$ and its lower ash content, usually below 10%wt [33]. However, from the point of view of the total amount of waste that is stored in the landfill in the form of unusable fractions from the MBT line, and, specifically, the waste from the energy use of solid alternative fuels, it is higher than if the total waste from MMW were used for energy. The possibility of co-combustion with biomass or even coal is a certain advantage of this concept. SRF can be supplied externally from suppliers within the Czech Republic, or an MBT unit could be set up in the Pardubice and Hradec Králové regions, in which case cooperation with local municipalities or a waste company would be necessary.

3.2 MBT of MMW and subsequent use of the resulting fractions

In the Czech Republic, there is still no technology for the MBT of MMW, however, an inspiration could be found in the neighbouring countries with similar waste management schemes including Germany and Austria [34]. The line must be designed precisely and for the needs of the relevant location as the composition of the used feedstock often depends on the location from which it originates. The technological concept of MBT for MMW is based on a number of modifiable processes leading to the production of an energy-rich fraction (retained fraction) and fractions that can be deposited in a landfill after treatment by biological processes (passing fraction). The configuration of each particular MBT line must be designed primarily with regard to the specific market potential and use of the energy-rich fraction. For illustration, a configuration of the basic technological operations of MBT is shown in Fig. 3.

Before entering the drum sorter, it is advisable to first subject the treated waste to pre-treatment in the form of crushing, homogenisation, drying, or granulation. To obtain even better output products, more sophisticated sorting systems can be used, including biological drying of MMW based on the principle of aerobic fermentation. However, this method is even more financially expensive than the previous. The example of a simplified MBT scheme with an anaerobic stage of utilisation of the biological fraction is evident in Fig. 4.

The method of MBT is used primarily for the energy use of the retained fraction of waste. Due to its properties, more than half of the waste at the entrance to the MBT does not find further use and is therefore deposited in landfills. The inspiration for our case could be the MBT unit from Poland, which was created 10–15 years ago. Poland has seen a rise in the number of MBT installations in recent years. According to the General Directorate for Environmental Protection, there are currently 124 MBT plants in the country.

These installations combine mechanical and biological treatment methods to process municipal solid waste (MSW) effectively [35]. Between examples of waste MBT plants in Poland belongs KKO-100 Technology and BIOFIX System [36]. Another possible inspiration comes from Austria or Germany, but they are not the most suitable for our case due to the economic differences of the individual states some of them were mentioned in previous part of these article.

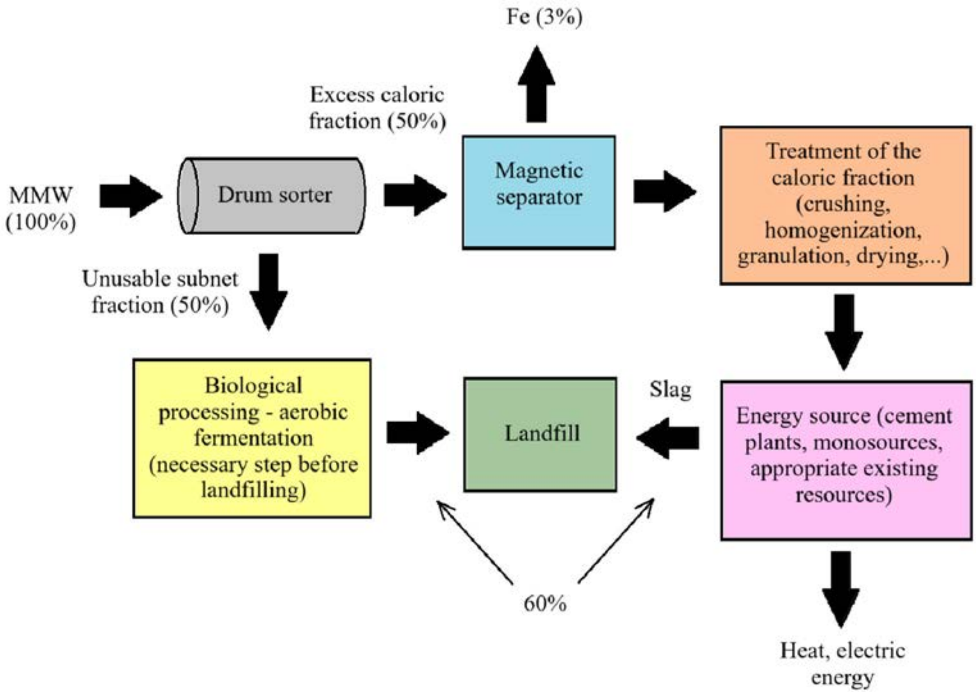

Figure 3: Scheme of MBT of MMW.

