Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Research on the Use and Recyclability of Flexible Plastic Packaging

Master's Final Degree Project

Miglė Balčiūnaitė

Project author

Assoc. Prof. Jolanta Baskutienė

Supervisor

Kaunas, 2021

Kaunas University of Technology

Faculty of Mechanical Engineering and Design

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Industrial Engineering and Management (6211EX018)

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Faculty of Mechanical Engineering and Design

Task of the Master's final degree project

Given to the student – Miglė Balčiūnaitė

1. Title of the project

Research on the Use and Recyclability of Flexible Plastic Packaging

(In English)

Lanksčių plastikinių pakuočių naudojimo ir perdirbimo galimybių tyrimas

(In Lithuanian)

2. Aim and tasks of the project

Aim: To investigate flexible packaging, its current recycling methods in European Union countries and evaluate possible ways to increase its recyclability in Lithuania.

Tasks:

1. To analyze advantages and disadvantages of flexible plastic packaging.
2. To analyze current flexible plastic packaging collection and recycling methods in various European Union countries.
3. To develop a questionnaire on possible flexible packaging collection methods in Lithuania.
4. To design a possible flexible packaging collection system in Lithuania.
5. To compare achieved results, propose and develop solutions.

3. Initial data of the project

N/A

4. Main requirements and conditions

Investigation of no less than 5 countries experience in single and multi-layer flexible plastic packaging use, analyze main barriers they face to meet goals stated in Directive 94/62/EC on packaging and packaging waste. Packaging must meet Regulation (EC) No 1935/2004, Regulation (EC) No 1907/2006, Solvent Emissions Directive (99/13/EC). Select Statistical Limited population proportionality range calculation method will be used to indicate required number of respondents.

1

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Supervisor	Jolanta Baskutienė		
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Balčiūnaitė, Miglė. Research on the Use and Recyclability of Flexible Plastic Packaging. Master's Final Degree Project, supervisor Assoc. Prof. Jolanta Baskutienė; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study field and area (study field group): Production and Manufacturing Engineering (E10), Engineering Sciences (E).

Keywords: Flexible plastic packaging, environmental, collection schemes.

Kaunas, 2021. 58.

Summary

Plastic packaging waste has been an important issue in the recent years as plastic is used as packaging material in many industries and in types of forms. In order to reach circular economy goals, member states still have to implement various measures in order to lower plastic packaging impact on the environment. The main aim of the final project was to investigate flexible packaging, its collection and recycling rates in European Union countries and to evaluate possible ways to increase its recyclability in Lithuania. To achieve this aim, advantages and disadvantages of flexible plastic packaging were analyzed. Later, collection system and recycling rates in 6 European Union countries, including Lithuania, were investigated. Questionnaire was developed in order to investigate citizens recycling behavior and to understand if separate collection system for flexible plastic packaging is needed. Survey results have showed the need of information about importance of correct packaging waste collection as well as improvements in collection system itself. After the evaluation of the results, improvement in waste collection system was suggested, with indications on required implementations. Finally, alternatives to increase recycling rates were provided.

Balčiūnaitė, Miglė. Lanksčių plastikinių pakuočių naudojimo ir perdirbimo galimybių tyrimas. Magistro baigiamasis projektas, vadovė doc. dr. Jolanta Baskutienė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E).

Reikšminiai žodžiai: lanksčios plastikinės pakuotės, aplinkosauga, rūšiavimo sistemos.

Kaunas, 2021. 58 p.

