SORTING AND RECYCLING SOLID PLASTIC WASTE

Challenges and opportunities

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Abstract:

As the title suggests, this thesis deals with the challenges and opportunities in sorting and recycling of solid plastic wastes. The author has taken the approach of literature review in conducting this study. More than 50 literary works on sorting and recycling of plastic wastes were selected in the beginning. Out of those 50 literature sources, 21 were sorted and used for the purpose of this study. All the sources are available online.

The literature contains current status of plastic waste globally, regionally and in Finland. It also contains the different classification of plastic. However, plastic recycling and plastic sorting techniques form the core of this research. Different sorting techniques and their respective limitations have been thoroughly discussed as the findings of this research. Furthermore, the new state-of-the-art sorting techniques have also been discussed in the latter stages of this study.

The main challenges pertaining to the sorting and separation of solid plastic wastes in the currently applied techniques seem to be the varying degree of density of polymers, fluctuating pressure during production, inability to identify dark and black polymers, lack of pretreatment techniques in some cases, lack of large-scale integration, safety issues while using X-ray, and inability to separate polymer types. The opportunities are mainly associated to averting the present challenges with the implementation of newly developed theories and techniques. The opportunities also discuss the use and integration of new techniques that have been theorized but are yet to be implemented practically on an industrial scale.

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List of Abbreviations

WMS	Waste Management System
AI	Artificial Intelligence
AMU	Atomic Mass Unit
PET	Polyethylene Terephthalate
PE-HD /(HD-PE)	High-Density Polyethylene
PVC	Polyvinyl Chloride
PE-LD /(LD-PE)	Low-Density Polyethylene
PP	Polypropylene
PS	Polystyrene
SPI	Society of the Plastics Industry
SPW	Solid Plastic Waste
FDA	Food and Drug Administration
BPA	Bisphenol A
FT-NIR	Fourier Transform Near Infrared
XRF	X-Ray Fluorescence
AI	Artificial Intelligence
VTT	Valtion Teknillinen Tutkimuslaitos

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1 INTRODUCTION

To recall the history of human civilization, plastic has been resonating with the economical drive. Cost-efficient, easy to use, chemical resistance, lightweight, transparency, and barrier properties have made this resource popular worldwide from households to industrial sectors (Poliakova, 2019). Imagining a modern world without plastic is almost impossible. With the adaptive nature of the consumers and industries, the demand for plastic in every economic sector was high and yet exponentially increasing, for example in packaging, transportation, healthcare, construction, and electronics (Ellen MacArthur Foundation and McKinsey & Company, 2016).

The increased use of plastic led to piling up the plastic waste without the proper knowledge of reducing, reuse and recycle. About 22-43% of used plastic goes direct to landfills and similarly, 10-20 million tons of polymeric waste goes to the marine world. Consequently, plastic waste making its path to oceans gets consumed by aquatic lives in the form of micro and nano plastics after breaking down affecting them and also human health as we consume marine species in a form of food (Milion, et al., 2018).

However, the global concern is reflected in modern days due to the impacts caused by plastic use haphazardly. The growing awareness has brought the world with the value of plastic as a resource than the utilities. The global voice is raised on slowing down the overconsumption and misutilization of plastics. Similarly, significant numbers of research on closing the loop of polymer manufacture by replacing with some organic polymers, are in process. The reason behind this is organic polymers are degradable and eco-friendly. On the other hand, various research on optimizing the pre-existing plastic recycling techniques is in progress.

2 BACKGROUND AND OBJECTIVES

This thesis will discuss the global status of plastic waste, the waste processing scenario with the Finnish environment, an overview of plastic waste production. Moreover, the situation of current and expected mismanaged plastic waste concerning regions, EU nations, and some other countries. Furthermore, this thesis reviews plastic waste recycling methods, Mechanical and Chemical. Advantages and limitations of some conventional plastic sorting technologies used worldwide are outlined, modern techniques and possible solutions for overcoming limitations are discussed.

The main objective of this thesis is to propose the significance of the sorting process of solid plastic waste and the challenges and opportunities associated with it. Furthermore, to develop the solution in the future to optimize plastic waste management, here we specifically discuss in detail some of the mechanical plastic sorting approach at present, limitations, the potential of optimizing the process.

3 LITERATURE REVIEW

3.1 Global status of plastic waste

Century 21st has been an opportunity for plastics to grow its production rapidly due to its nature that its cheap, versatile, and reliable. This has generated a massive amount of plastic waste, especially in high and upper-middle-income countries. The plastic waste generation process is segmented as; 9% recycled, 12% incinerated, and 79% landfill. As the development of human civilization, this result doesn't resemble us as a visionary in utilizing the resources.

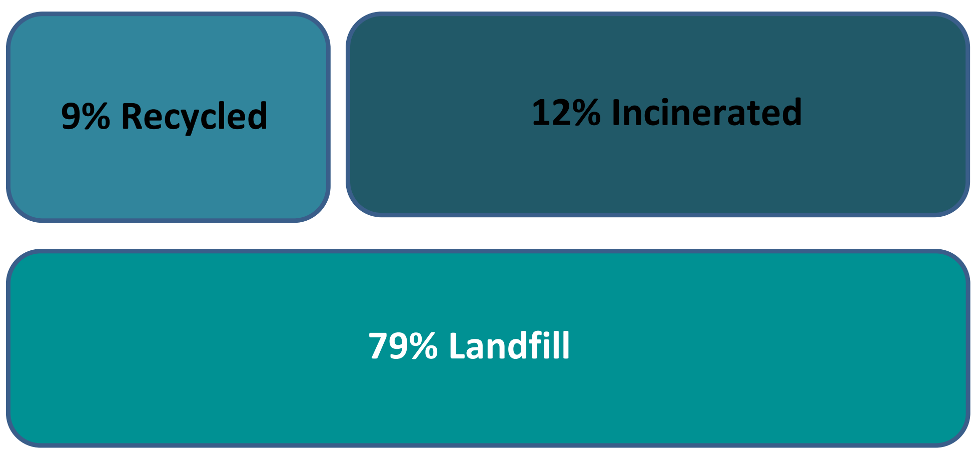

Figure 1. Plastic waste status globally (KPMG, 2019)