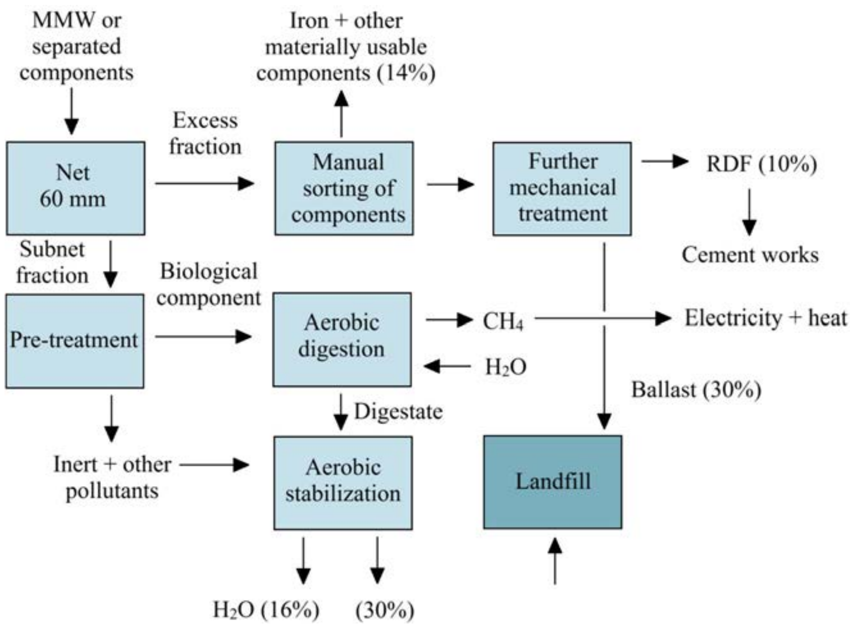

Figure 4: Example of a simplified MBT scheme with an anaerobic stage of utilisation of the biological fraction.

3.3 Possibilities of energy utilisation of the retained (caloric fraction) or passing fraction

Caloric fractions after MBT treatment are referred to as RDF (refuse-derived fuel) and are still waste according to the air law. RDFs find a wide range of uses in energy sector. Some examples of their use in the Czech Republic include cement plants, monosources, WtE facilities, aerobic processing, use of the passing fraction, classic power plants such as heating plants or power plants, primarily those equipped with fluid boilers; in these sources they burn together with classic fuel, most often with brown or black coal; new sources to burn SRF, gasification, pyrolysis, WtE facilities.

The most common utilisation of RDF and SRF in the Czech Republic is shown in Fig. 5.

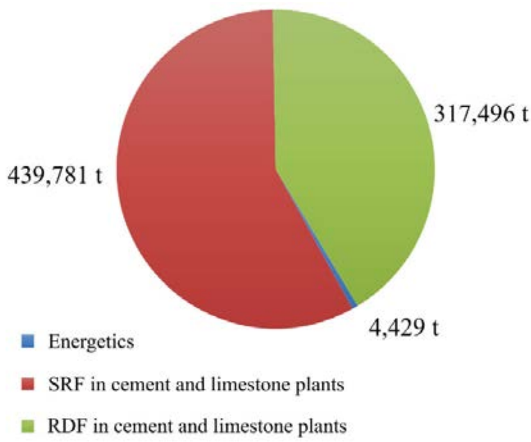

Figure 5: Statistics on the energy use of RDF in the Czech Republic.

