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TOWARDS A CIRCULAR ECONOMY – CHANGING NEEDS AND SOLUTIONS FOR WASTE MANAGEMENT SYSTEMS

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In recent years, the circular economy has become an important element of sustainable development. Products become waste at the end of their life cycles. This problem is accompanied by a parallel decline in the availability of certain critical raw materials. It is obvious that the materials that become waste should be recycled and their components reintroduced into the economy, recovering the necessary raw materials and energy. The issues concerning the practical implementation of this are technical, economic and legal. Over the last decade, significant progress has been made in terms of how waste can be treated and recovered. Meanwhile, both the quality and quantity of collected waste have changed. To ensure that waste management systems can continue to operate properly under these changing conditions, it is necessary to examine the impact of such recent changes. Furthermore, it is important to provide feedback to decision-makers with regard to how much their efforts have contributed to the principles of a circular economy in the EU member states. In this work, the regulatory framework of the two main periods, namely before and after 2010, will be reviewed while examining the evolution of waste-sorting technologies by especially focusing on the mixed and selectively collected municipal solid waste streams. To reduce the amount of landfill, mechanical biological treatment plants had already been developed and packaging materials sorted before 2010, but it is crucial to examine how regulations and technological possibilities are evolving step by step as well as how they affect each other. Predictions are also made concerning upcoming trends in and the future of waste management.

Keywords: circular economy, waste regulation, EPR, DRS, MBT, Selective Sorting Plant

1. Introduction

The state of our environment has become an increasingly important issue in our daily lives, whereas previously this was regarded as more of a localized problem, it has now become a global concern. In recent years, although the importance of environmental awareness has become part of public consciousness, it is not only deemed as a problem but has also encouraged measures to be taken. However, objectives have had to be followed by regulations. A significant proportion of global environmental problems can be traced back to the issues of waste generation, collection, disposal and recovery, or lack thereof. The legislative framework in this area also reflects the goal to achieve a circular economy. As the impact of these has already become global, regulations and possible solutions should also be implemented worldwide.

In parallel to the legal framework, the technical possibilities of waste management and treatment have evolved significantly over the last 10-15 years. The development of collection systems, pre-sorting and sorting technologies as well as the increasing number of recovery options may facilitate a reduction in the amount of waste produced as well as primary raw materials and fossil fuels consumed.

To achieve the goals of a circular economy, it is necessary to periodically review the regulatory frameworks already in force to compare them with the originally set goals. It is important to conduct a study on the applied waste-sorting technologies that have been implemented in the past to be able to optimize and modify them in the present and future, respectively, as well as meet needs using sophisticated tools. The development of sensor-based sorting techniques to identify new applications in waste management must also

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be taken into consideration. Our aim is to review the changes to legislation over recent decades as well as estimate the resulting changes to the quantity and quality of household waste streams with regard to both mixed household waste and separately collected waste.

Another closely related objective of this study is to introduce new waste management technologies for these two main waste streams in order to determine whether the goals set in accordance with regulations can be reached by applying existing practices and equipment.

2. Methodology

To achieve our goals outlined in the introduction, a comprehensive study on legislation was written based on available documents found mainly on the official online database of EU law amongst other articles, whilst for the technical overview, mainly related articles were chosen.

The aforementioined two periods were selected to informatively and comprehensively examine the changes as well as draw comparisons.

The year 2010, especially in Central Europe, was chosen as a boundary as in this epoque significant changes took place over a relatively short period of time. Obviously, this not only applies to 2010 but represents a wider period of 2-3 years.

During this epoque, strategic changes took place that affected legislation, meanwhile new financial resources were offered by the EU through Cohesion Funds to realize previously planned investments. Legislative goals also required financial resources, facilitating new quantitative goals to be set that could contribute to the principles of a circular economy. Most of these changes and a rapid increase in the number of new investments were witnessed around this time mainly in the less developed Central and East European region. The use of EU funds at this time culminated in the realisation of new, modern regional waste management systems.

Focusing on a comparative investigation of the legal environment and the evolution of available technologies, how closely related the needs and possibilities were and are was examined. Our goal was also to draw conclusions about the expected legal and technical development trends in coming years.