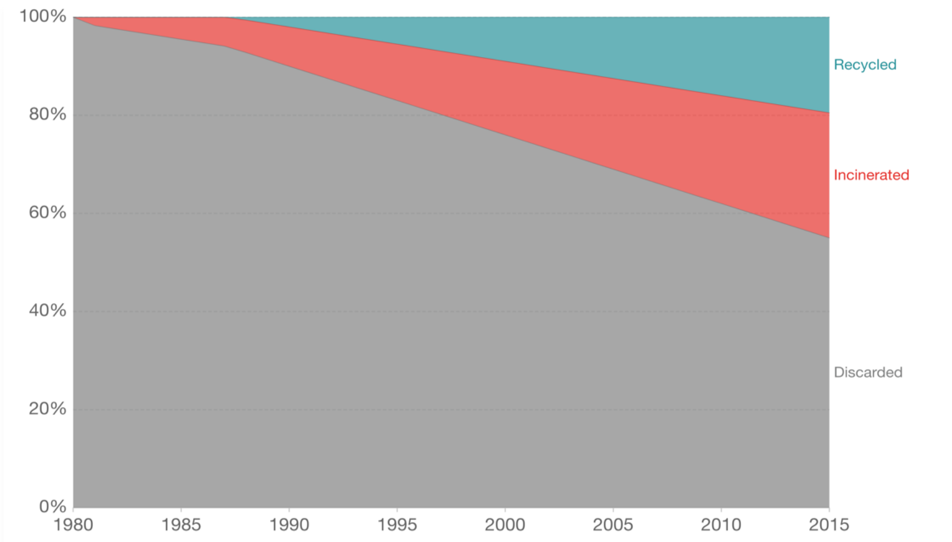

Figure 2. Global plastic waste by disposal, 1980 – 2015 (Ritchie & Roser, 2018)

However, as per the research database, recycling and incineration have shown some progress as per the chart in figure 2. In the past 35 years, the discarded plastic waste has been decreased by almost 45%.

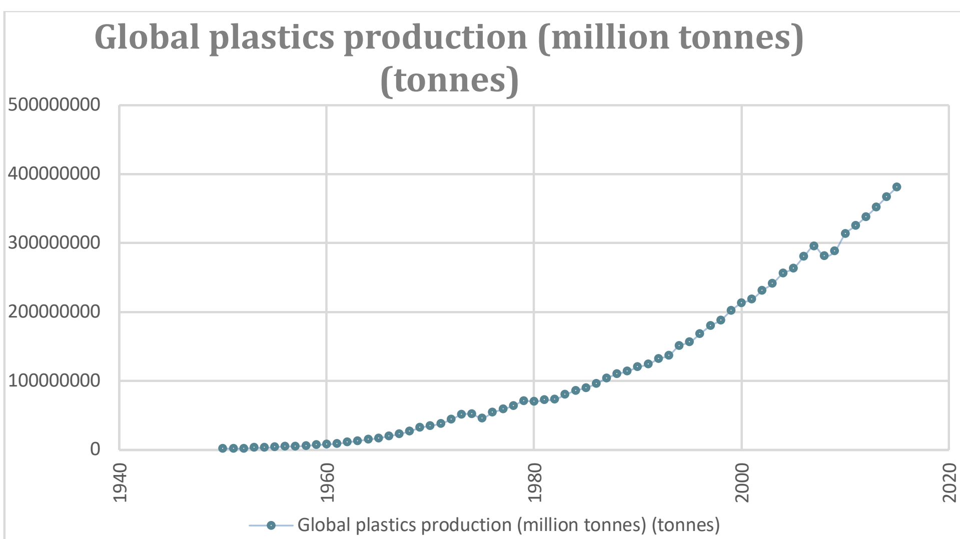

Figure 3. Global plastic production in metric tonnes per year (Ritchie & Roser, 2018)

Despite the fact, plastic has disrupted the ecological balance; the amount of plastic production has been increased insanely in the past 7 decades. The industrial revolution increases in population & households and user-friendliness with low cost have been the key elements to catalyze plastic production. Global plastic production from 1950 to 2015 is shown in the chart in figure 3. It shows annual global polymer resin and fiber production (plastic production), measured in metric tonnes per year (Ritchie & Roser, 2018).

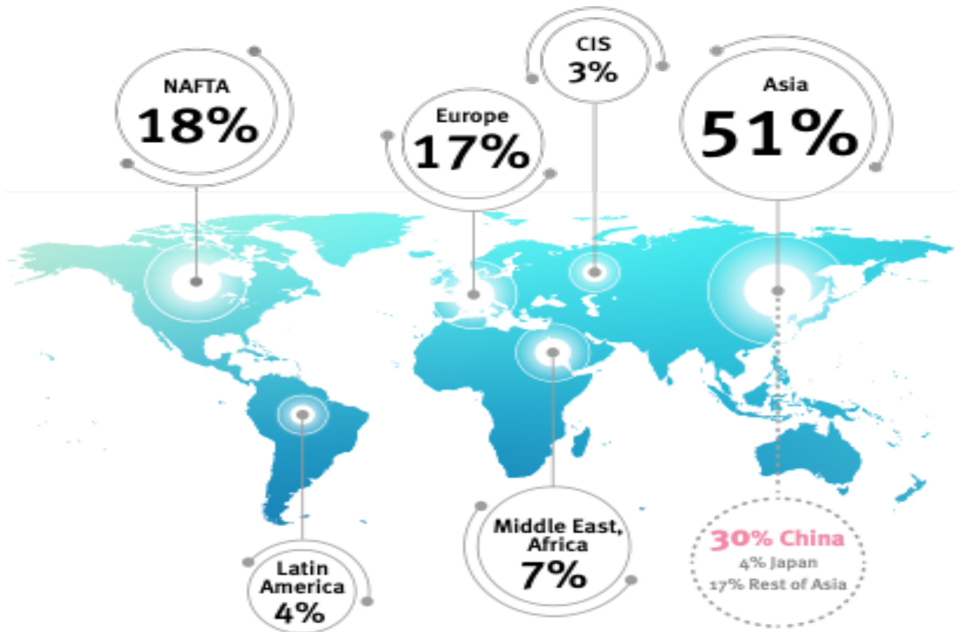

Figure 4. Global plastics production distribution (PlasticsEurope AISBL, 2019)

The above map in figure 4 shows the regions where plastic production is mentioned. Asia covers the most with 51% of plastic production with Europe being the 3rd with 17% of global market share. About 9,4 bn € plastics are manufactured whereas 5,8 bn € is used to process the plastics in 2018 in Europe.

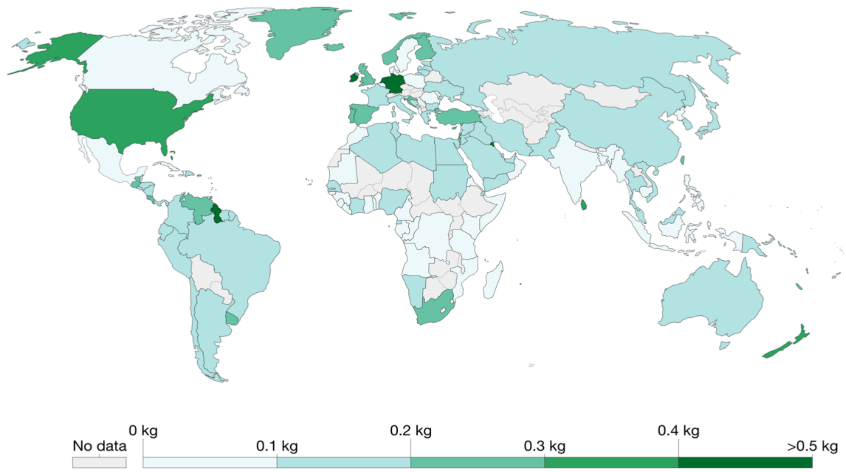

Figure 5. Plastic waste per capita (Ritchie & Roser, 2018)

The increasing amount of plastic waste can further be classified into a generation of plastic waste per person on a daily basis measured in kilograms. However, the data provided in figure 5, doesn't directly indicate the distinction in waste management, recycling or incineration. Likewise, risk of pollution to waterways or marine environments is not accounted. German, Ireland, and Guyana have the highest plastic waste generation in the globe whilst the USA tops next. Figure 5 also presents the clear insight that in Europe plastic waste generated per individual per day is somewhere between 0-0.3 kg whereas in Finland it is between 0.2 - 0.3 kg (Ritchie & Roser, 2018).