3.3.1 Cement plants

Cement plants are limited by the number of cement kilns, and quality requirements for converted fuel are also important. SRF with a high calorific value and a homogeneous character is most often used in cement plants. The content of harmful substances is also an essential parameter. In order to reach the required parameters, it is necessary for them to go through sophisticated MBT technology. In 2021, according to statistics, 367,935 tons of SRF from domestic producers and imports were used in Czech cement plants. In the last ten years, the use of SRF in cement plants has increased by more than 100% and covers almost 47% of the total heat consumption in cement plants. However, for technological reasons and capacity restrictions, it is no longer possible to count on a further increase in SRF for heat production for cement plants.

3.3.2 Monosources

Another possible use is monosources built specifically for using the caloric fraction from MBT. It is practically WtE, adapted for burning waste with a higher calorific value of around 15–20 MJ·kg^{-1}. It is also possible to burn these fuels in classic energy sources in combination with coal or biomass, where the advantage is low investment when applied to existing facility. This option is highly justified, both from a technical and economic point of view. During the practical test, no technological problems were found at 10% of the SRF addition. In the case of combined combustion, it is necessary to build several stages of flue gas cleaning, just as in the case of incinerators. The danger arising from this co-incineration is the attack of the equipment by chlorine or phosphorus corrosion, which arises from the presence of the incinerated admixture [37], [38].

3.3.3 WtE facilities

It is possible, but very unlikely, to use the caloric fraction in any of the operating WtEs. The most significant disadvantage of this concept is that these devices are sized for a fuel with a calorific value in the range of 7–14 $MJ \cdot kg^{-1}$, whereas the mentioned caloric fraction has a calorific value of 13–17 $MJ \cdot kg^{-1}$ or even higher. It would be ideal to add only a limited amount to the mixture burned in WtE. In practice, this limitation is manifested even today, when there is an effort to use the so-called rejects or otherwise materially unusable fractions from the sorting lines of plastics (or paper) in WtE, which have a higher calorific value than MMW.

3.3.4 Aerobic processing

During the aerobic processing of the fine fraction, there is an environmental risk. In order to avoid it, it is necessary to use modern equipment that treats waste in enclosed fermenters. Such modern equipment is currently used, for example, in Poland. One company in Poland that utilises an integrated anaerobic digestion and biostabilisation system for waste processing is Mostostal Warszawa S.A. Their MBT biostabilisation and anaerobic digestion plant in Biala Podlaska employs innovative green technologies to recycle organic waste and produce renewable energy. The plant features an aerobic processing line that further stabilises digestate, including a system of three Scarabeo™ biocells and a biofilter [39].

3.3.5 Use of the passing fraction

The passing fraction of MBT is originally intended exclusively for disposal by landfilling. Their use to create compost is not possible due to the presence of pollutants. The Waste Act unequivocally regulates the conditions under which it is possible to deposit the passing fraction in landfills, where the calorific value is decisive. The maximum value is set at 6.5 $MJ \cdot kg^{-1}$ in dry matter and the biological activity parameter equal to AT4.

Among other things, the above-mentioned facts limit the introduction of MBT into real practice, and to this date, there is no known functional project in the Czech Republic with all the conclusions and benefits resolved. Due to the low calorific value, the passing fraction cannot be used in WtE. The energy use that could most likely be used is the production of fuel from the passing fraction. The concept of producing solid alternative fuels from the biologically active passing fraction is very strict, but, at the same time, environmentally beneficial due to the legislative restriction on the disposal of waste in landfills. This concept responds to MBT projects that might not end in success due to the economically disadvantageous processing of the passing fraction to the required level set by legislation.

3.4 Basic economic analysis of MBT concept operations

The economic status of MBT can only be roughly estimated because this facility is not and has never been operated in any region of the Czech Republic. It is appropriate to evaluate the MBT economy from abroad, especially in Poland due to the similar structure in this area. A key factor in the price for handling MMW is the price of the calorific fraction for energy use. Considering a positive price for the sale of the caloric fraction is currently unrealistic due to the costs of flue gas cleaning. MMW processing costs range from €40/t to €80/t, depending on technology, financing, and facility capacity. The cost of storing the passing fraction is also a considerable item. The total costs of processing one ton of MMW in one of the MBT modifications can only be estimated and will only become clear after the MBT line is put into operation in the Czech Republic.