3. Overview of legislative changes – the regulatory environment

3.1. Up to the 2010s

As an autonomous international legal entity, the European Economic Community, which was created by the Treaty of Rome (1957) [1] and established after the Maastricht Treaty (1992) [2] has been shaping the legal framework for waste management for more than four decades. *Figure 1* shows the hierarchy in waste management that sets strategies regarding legislation.

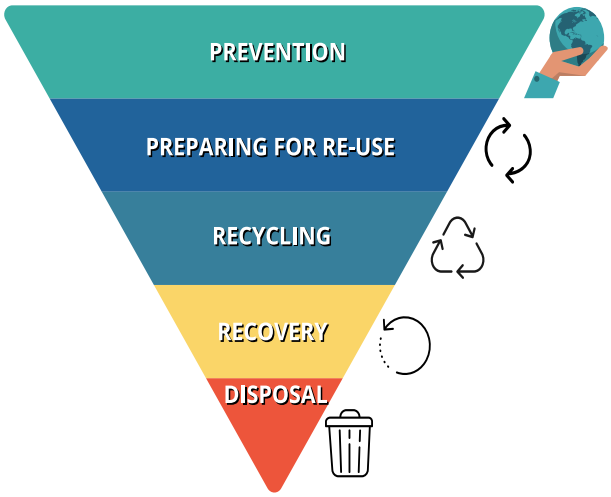

Figure 1: The Waste Framework Directive defines a hierarchy in waste management
Source: https://chesse.org (retrieved on 20/10/2023)

EU waste management is based on Directive 2006/12/EC [3] of the European Parliament and of the Council consolidating Council Directive 75/442/EEC [4] as well as its amendments, which set out principles in addition to technical and institutional elements, as well as on Council Resolution 97/C 76/01 [5] on a community strategy for waste management. A further major overhaul was brought about by Directive 2008/98/EC of the European Parliament and of the Council (Waste Framework Directive) [6].

Directive 2008/98/EC

Compared to the previous framework directive, substantial changes were enforced in Directive 2008/98/EC in order to integrate horizontal legislation. Its key areas are as follows:

- Article 8 on extended producer responsibility as well as Article 16 on the application of the principles of self-sufficiency and proximity. The purpose of these provisions is that all member states should ensure the recovery and disposal of waste.
- The Directive extended the previous three-tier hierarchy to five tiers which is referred to as the waste hierarchy pyramid, so that re-use is linked to prevention leading to waste reduction, while preparation for reuse, recycling and other forms of recovery, e.g. energy recovery, now encompass a single tier within waste recovery.
- Ensuring competitive neutrality. Establish equivalent environmental requirements for the treatment of different types of waste. To this end, a register of waste has been introduced (Commission Decision 2000/532/EC) [7].
- "Biowaste" has become a separate material stream. Article 22 of the Directive deals with general issues concerning biowaste management to better process waste for its reuse and recycling.
- Article 6 of sets out the criteria under which a substance or fraction ceases to be waste, namely is no longer considered waste.

Other regulations related to Directive 2008/98/EC

It was important for the EU to standardize the classification of types of waste. A list of types of waste was implemented by Commission Decision 2000/532/EC consolidating the previous lists of hazardous and non-hazardous waste. This Decision has been amended several times since its adoption.

The main objective of Directive 2000/76/EC [8] of the European Parliament and of the Council is to prevent and limit the negative effects on the environment from the incineration and co-incineration of waste. Since 12 July 2006, the transboundary movement of waste has been subjected to various procedures and controls in accordance with Regulation (EC) No 1013/2006 of the European Parliament and of the Council [9].

Council Directive 1999/31/EC on the landfill of waste [10] which contains provisions for measures, procedures and guidelines to prevent or reduce the negative impacts on the environment was published before Directive 2006/12/EC.

A coherent framework for waste management was followed at the European Community level until 2010. Definitions were clarified and the main orientations of the legislation set. Tasks, responsibilities and institutional expectations of member states were defined.

3.2. From the 2010s to 2020s

The objectives of Directive 2008/98/EC set out specific future obligations for the member states. They were obliged to finalise their National Waste Prevention Programme by 12 December 2013.