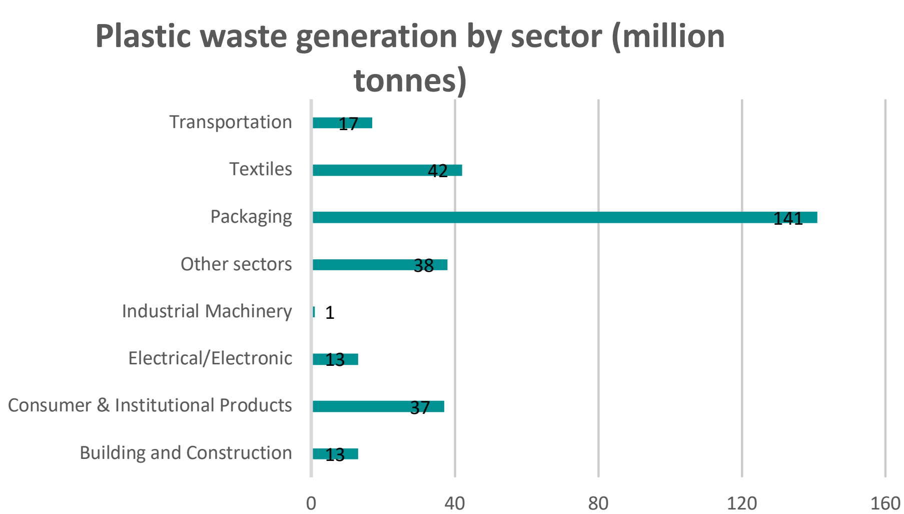

Figure 6. Plastic waste generation by sector (Ritchie & Roser, 2018)

The above horizontal bar graph in figure 6, presents the data regarding plastic waste generation by industrial sectors. The packaging industry generates a majority of the plastic waste i.e., 141 million tonnes. The data based on the mean product lifetime of plastic uses, 2015 shows that packaging has a comparatively less mean lifespan of only half a year accountable for the maximum waste generation. Hence, the packaging sector is dominant in generating an excess of plastic waste which needs to be considered while planning for optimization (Ritchie & Roser, 2018).

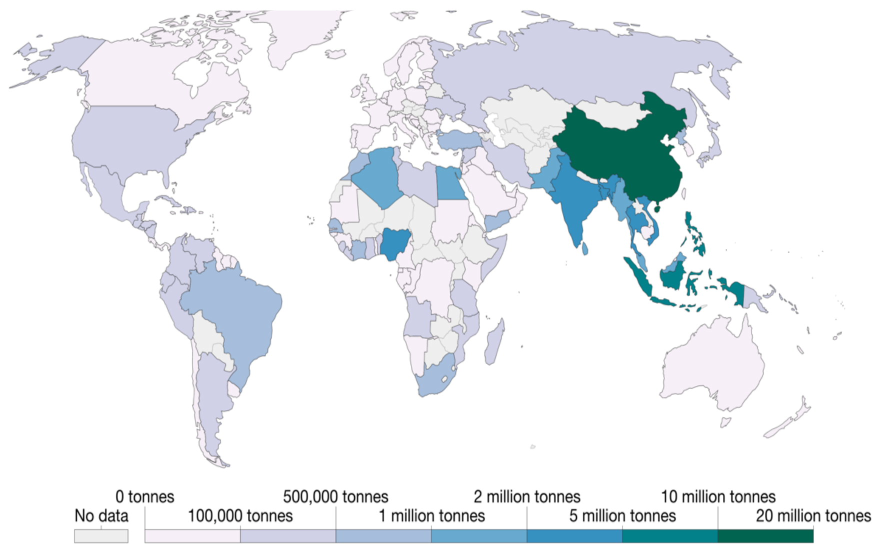

Figure 7. Mismanaged plastic waste projection by 2025 (Ritchie & Roser, 2018)

With a current rate of growing plastic wastes, the mismanaged plastic waste by 2025 is projected by populations within 50km of the coastline and thus defining it as a high risk of entering the ocean. Mismanaged plastic waste is defined as ‘’plastic that is either littered or inadequately disposed. These disposals are not formally managed and disposed in dumps, open or uncontrolled landfills. It could eventually enter the ocean via different artificial or natural ways such as waterways, wastewater outflows, winds, or tides (Ritchie & Roser, 2018).

In the figure 7, it can be seen that China is leading its way to mismanaged waste as well as the countries which are surrounded by the Indian Ocean. These countries with minimum innovation on recycling plastics would proceed with their solution to dump in the ocean. On the other hand, Canada, almost the whole of Europe would be managing the plastic waste to the fullest (Ritchie & Roser, 2018).

3.2 Plastic waste management system (WMS) overview by regions

With the given data in figure 4, effective plastic waste management performance should be applied, which by far is directly correlated to the income status of the countries and the awareness in the general population. Past decade timeline suggests that high-income countries by far have been developing the system for the plastic waste collection higher. However, low levels of recycling and easy way of landfilling don't seem to be an effective solution in a long run (Advisors, et al., 2019).

In Europe, due to health, safety, quality, or contamination reasons almost half of the total collected plastic wastes cannot be recycled which concludes the loss of materials. Moreover, the recycled secondary materials developed through recycled plastics are of lower quality concerning its primary material. Thus, trading it for a lower price. Even though waste plastics can be a real resource by increasing their quality, operational costs to develop it as the resource is really expensive due to its supply chain process from waste collection, separation, and limited supply of recyclable plastics. Encouragement from national policies is pushed in order to support the upstream actors to develop alternatives (Advisors, et al., 2019).