4 PROVISION AND AVAILABILITY OF WASTE FOR OPATOVICE WTE

The planned Opatovice WtE capacity is set at 150 kt per year of mainly MMW, which must meet the required maximum calorific value after mixing in the bunker up to 14 GJ/ton. These wastes can be secured in the long term within the Hradec Králové and Pardubice regions, which is the optimal option from the point of view of logistics and economy in terms of energy use in Opatovice WtE. From the point of view of competing technologies and equipment, the intention of further construction of WtE or MBT in the Pardubice or Hradec Králové regions is unknown. The essential factor is economic profitability, which depends on the saturation of WtE capacity from waste in the surrounding regions and on the price of waste at the gate. This price will depend on the legislation and the resulting economic context.

Fig. 6 shows the structure of waste usable for WtE in the graph. In the graph, MMW is in significant majority, therefore, the other wastes are only supplementary, and the analysis will mainly focus on MMW and bulky waste.

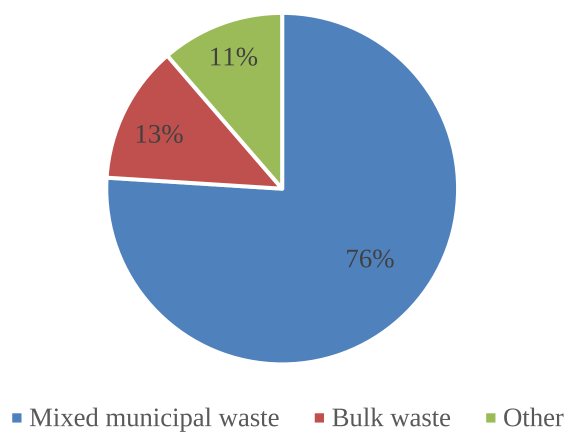

Figure 6: Average structure of usable waste in 2019–2021.

4.1 Production of waste in Pardubice and Hradec Králové regions

The amount of usable waste needs to be determined for the year 2030 at the latest when the law banning landfilling applies. The forecast for the Pardubice and Hradec Králové regions is that both regions independently produce enough usable waste that they would be able to fill the capacities of the proposed Opatovice WtE. The Hradec Králové Region would even be able to fill the mentioned WtE capacities with only MMW waste, because of the production of 152 kt of this waste. Other planned waste treatment facilities are still debatable due to both economic and environmental reasons. In 2021, a total of 2,813 kt of MMW was produced in the Czech Republic, while approx. 750 kt, 26.6% of the total production was used in the existing WtE while the total capacity was 815 kt. The capacity of individual existing WtEs on the territory of the Czech Republic is shown in Fig. 7.

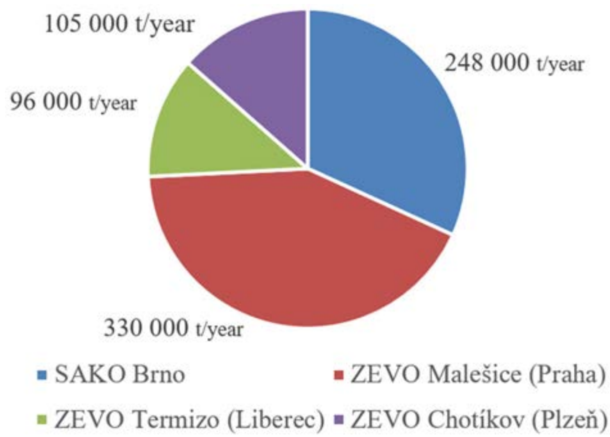

Figure 7: Capacity of currently used WtE in the Czech Republic.

Based on Table 1, it can be seen that there will be enough MMW and bulk waste for the operation of the Opatovice WtE in the planned capacity, already from 2028. In the years 2030 and above, there will be an excess of usable waste, not only in the two considered regions but also in other parts of the Czech Republic, even if it is possible to implement the planned capacities of WtE or even small WtE in the intended locations. If necessary, it is possible to import usable waste from the entire Czech Republic by efficient rail transport, but due to the previously mentioned facts, a sufficient amount of waste will be produced by both regions, so this option will not be necessary. Table 1 shows predicted production of waste in the Czech Republic, due to which a plan for waste management and future WtE plants construction can be settled.

Table 1: Prognosis of waste production in the Czech Republic.