Meanwhile, Directive 2008/98/EC has been amended several times, namely on 01/06/2015, 31/07/2015 and 05/07/2018, and the followings targets set:

- By 2015, the separate collection of paper, metal, plastic and glass had to be introduced.
- By 2020, the weight of paper, metal, plastic and glass from households (amongst other sources that produce waste similar to households) that is reused and recycled should be increased by at least 50%.
- By 2020, the weight of non-hazardous construction and demolition waste, including backfilling using waste as a substitute for other materials, that can be reused and recycled amongst other forms of material recovery should be increased by at least 70%.

Following these changes, Directive 2008/98/EC continues to define European waste management with revised and modified objectives that reflect the growing volumes of waste. The obligations concerning the collection and recovery of waste streams have been refined. For example, 55% of household waste must be recycled by 2025 and less than 10% of the weight of municipal waste can be dumped in landfill sites by 2035 in accordance with Directive (EU) 2018/850 that amends Directive 1999/31/EC, which is ambitious as targets of 35 and 49% were set for Hungary in these fields, respectively, during 2022.

The EU has also proposed a new Environment Action Programme to 2020 [10] entitled *"Living well, within the limits of our planet"*, which aims to enhance Europe's ecological resilience and transform the EU into a sustainable, green organisation.

Circular economy

The legislative changes have made the objectives of waste management more specific. The circular economy and the management of scarce materials have become priorities [12].

The recovery of materials from waste (collection, manual and mechanical sorting, etc.) and the use of recycled materials in production have been focused on and become obligations.

In the circular economy model, non-renewable materials remain in a closed loop. To meet these requirements, the aforementioned principles must be taken into consideration even as early on as when a product is designed. Products should be durable so that they become waste as late as possible and then, fulfilling the aim, waste will be a thing of the past in the framework of a “circular economy” [13]. Using selective waste collection materials is an essential component of recycling to ensure their transition into raw materials.

The European Commission has published a Communication *"Towards a circular economy: a zero waste programme for Europe"* [14] and proposed amendments to key EU waste legislation to achieve its goals in 2014, but the proposal was withdrawn by the new European Commission (set up after the European Parliament elections later that year) with the intention of presenting a new, more comprehensive proposal in 2015, focusing not only on the waste phase of the life cycle of a product but on it as a whole.

The European Commission published its new package of proposals on a circular economy in 2015. The package consisted of two main parts: a new Communication entitled *"Closing the loop - an EU action plan for the Circular Economy"* and proposals for legislative changes [15].

In this Action Plan, the Commission outlined the measures it intends to take, including legislation and funding from EU funding programmes. As a first action within the Action Plan, the Commission published its proposal for modifying EU waste legislation, especially the Waste Framework Directive, Landfill Directive, Packaging and Packaging Waste Directive, End-of-Life Vehicles Directive, Waste Electrical and Electronic Equipment Directive as well as the Battery Directive.

In addition to the compulsory collection of paper, metal, plastic and glass fractions since 2015, the new rules will also extend separate collection to biowaste from the beginning of 2024 onwards as well as to textile waste and hazardous waste from households by the beginning of 2025.

Table 1: Recycling target values

	Recycling target value		
	by 31 December 2025	by 31 December 2030	Derogation options
Plastic	50%	55%	The derogation may be a maximum of 15% or divided between two subgoals.
Wood	25%	30%	
Ferrous metal	70%	80%	
Aluminum	50%	60%	The recycling rate for each target value cannot fall below 30%.
Glass	70%	76%	
Paper and cardboard	75%	85%	For glass and paper, the target number cannot be less than 60%.
Packaging waste sum	65%	70%	

The legislation clarifies how producers must take responsibility for managing waste from their products enforced by new rules called *Extended Producer Responsibility* (EPR) policies.

The European Parliament and the Council have also amended Directive 94/62/EC [16] of the European Parliament and of the Council on packaging and packaging waste by Directive (EU) 2018/852 [17]. The Directive describes the *Deposit-Return Scheme* (DRS) to increase the amount of the selectively collected waste and remove mainly packaging materials from mixed household waste [18]. It is also expected that the selectively collected materials will be less contaminated. The goal of the member states is to collect 77% by 2025 and 90% by 2029.

In the future, it is expected that cleaner and larger quantities of selective waste streams will be recovered contributing to the Circular Economy that has also been established in all the member states, including Hungary [19].