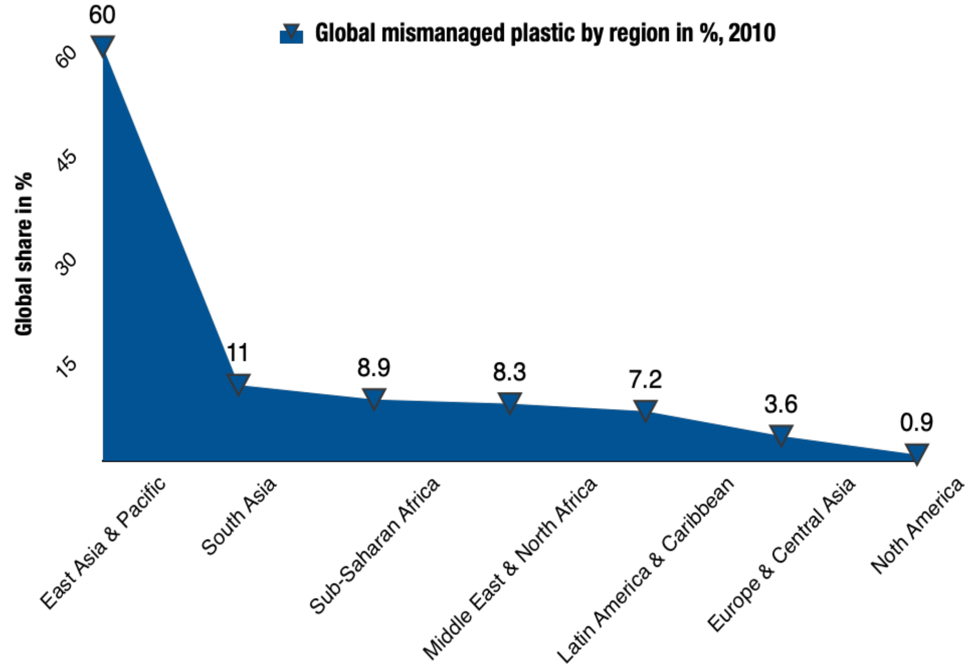

Figure 8. Global mismanaged plastic by region in % 2010 (Ritchie & Roser, 2018)

In the chart in figure 8, there is a clear picture of the global distribution of mismanaged plastic waste as per region where East Asia & Pacific region dominating with about 60% of the global share in total with the main region being China accounting almost 25,79% alone. Since China is the producer & manufacturing hub of the world's materials for various products. South Asia ranks second contributing about 11% of the global share that almost is 5 times less than East Asia & the Pacific (Ritchie & Roser, 2018). The main region for it to hold in the second position in India. The main region can be the population distribution in these regions where it accounts for almost 59,76% of the world population living 50,9% in urban areas (worldometer, 2019). North America and Europe are leading in managing the mismanaged waste and if these regions would successfully address the procurement, then it would successfully eliminate plastic use. This, resulting in global mismanaged plastic declination by 5% because these two regions generate a significant amount of plastic waste on a per capita basis (Ritchie & Roser, 2018).

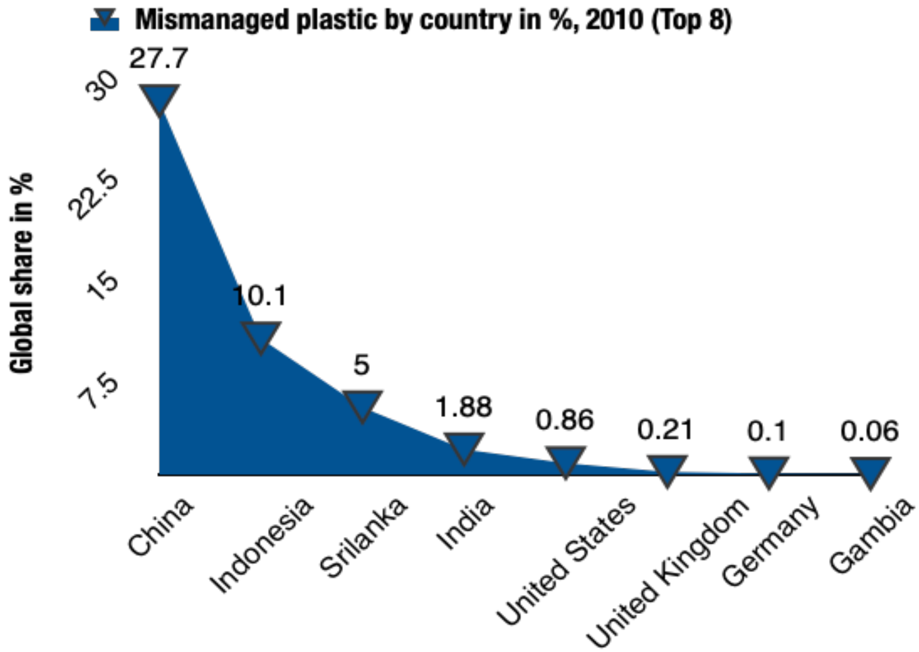

Figure 9. Mismanaged plastic by country % 2010 (Ritchie & Roser, 2018)

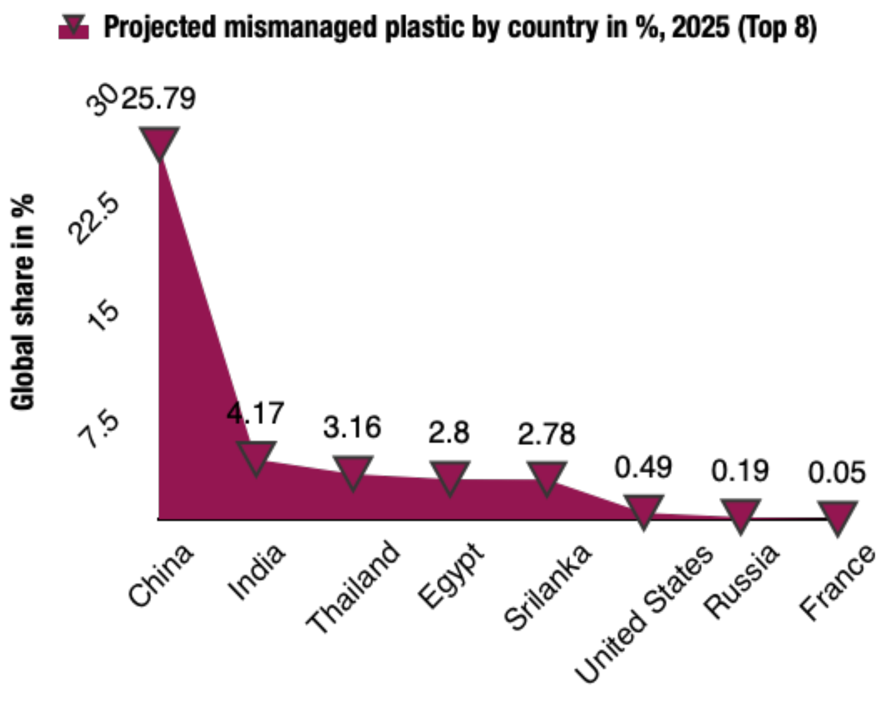

Figure 10. Projected mismanaged plastic by country in % 2025 (Ritchie & Roser, 2018)

In figure 9, we see what percentage share of global mismanaged plastic the different countries held a decade back. Figure 10, on the other hand, presents the projected mismanaged plastic waste in the next 5 years from now i.e., 15 years from 2010.

Comparing the data above, the projection of mismanaged waste overall will not increase much high, with a contribution from China drops by 2% whereas, India seems to jump in the chart to 2nd position. There are newcomers in the projected graph like Thailand, Egypt, Russia, and France. Almost all the European countries are dropped down except France.