Year	MMW (kt)	Bulk waste (kt)	Total (kt)
2022	2,812.835	704.509	3,517.344
2023	2,811.535	727.448	3,538.983
2024	2,809.437	748.782	3,558.219
2025	2,807.798	768.971	3,576.769
2026	2,808.089	787.998	3,596.087
2027	2,805.287	805.427	3,610.714
2028	2,804.406	821.757	3,626.163
2029	2,801.098	837.562	3,638.66
2030	2,799.75	851.638	3,651.388
2031	2,798.216	864.204	3,662.42
2032	2,796.54	876.286	3,672.826
2033	2,794.781	887.954	3,682.735
2034	2,790.195	898.225	3,688.42
2035	2,788.464	907.539	3,696.003
2036	2,786.225	915.956	3,702.181
2037	2,784.777	924.493	3,709.27

4.2 Calorific value of waste for Opatovice WtE

The energy value of usable waste for Opatovice WtE is set at 10 $MJ \cdot kg^{-1}$. This is a reference value from which further calculations and balances will be based. The value is derived from the basic waste component used (MMW). The long-term trend of the calorific value of the given waste is monitored mainly in the existing WtE in the Czech Republic, and these data can be considered and interpreted for planned sources. MMW production in the Czech Republic is very heterogeneous and contains both highly calorific and inert materials. The analysis of MMW, pictured in Fig. 8, represents the average values of MMW for the entire country for the so-called residual MMW, which results after the primary sorting of components.

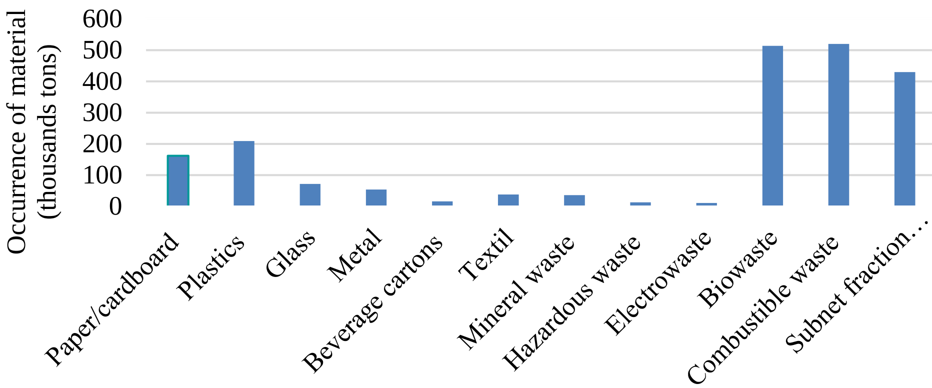

Figure 8: Average composition of MMW of the Czech Republic in 2020.

Fig. 8 shows the number of individual types of waste in MMW produced in the Czech Republic in 2020. Values are given in thousand tons. From the graph, we can see that the differences in the production of individual types of waste are striking. Bio-waste, combustible waste and the sub-network fraction of waste reach the largest amount. This is followed by classic waste subject to sorting, such as paper, plastic and glass, where glass is of this waste at a slightly lower level than plastic and paper, the reason being its sustainability and renewable and recyclable character. Metals with a similar recovery character to glass follow. Then textiles, mineral waste, electrical waste, hazardous waste and cardboard food packaging.

5 CONCLUSION

The study discusses the commitment of the Czech Republic to end or significantly reduce landfilling of waste by 2030 and the emphasis on sustainability across various sectors, including the energy sector.

The document explores the new concept of the Opatovice power plant, which considers energy utilisation of waste in two different ways: combustion adapting the MBT and gasification. It provides an in-depth analysis of waste production in the Czech Republic and its specific region, the legislation associated with it, and the use of outputs from the mechano-biological treatment of fuel.

The study also discusses the environmental impact and the entire evaluation of the concept of the Opatovice power plant. It further delves into the possibilities of energy utilisation of the retained or passing fraction of waste and provides a basic economic analysis of MBT concept operations.

In conclusion, the document presents a detailed exploration of the concept of energy utilisation of waste, with a focus on the Opatovice power plant. It highlights the importance of sustainability and the need for innovative solutions in waste management and energy production.

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