The new goals are ambitious as significant percentages of recycled waste are targeted as illustrated in *Table 1* [20].

As an outcome of the regulatory changes, strategic directions are refined in the latest *"Environment Action Programme to 2030"* [21] from which the current waste collection targets and methods can be predicted, thereby significantly changing the inputs of the existing waste handling and sorting technologies within the upcoming few years. It is expected that cleaner and larger quantities of selective waste streams will have to be treated, sorted and recovered.

During this period by relying on the existing legal frameworks, clarifications and quantifications were the main objectives, moreover, the establishment of a circular economy became a new strategy.

4. Overview of technological changes and directions for development

4.1. Municipal solid waste (MSW) - mixed fraction

The disposal of mixed household waste by landfilling is still significant. The landfilling of organic waste has a negative impact on the environment and public health [22]. Firstly, the problem of landfilling was addressed as even new regulated landfill sites still exhibit significant effects on the surrounding environment.

To reduce the fractions of solid waste at landfill sites, two approaches have emerged in Europe:

- mechanical biological treatment (MBT)
- waste incineration

4.1.1. Until the 2010s

Since the 2000s, thanks to EU landfill regulations and financing, several investments have been made to divert waste from landfills.

The first simple MBT plants were established in Germany in the 1970s [23]. While MBT plants have become widespread in, for example, Germany, Austria and Italy, Scandinavian countries and others like Switzerland have opted for incineration.

MBT focuses on the pre-sorting of waste and seeks to minimise the biodegradable fraction of residues at the end of the process, rather than treating the entire waste stream in one step, unlike incineration [24]. With this integrated and complex treatment, the objective of waste management is to prevent the generation of landfill waste and maximize utilization by the separation of valuable fractions. In some cases, not only is the production of alternative fuels like Refuse Derived Fuel (RDF) sought but leachates of biofractions can also be a potential source of energy [25].

EU funds were available to member states, including Hungary, for the planning and implementation

of MBT plants with financial support from ISPA (Instrument for Structural Policies for Pre-Accession) and Cohesion Funds [26]-[27]. For instance, in Hungary, in order to establish new regional systems, the National Waste Management Plan predicted the amount of waste to increase from 4.7 to 5.2 million tons [28].

MBT plants, in line with Directive 1999/31/EC, aimed to achieve the following goals:

- to separate by mechanical means the fractions that can still be recovered (as material or energetically);
- to reduce the amount of the biologically active fraction by biostabilization;
- to improve the quality of the biologically active fraction by making it less hazardous, thereby activating, biostabilizing and recovering a cover material for landfill sites.

4.1.2. From the 2010s to 2020s

In Hungary, for example, the first MBT plants were built between 2005 and 2012 with EU funding by the New Széchenyi Plan 2007-2013 [29].

Subsequently, a significant increase in the number of technologies both in Hungary and Europe has been seen. In the case of Hungary, in 2017, already 27 MBT and mechanical treatment (MT) plants were in operation with a cumulative input capacity of 1.62 million tons of MSW, that is, approximately 55% of the total mixed municipal waste collected [30] and this figure is still growing. The estimated capacity in Europe by 2025 is 65 million tonnes of mixed waste, which will be processed in 690 plants according to a research report by Ecoprog in 2017 [31].

According to *Figure 2*, a decrease in landfilling between the two examined decades can be observed.

Despite the realized regional MBT plants and the technological progress made over the last 10 years, numerous EU member states still fall very short of achieving landfill minimization targets. It should be noted that these targets must be reached within a very short timeframe, that is, by 2030 (or 2035 in the case of derogation).

Due to unclear specifications and a lack of MBT regulations, which had been planned several times before but were not finalized, these systems were implemented in a variety of ways.

The applied technologies ranged from a simple mobile equipment system to complex technologies capable of selecting multiple material flows, which makes it difficult to compare these systems. In many cases, analysis of the output material streams was required. Simple systems were useable for more or less stable inputs, whilst robust systems could produce stable output material with changing inputs, e.g. due to seasonal variations.

Simple technology

By applying simple technologies like those illustrated in *Figure 3*, weaker quality can be ensured with the same input material compared to more complex technologies, and the simple technology is more sensitive to impurities in the incoming waste.