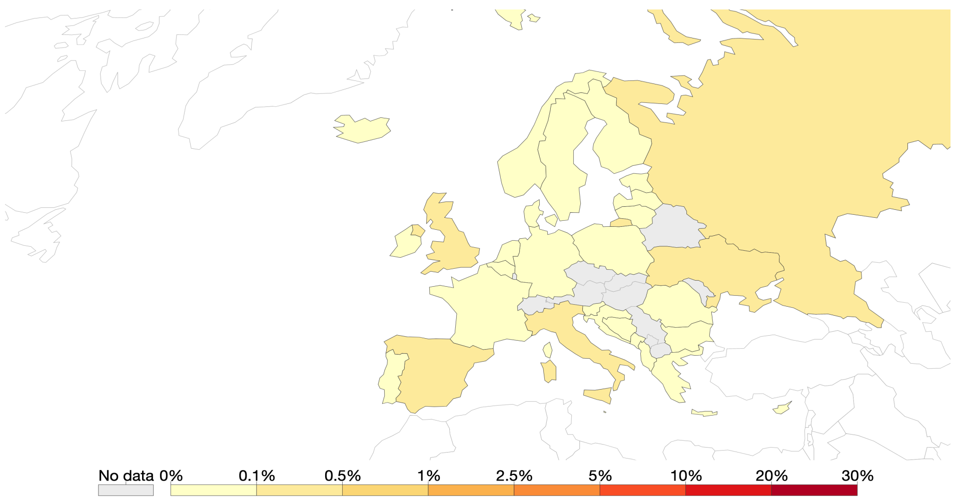

Figure 11. Share of mismanaged waste in Europe, 2010 (Ritchie & Roser, 2018)

In a map, in figure 11, it can be seen that mismanaged plastic wastes in Europe are minimal. Finland is one of the countries that properly manages the generated plastic waste however it lacks the proper recycling techniques. The UK with 0,21%, Spain with 0,41%, and Italy with 0,1% of global share have been mismanaged plastic wastes as per data 2010 (Ritchie & Roser, 2018).

3.3 Plastic waste scenario in Finland

Actions to implement have been a little late when the world is covered by the chemical challenges due to plastics. Despite the public awareness of the environmental impacts caused by plastics, the trend of using it because of its usability grew exponentially before it can be processed and managed systematically. Until early 2016, Finland was using conventional approach for recycling plastic waste but was yielding high recovering scale. In first quarter of year 2016, the Rinki recycling network was established, with waste collection points in cities, a slow and unsure start. It showed the great result already a year later, with nearly three folds more plastic waste per household were collected for recycling per heads (YLE Uutiset, 2017).

In Finland, annually, 100,000 tonnes of plastic waste are generated which is exclusive of beverage bottles which were returnable and exchanged for 10 to 40 cents each.
Of the total collection, back in 2017 only a minimum of 16-17 percentage got reprocessed. The recycling work is carried out in Ekokem recycling plant in Riihimäki, which belongs to state energy company, Fortum. Experts say a range of logistical and chemical challenges is making reprocessing process slow (YLE Uutiset, 2017).

4 PLASTIC AND ITS CLASSIFICATION

The ability of a material to deform without breaking, the plasticity, is referred to by the name "Plastic". Plastic is an organic polymer; synthetic or semisynthetic. Meaning, it always includes hydrocarbons while other elements might also be present. Most commercial plastics are made from petrochemicals though they can be manufactured from just organic polymers. There are two types of plastics: *Thermoplastics and Thermosetting* (Helmenstine, 2020).

Thermosetting polymers, commonly known as thermosets, are amorphous solids with infinite molecular weight. Thermosets solidifies into a permanent shape. Unlike thermosets, it is possible to remold thermoplastics time and again with a certain elevated temperature and a mold. Therefore, thermoplastics are also known as thermo-softening plastic. Thermoplastics are considered to have a molecular weight in the range of 20,000 to 500,000 amu (atomic mass unit) (Helmenstine, 2020).

Thermoplastics are named by the acronyms for the chemical formulas, hence there are a large number of thermoplastics in use around the globe. From the significantly wide range of plastics in existence, the modern world has summarized plastic and waste in seven different types: Polyethylene terephthalate (PET), High-density polyethylene (PE-HD), Polyvinyl chloride (PVC), Low-density polyethylene (PE-LD), Polypropylene (PP), Polystyrene (PS), and Others with the unique identification codes. The unique identification codes are nothing more than a number within the recycling symbol and are known as SPI Code. This provides information about the resin used, safety, and biodegradability of different types of plastics. Once we understand these codes, we know how the used plastics need to be sorted for further recycling (Helmenstine, 2020).

The table below shows the seven different plastic resin codes and a little deeper understanding of them.

Table 1. Plastic identification codes

1 PET	First used in 1940, commonly used as beverage bottles, decomposable food containers. PET plastics can be recycled and easily disposed, and recycling industries don't hesitate in taking them. But at extremely high temperatures, PET containers get leached into the foods and liquids. They are recycled into furniture, carpet, and winter wears fiber.
2 PE-HD	First synthesized in 1950s by Karl Ziegler and Erhard Holzkamp. FDA has considered PE-HD to be safe for food contact as its internal structure is by far stronger than PET hence, safely reusable. These plastics are suitable for both freezing and high temperatures. Containers made out of HDPE have a minimal risk of leaching into the foods and fluids. In our daily lives, we're familiar with this kind of plastic in the form of milk, yogurt containers, cosmetic and cleaning product containers, planting pots, pipes, and also playing toys.
3 PVC	First created in 1838, also known as Vinyl and it's one of the oldest plastics. PVC becomes flexible with plasticizers addition though it is rigid at the beginning. They also have a wide range of applications like other plastics, found mostly in medical equipment, ATM cards, and other similar cards, food wrap, and so forth, and rarely recycled.

	PVC contains harmful chemicals which might cause various ailments. It might also cause liver and bone problems, growth and development issues in infants and children. Nowadays, PVC is recycled into roadside gutters, floor coverings, roofing sheets, cable insulation, and so on.
4 PE-LD	With its simplest structure and easy manufacturing procedure of all the plastics PE-LD is popular among us. They are mostly used in the form of bags. Low density, clean and safe plastics are widely used in household materials like frozen food wrap, green vegetable wrap, squeezable bottles, for example, oil bottles. Although it's difficult to recycle LDPE, recycling firms have started to accept it for recycling to make it into garbage cans, furniture, floor coverings, and bubble wrap.
5 PP	A hard, stiff, and high-temperature resistant PP is first discovered in 1951 at a petroleum company. PPs are found in automobile parts, thermal vests, yogurt containers, and so on. This kind of plastic is often thrown away whilst it can be recycled like others. PPs are recycled into heavy-duty products like ice scrapers, battery cables, and pallets.
6 PS	It was accidentally discovered in 1839 in Germany. Also known as Styrofoam and are an easily recognizable kind of plastic. PS is widely used in disposable dinnerware, beverage cups, egg carets, and several packing materials. It's easy to create, cheap, and easily available everywhere, but unsafe. Styrofoam's known for both destructive synthetic substances, especially when warmed, and poor recyclability.
7 OTHERS	Every other plastic that doesn't come under the aforementioned plastic categories falls in SPI code 7 plastic-type, miscellaneous plastics. This plastic contains harmful chemicals BPA (Bisphenol A) and is dangerous. These types of plastics are extremely difficult to recycle because they don't break down easily. Despite all, they are used in many items, for instance, compact discs, sunglasses, nylon, casing in many electronic devices, etc. Recycling plants recycle this plastic into some specialized products and plastic lumber.

5 PLASTICS RECYCLING

Due to the various recycling and recovery activities, 'Plastics Recycling' is confusing and also complex terminology to understand. These activities allow recycling plastic into four main categories:

- Primary recycling (mechanical reprocessing) where a product with equivalent properties is obtained
- Secondary recycling (mechanical reprocessing) where a product with lower properties is obtained
- Tertiary recycling (chemical or feedstock recycling) where the polymer is de-polymerized to its chemical constituents
- Quaternary recycling is the recovery of energy from waste

The quantity of post-consumer plastic waste is five-time higher as compared to generated in commerce and industry. Hence, to obtain high recycling rates, post-customer, as well as post-industrial waste, need to be recycled optimally (Hopewell, et al., 2009).

5.1 Mechanical recycling of plastic waste

Also known as secondary recycling, mechanical recycling is recovering of materials from waste by physical means. For instance, shredding, cutting, rinsing, and so on. In mechanical recycling, polymers are converted into granules by melt filtration extrusion. The ending stuff, like flakes and granules, is obtained as a result of a process; sorting, cleaning, and drying of mixed plastic solid waste. These granules are the raw materials and are manufactured into several other final goods, for example, chopping boards, buckets, automotive parts, electric insulators, etc. The major problem in mechanically recycling is the heterogeneity of the solid polymer and quality degradation of the final product after every individual cycle. The chain-scission reactions caused due to the presence of acidic contaminations and water causes the molecular weight reduction of recycled polymer thereby deteriorating the product's properties. To keep the average molecular weight of the product during recycling, some strategies are made which include the use of polymer chain extender compounds, thorough drying, recycling with vacuum degassing, and so on. The superior result could also be obtained by adding some virgin materials during the melting phase. As thermosets cannot be melted and reprocessed, they are made into roads covering tar or cement kilns while mechanical recycling is a suitable option for thermoplastics (Francis, 2016).

Mechanical recycling is the conventional recycling technique, which is popular all over the globe. This method has few simple steps which are as follows:

1. Collection
2. Washing and drying
3. Coloring
4. Extrusion
5. Manufacturing of the end product.

Needing homogenous and fairly clean plastics is a cost-effective approach but needs a costly initial setup (Francis, 2016).

5.2 Chemical recycling of plastic waste

Chemical recycling is also recognized as feedstock or tertiary recycling method. Feedstock reprocessing is an advanced method as it leads to the total depolymerization of polymer into monomers, or oligomers (partially depolymerized molecules) and some chemical constituents. The interesting fact is that the monomers could be re-polymerized back to get the original polymer. Converting plastic stuff into smaller molecules, likely gases, and liquids, as a raw material for the creation of new polymeric goods or petrochemicals by means of chemical agents or heat. It has been scientifically proven that a final output obtained by depolymerization technique in chemical recycling is a fuel, which is highly profitable nevertheless sustainable (Francis, 2016).

At present, tertiary reprocessing is gaining much attention due to its outputs being a valuable energy resource. One of the most used and effective chemical recycling processes is thermolysis. Thermolysis is carried out at a high temperature and in a non-oxidative surrounding. Plastic waste gets upgraded to fuels of different states and valuable chemicals after thermolysis. Chemical recycling involves the following methods:

1. Hydrogenation

2. Gasification
3. Chemical de-polymerization
4. Thermal cracking
5. Catalytic cracking and reforming
6. Photodegradation
7. Ultrasound degradation
8. Degradation in a microwave reactor.

At present, various degradation methods to achieve petrochemicals are under exploration and some advanced research is going on to find favorable conditions for pyrolysis and gasification (Francis, 2016).

5.3 Biological recycling of plastic waste

By this process, biodegradable plastic waste is reduced to carbon-based residues and water involving microorganisms in the precise treatment in the presence of carbon dioxide (composting) or with methane (digestion) (Poliakova, 2019).

6 PLASTIC SORTING TECHNIQUES AND THEIR LIMITATIONS

In waste processing, after the waste arrives processing plant, sorting is the initial stage in the waste processing hierarchy. The proper sorting and separation of plastic waste are crucial to the optimization of the use of sorted waste. Hence, there are several sorting techniques used in the sorting of plastic waste these days. In this era of technical advancement majority of the sorting is performed in a computerized way but to find the precision of automated sorting some manual sorting is also performed from time to time. Below are some common sorting techniques used and their limitations.

6.1 Flotation

This method of sorting is a straightforward density-based separation technique, and also known as float-sink separation (Ragaert, et al., 2017). The floating technique bears several specific features which are related to the distinct plastic properties, such as density and surface energy (Wang, et al., 2015). It uses water as a floating agent and is prominently used for sorting shredded flakes. To optimize the sink fraction, much denser floating agents can be used instead of water. With flotation, polymers with a density less than 1g/cm^3 will float while others sink.

The limitation identified in this simple sorting technique is the wide range of density of the polymers. Most of the polymers are PC derivatives that don't have a single density but a density range and cause the overlapping which makes separation less effective into mono-stream.

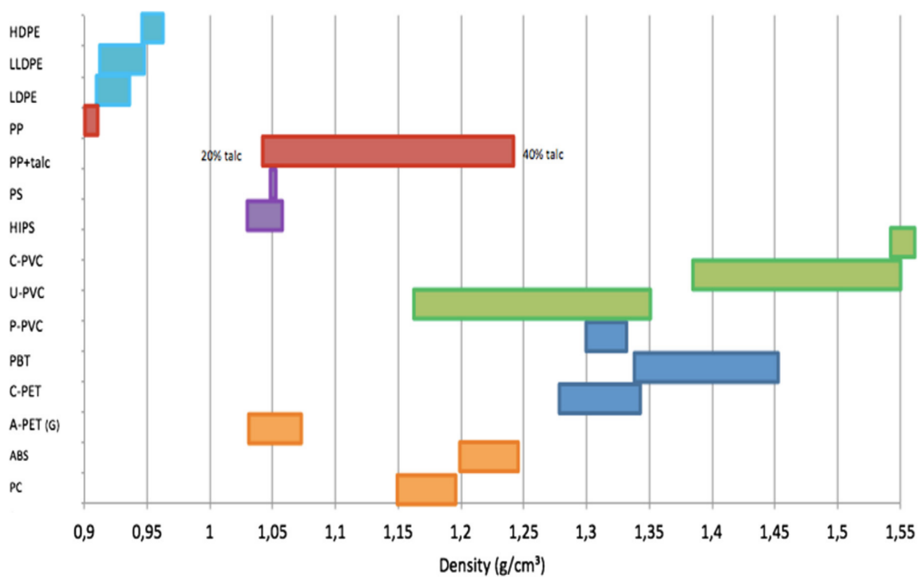

Figure 12. Density ranges of the most common polymers in SPW (Ragaert, et al., 2017)

6.2 Melt- Filtration

As mentioned by the name itself, this melt filtration removes non-polymeric particles (metal pieces, woods, glass, papers, sand, etc.) from the recycled plastics. Essential for the quality output, it is considered a key technology building block for polymer recycling systems. To obtain a high-quality pellet as an end product, selecting the right filtration method depending on input materials is crucial. Melt filters come in different mesh sizes, where the filter with smaller mesh size filters more containments (Horrocks, 2019).