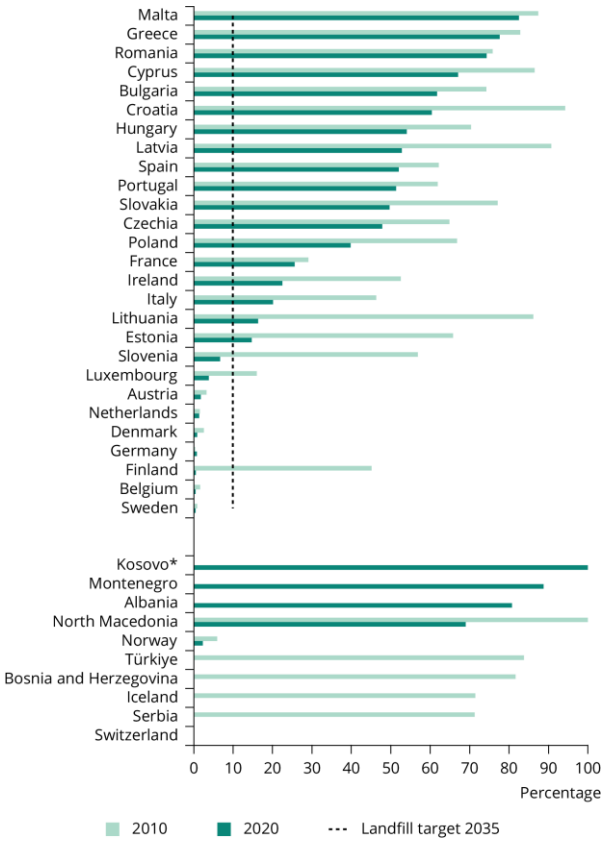

Figure 2: Municipal waste landfill rates in Europe by country
Source: European Environment Agency
https://www.eea.europa.eu/data-and-maps/figures/municipal-waste-landfill-rates-in-1

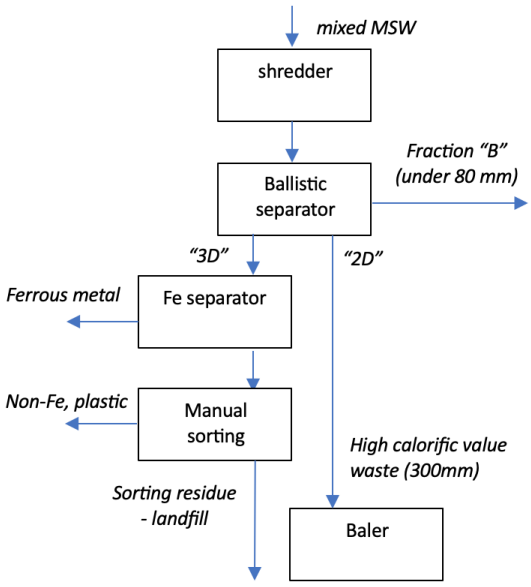

Figure 3: MBT Simple technology

Complex technology

A complex technology is usually more robust and can create more recyclable material streams to produce alternative fuels.

A good example is shown in *Figure 4* about North-Balaton Regional MBT plant in Királyszentistván, Hungary. Here different quality products can also be made parallelly [32]-[33]. In more complex systems, the outputs can be assured and protective steps installed mainly for the mechanical protection of sensitive units. In these systems, sensor-based sorters are already used for negative or positive sorting in order to extract impurities, e.g. chlorine or PET, respectively, as desired.