The major problems with melt-filtration are potential pressure fluctuation in production due to filter blockage due to contaminants, not suitable for the polymers with critical dwell-time behavior (Kellie, 2016).

6.3 FT-NIR

FT-NIR spectroscopy is one of the most used automated waste plastic sorting techniques worldwide. FT-NIR is used for polymer type analysis and also uses optical color recognition camera systems to distinguish the stream into colored and clear fractions. By the use of an optical system, clear, light blue, dark blue, green and other colored PET containers can be differentiated (Hopewell, et al., 2009).

Despite being the most widely used computerized plastic sorting technique, an optical surface technique, it can sometimes produce a false result. For instance, if one product is inside another and light not being able to reflect back due to dirt and dust the sensor might read a label of a bottle underneath. Likewise, in the case of multiple layer packaging sensor will pick up the reading of one that is presented towards it during sensing. Besides, one of the major drawbacks of NIR is not being able to identify dark and black polymers (Hopewell, et al., 2009).

6.4 Tribo-electric(electrostatic) separation.

Due to the simplicity, triboelectric separation is an economical process in which polymer flakes are separated into charging units after the initial treatment like crushed and screened into proper size (Wu, et al., 2013). In this process, polymer flakes collide in a charging unit due to the intensive friction charging method, resulting in one polymer flake being positively charged while the other is negatively charged at the surface. From this point forward, they will get isolated by their distinctive deflection in an electric field (Ragaert, et al., 2017).

Practically, this technique has shown a good result in the sorting of binary particle mixtures (for instance, HDPE/PP, PET/PVC, PVC/rubber, ABS/PC, and other mixtures). But in theory, it is supposed to work also for a complex blend of polymers.

The challenge identified in triboelectric separation is for example, in some mixtures PP/PE, a pre-treatment is needed (e.g., electron beam irradiation) to allow homogenous material fraction separation.

6.5 Froth flotation

This process selectively separates polymers based upon their hydrophobic (water-repelling) or hydrophilic (affinity for water) property. Unlike the density separation process, froth flotation is not solely density-dependent but also in the material's hydrophobic nature. Froth flotation has been used successfully over the years because plastics are generally hydrophobic materials. For example, two different plastics floating in a certain liquid phase can be segregated by adding a wetting agent which is selectively absorbed by one of the plastic materials. Hence, sinks to the bottom, and other hydrophobic material floats on the surface and is removed (Quinn, 2016).

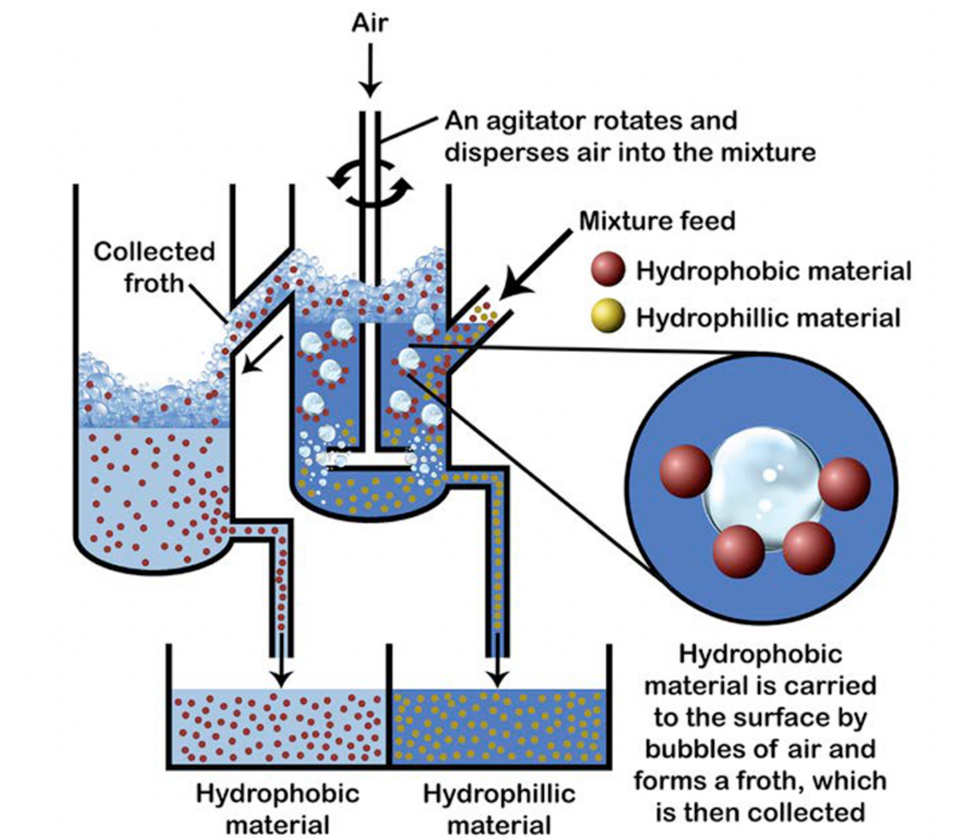

Figure 13. The process of froth flotation (Quinn, 2016)

The challenge faced in froth flotation technique; a foundation step is required in the polymer's surface properties such as hydrophobic to hydrophilic ('selective wetting', for a mixture of hydrophobic polymers) or the hydrophilicity of one of the polymers is raised ('selective hydrophobization', for party wettable polymers). Moreover, this technique is only limited to lab research purposes rather than large scale in industries (Quinn, 2016).

6.6 Magnetic density separation

Magnetic density separation (MSD) is an advancement of density-based technology in which a magnetic fluid is used as a separation medium in the mixture of multiple polymers. The used magnetic liquid is a constitute of water (i.e., a liquid) and magnetic particles (i.e., iron oxide particles of about 10-20 nm) suspended in the liquid. Artificial gravity is generated, like a magnetic force through the special magnetic field. This magnetic force differs exponentially in the vertical direction and so does the density of the liquid. As a result, the waste plastic particles will float in the fluid at a level where effective density equals their density. Plastic particles with marginal density differences, like PE and PP, PVC and rubber can be separated (Serranti & Bonifazi, 2019)

In some cases, turbulence in the flow stream negatively affects particles flow inside the magnetic fluid. To omit this, some of the fundamental steps have to be addressed; (1) wetting, (2) feeding, separating and collecting.