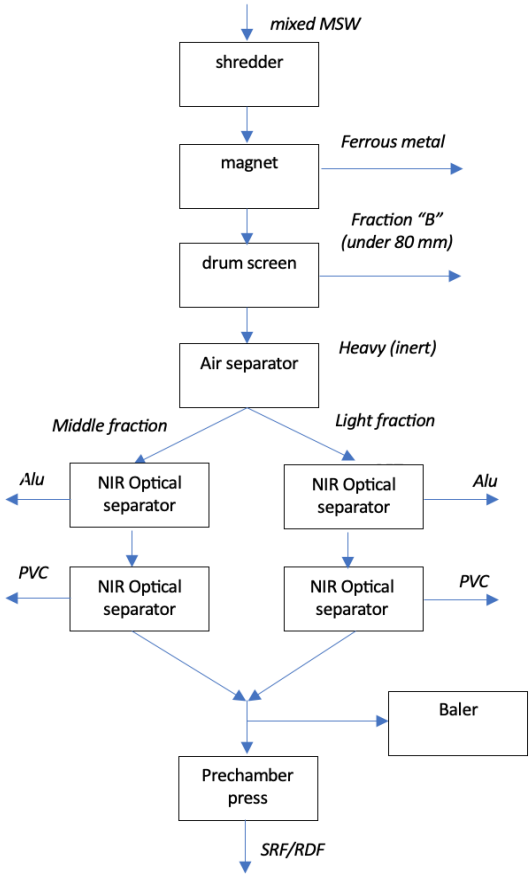

Figure 4: MBT Complex technology

A lack of homogeneous technologies and the absence of certain regulatory elements make it difficult to compare technologies in terms of both their operation and potential. According to the local input materials, the optimisation of MBT plants had to also be addressed to ensure the operational parameters are achieved in order to produce the desired quality of outputs [34].

In the light of the aforementioned reasons, it is beneficial to compare the existing technologies, model operational and functional alternatives as well as simulate them for the purpose of further analysis.

4.2. Municipal solid waste (MSW) - separately collected fraction (packaging materials)

4.2.1. Up to the 2010s

Separately collected "waste" streams have already played an important role following the world wars as important raw materials for rebuilding [35]. Afterwards, the existing deposit scheme in Europe focused on refilling empty glass bottles, moreover, metals and paper were recovered at specialized locations. Although normal waste collection started to expand as a result of sanitation activities in settlements, no separate collection facilities were available to the public in public areas nor through special containers at households for packaging or other forms of selected waste.

During this period in Hungary, the percentage of selectively collected waste was only 2-3% of the whole amount of collected waste compared to 15-20% in Western European countries, even 25-30% was achieved in some countries, e.g. Austria, Germany, Holland, Switzerland and Sweden [28].

To reduce the amount of mixed household waste, a separate collection system for glass, metal, plastic and paper waste from households (selective collection) was established between 2010 and 2015 based on the legal provisions.

After the establishment of this collection system, the waste streams needed to be cleaned in order to be processed further in industry as raw materials. Numerous manual sorting facilities for this purpose are located in Europe.

Simple technology – manual sorting

Manual sorting, even of relatively "clean" material streams, is typically of low quality due to the low pay and prestige of the work, high turnover and scarcity of motivational tools. A typical sorting facility is shown in *Figure 5*. As a result, materials present at the time of collection can be 'lost' in this operation, making it difficult to achieve recovery targets.

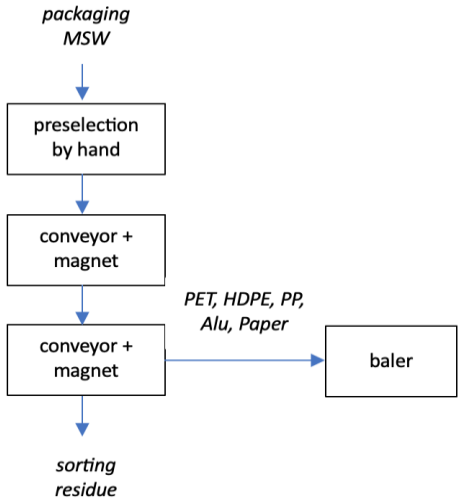

Figure 5: Basic hand-sorting facility

Manual sorting is complex and flexible. Even though changes to selected materials amongst other parameters can be easily enforced, it has significant shortcomings. How workers are trained is crucial. Setting the right size of workforce can be cost-effective. This process was used in countries where the cost of labour is relatively low and the amount of handled material was less compared to after 2010 due to a lack of selective collection systems.

4.2.2. From the 2010s to 2020s

To fulfil the requirements of changes to legislation, more and more packaging waste started to be collected. Larger quantities and problems associated with manual sorting encouraged the development of sensor-based techniques to meet higher demands. In addition to simple manual sorting, new hybrid systems were developed to supplement existing ones alongside novel complex automated systems.

Complex technology – optical machine sorting line

In complex technologies, the most valuable components are selected by Near-Infrared Optical Sorting Machines. The operation is continuous requiring a minimal human workforce to maintain the line. The setup can be configured to meet needs. For the configuration, a mathematical modelling system can contribute towards identifying the most cost-effective arrangement, an example of which is presented in *Figure 6*.

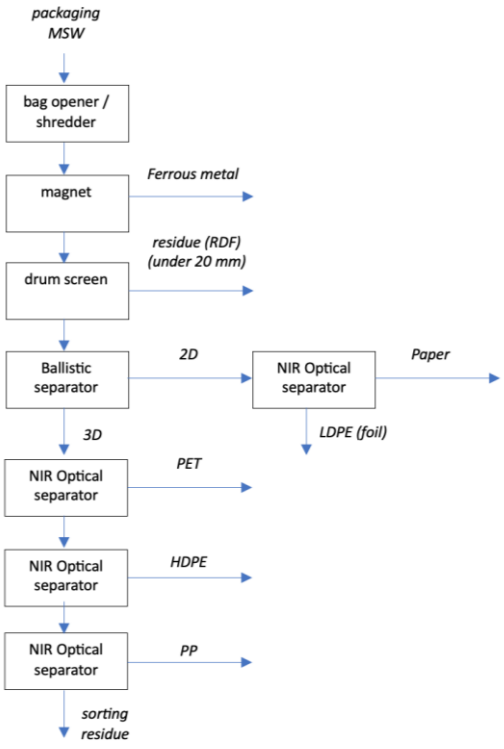

Figure 6: Complex sensor-based sorting facility

5. Trends

Trends in waste regulations and available technologies are evolving mutually. New, e.g. sensor-based, technologies, let decision-makers set higher expectations that also facilitate technical developments. In line with new legislation, the development of waste-focused consumer products and the setting of ambitious targets with regard to recycling should be sought.

In the upcoming years, more waste streams are planned to be selectively collected or capable of being sorted by modern equipment to inject new energy sources and raw materials into the economy. In the case of municipal packaging waste, it is expected that DRS systems and optical separation will become widespread. These sophisticated automated sorting plants can contain numerous optical sorting units to increase their capacity and reduce the degree of necessary human factors.

Instead of the realisation of new MBT plants, additional upgrading of existing one is likely to reduce landfilling [36]. For this purpose, the modelling of waste treatment technologies such as MBT and packaging waste sorting plants might be beneficial for cost optimisation as well as enable changes in the outputs of such technologies to be predicted should inputs vary, for instance, as a result of new DRS systems.

6. Conclusions

In terms of legislation, the new regulations demand that specific waste management targets be met in the upcoming years in accordance with the goals of a circular economy. In the regulatory environment, the relevant directions, strategies and legal framework were established in the 2000s.

The implementation of specific instruments and targets was strengthened from around 2010 onwards to significantly reduce waste and reintroduce material streams back into the economy as raw materials, energy sources or nutritive substances.

With the introduction of DRS, EPR as well as the collection of new waste streams such as biological waste and "green" product requirements, it is hoped that not only more raw materials will be produced but crucial scarce materials preserved for modern industry.

From a technological point of view, techniques are available to reduce landfilling. From the 1970s onwards, mixed household waste began to be pre-treated for this reason. The use of mechanical and biological technologies, which were mainly designed before 2010 and are still effective today, has led to a reduction in landfilling.

Since the realised MBT technologies are very different, their outputs differ despite having almost identical inputs. It is questionable how such installations will cope with changing input waste streams due to legislative changes and whether they will be economically viable. The sorting of selectively collected (packaging) waste is necessary following regulatory

changes. Human factors, e.g. knowledge, motivation and capacity, must be addressed when manual sorting. Although automated or hybrid (mechanical and manual) sorting is expected to become widespread, the proper planning of yield and flexibility is essential to meet future goals.

In general, current technologies are suitable to realise set goals in line with legislation. Since their scaling and modelling can ensure their cost-effectiveness, legislators may be given an impetus to set further directions and ambitious goals. Meanwhile, experiences concerning selection must also be incorporated into the design phase of products in accordance with the principles of a circular economy.

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