6.7 X-ray fluorescence (XRF)

In the XRF-based sorting, a sample that is beforehand energized by X-ray is used to detect the emitted wavelengths and released energy. The atoms of such energized sample release energy that is responsible for the generation of X-ray fluorescence radiation.
Though this technique is expected to be widely used in the future in plastic sorting, it is generally used to sort PVE from PET at present. A new XRF-based approach, the Energy Dispersive X-ray Fluorescence (EDXRF) has come forward currently adding tracers to the polymer matrix (Pacheco-Torgal, et al., 2018).

In both methods, sorting manner are similar. In EXDRF, the operative unit is composed of an X-ray beam energizing the waste transported on the conveyor belt to evaluate and sort. A focused X-ray beam is passed through the supplies until it reaches the sensor. The signal collected by the sensor is evaluated, presence of tracers recognized and blown out by the air according to the preset rules.

The advantage of XRF is, it does not need sample preparation; it has good results with the identification of black and even very dark plastics. Moreover, it can also identify the presence of contaminants on the polymer surface.

The limitation of the XRF plastic sorting technique is that it is costly, it can't differentiate the polymer types, and using X-ray sources has some health and safety issues. (Pacheco-Torgal, et al., 2018).

Table 2. Plastic waste sorting techniques and limitations

Method	Working principle	Limitation
Floatation	Density difference separation	Density overlaps
Magnetic density separation	Magnetic fluid as a separation medium	Turbulence in the flow stream
FT-NIR	Reading molecular vibration of functional group in polymers	Black materials are undetectable
X-ray fluorescence	Same as FTNIR but the different wavelength	Costly and also can't identify polymer types
Forth floatation	Separation on the difference of hy-drophobic nature of particles	Not effective with plastic waste
Trio-electric Separation	Particles are charged and separated close to positive and negative elec-trodes and separated at the exit	Inconsistent charging
Melt filtration	Separation based on high and low melting point	Pressure fluctuation problems

7 POTENTIAL OF STATE-OF-THE-ART NEW SORTING TECHNIQUE

7.1 Bi-directional magnetic projection

This method was proposed in 2020. A single-step separation of multiple mixed plastic wastes remains a perplexing concept hence a stepwise approach, a conventional methodology, bi-directional magnetic projection which showed an amazing result of 95% (percentage) by weight retrieval rate of all constituents has been introduced (Zhao, et al., 2020).

In this method, a mixture that needs separation of its material constituents is submerged in the container containing a paramagnetic medium. The permanent magnet is placed alongside a container to supply a magnetic field. Finally, the particles get separated in the landing areas due to the influence of the magnetic field, upthrust, and gravity (Zhao, et al., 2020).

The main advantage of this method over existing methods is a proficient and effective single-step technique with good results and requires no additional energy inputs. Yet, some more investigation is needed to make it a viable and cost-efficient sorting method for mixed plastic solid waste.

7.2 Artificial intelligence (AI) in sorting solid plastic waste

Nowadays, a new method, AI is introduced in the sorting of plastic waste. In most cases, AI uses labeled data through a machine learning model in the identification of plastic. The facts are then processed through a machine learning algorithm. Recent research indicates that AI is capable of providing a faster and enhanced manner to improve plastic recycling.

Employing AI in sorting plastic waste has the potential to massively upgrade the current sorting processes. For instance, the Near Infrared (NIR) technique is not able to recognize black plastic. However, the use of AI can easily bring a remedy to this problem as it can be programmed to identify black plastic. In addition, the AI can be trained to sort plastic concerning its color or shape which will eventually help in segregating different types of plastic more efficiently thus generating a better-quality plastic product. The advantages of AI do not stop here. The AI can be integrated into the conventional sorting methods which would allow the system to segregate the plastic classes before they are shredded. It would minimize the workload of the system and at the same time cut the overall costs. This would enhance the efficiency of the system in terms of both process and cost.

Method	Limitation	Integration of AI with traditional separation
Floatation	Density overlap	AI could identify different types of plastic with similar densities
FT-NIR	Black materials are undetectable	AI could easily read black material
X-ray fluorescence	costly	AI would reduce load on X-ray and hence makes it cost effective
Trio-electric separation	Inconsistent charging	Not applicable
Melt filtration	Pressure fluctuation problems	AI could remove high melting point objects prior to melt filtration

Figure 14. Effect of AI integration in conventional waste sorting methods (Quinn, 2016)

8 DISCUSSION

There are different ways of controlling plastic pollution and various ways also have been innovated relative to time. Before it came into human consciousness, we managed to dump the plastics in an environment with an uncontrollable amount. However, the most challenges faced are due to micro or nano plastics that are blending in environmentally with unfriendly nature. The decision of the recycling process hasn't been decisive due to variant parameters from sorting mechanically to using the chemical catalyst for the recyclates to develop it as functional equipment (Tenhunen & Pöhler, 2020).

The given recommendations below might help in reuse, recycle plastics. Average household waste consists of 2/3 parts of plastic and is often made out of different layers of different plastics which maximize the difficulties with recycling. A researcher at the Valtion Teknillinen Tutkimuslaitos (VTT) Technical Research Centre of Finland, Satu Pasanen argues that simplifying consumer plastics is crucial to optimize the recycling. In order to simplify the plastic types into a single type, it requires a world-wide cooperation which itself is big challenge. Despite this, UK's Ellen MacArthur Foundation is investing in the research in this field (YLE Uutiset, 2017).

Recently, sorting and separation of plastic waste are carried on a manual or automated basis with high error margins like the use of harmful additives which currently can't be traced with current automated technology like optical sensor systems.

This brings a potential to create a database and unique marking system in the plastics with information like additives or other applications information that can be utilized for reprocessing. We could utilize the power of Artificial Intelligence in developing the solution for the science of sorting and separation with lean manufacturing and help in a closed-loop recycling system. Advanced sensors and detectors are innovated and with the advancement in the tech industry, it could be possible to design complex software to recognition of plastic types.

9 CONCLUSION

The first and foremost process to control plastic waste is sorting and separation. The plastic types are defined by polymer type and their molecular weight. The plastic waste mixed during recycling degrades the quality of recyclates. Thus, plastic-type separation beforehand is of utmost importance to create the valued recyclates for the most cyclic ways to boost circular economy and sustainable solution. Lately, Finland is doing great progress in the overall recycling of plastic and only a minimum of 5% is going to landfilling.

Now the question may arise, how do we proceed with AI in sorting and separating plastic waste with the help of sensors and detectors?

Plastics can be identified from physical properties, spectroscopy, or visual inspection. Sensors and cameras so far have been playing a role, in general, to integrate plastic properties and defining them. Using Artificial Intelligence, we could in the future get matured with enough database where we send output to robots to segregate the plastic as its types. However, jumping into polymers these solutions might not be very effective due to its limitations. Most of the current research are theoretical and the progress is just limited to laboratory-scale. Therefore, in order to optimize the whole process and approach towards sustainability, more research and studies need to be conducted to implement the research done so far to reality.

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