Santrauka

Pastaraisiais metais viena iš aktualiausių problem buvo plastikinių pakuočių atliekos, kadangi jos yra plačiai naudojamos įvairiomis formomis, įvairiose pramonės šakose. Siekiant įgyvendinti žiedinės ekonomikos tikslus, šalys vis dar turi įgyvendinti įvairias užduotis, siekiant sumažinti plastikinių pakuočių poveikį aplinkai. Pagrindinis baigiamojo projekto tikslas buvo ištirti lanksčių plastikinių pakuočių surinkimo ir perdirbimo rodiklius Europos Sąjungos šalyse ir įvertinti galimus būdus, kaip padidinti jų perdirbimą Lietuvoje. Šiam tikslui pasiekti, pirmiausia, buvo išanalizuoti lanksčios plastikinės pakuotės privalumai ir trūkumai. Vėliau buvo išanalizuotos surinkimo sistemos ir perdirbimo rodikliai šešiose Europos Sąjungos šalyse, įskaitant ir Lietuvą. Siekiant ištirti vartotojų požiūrį į pakuočių rūšiavimą ir perdirbamumą Lietuvoje, bei suprasti ar atskira plastikinių pakuočių surinkimo sistema yra reikalinga, buvo sukurtas klausimynas. Apklausos rezultatai parodė, jog Lietuvoje yra juntamas informacijos apie tinkamą pakuotės rūšiavimą ir perdirbimą trūkumas, taip pat, apklausos dalyviai įvardino surinkimo sistemos tobulinimo poreikį. Įvertinus rezultatus ir apžvelgus literatūros šaltinius buvo pasiūlyta patobulinta atliekų surinkimo sistema. Galiausiai buvo pateiktos papildomos rekomendacijos, plastiko pakuočių perdibimo didinimui.

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Introduction

Over the last years one of the biggest priorities in European Union is a transition towards a circular economy in order to improve materials recycling with lower amounts of resources needed and thus extending materials lifetime. The aim of the circular economy is to increase the recovery of packaging and packaging waste, with recycling rates of 85% for paper, 55% for plastic, 60% for aluminum, 80% for metal and 75% for glass by 2030. To be able to reach such rates, it is important not only to invest in recovery plants, but to improve waste collection systems, which would allow for recyclable materials to be sent to the appropriate recovery facilities and to avoid disposal in landfills. European Union countries, in recent years, have invested in national waste management systems, including implementation of various collection systems, sorting, material recovery and infrastructure, in order to achieve circular economy goals. However, with implementation of different collection schemes not only between countries, but between municipalities as well, separate, and mixed waste rates vary, and it shows, that improvement of waste management systems still remains one of the European Union priorities.

The biggest challenge for the member states is to reach plastic packaging recycling goals. Due to its easy production and low cost, plastic is often chosen for product packaging not only by the the manufacturers, but by the consumers also. Plastic packaging demand is increasing annually, however most of the plastic packaging is designed for a single use or have a short life. Flexible plastic packaging is often considered as non-recyclable material and, as a result, it is being disposed to the landfill or recovered as energy. However, in many countries, flexible plastic packaging is disposed in mixed waste stream, where it gets contaminated and it makes it impossible to separate different materials. When disposed incorrectly, flexible plastic packaging causes negative impact on the environment. Waste collection and recycling is closely linked to the consumption patterns, citizens lifestyle, employment and income levels, as well as many other social, economic and cultural factors. With implementation or improvement of waste collection system it is important to consider each factor closely in order to reach sought results.

The aim of master thesis is to investigate flexible packaging, its current recycling methods in European Union countries and evaluate possible ways to increase its recyclability in Lithuania.

In order to achieve the aim, these tasks have to be completed:

1. To analyze advantages and disadvantages of flexible plastic packaging.
2. To analyze current flexible plastic packaging collection and recycling methods in various European Union countries.
3. To develop a questionnaire on possible flexible packaging collection methods in Lithuania.
4. To design a possible flexible packaging collection system in Lithuania.
5. To compare achieved results, propose and develop solutions.

1. Analysis of the Literature and the Current Situation

1.1. Generation, Management, and Resource Efficiency of Plastic Packaging Waste

Plastic products are particalarly important for many industrial processes and are used for a variety of industrial applications. In modern society, plastic is considered as a cheap disposable single-use material, with very low recycling. Half of all plastic waste in Europe is landfilled. Some plastic products can contain harmful substances, which can lead to unwanted emissions and the accumulation of polluting residues when disposed in landfills. In Europe, the most commonly used plastics are HDPE, LDPE and PP and the most common plastic application is packaging, which accounts for about 40% of the total plastic distribution [1].

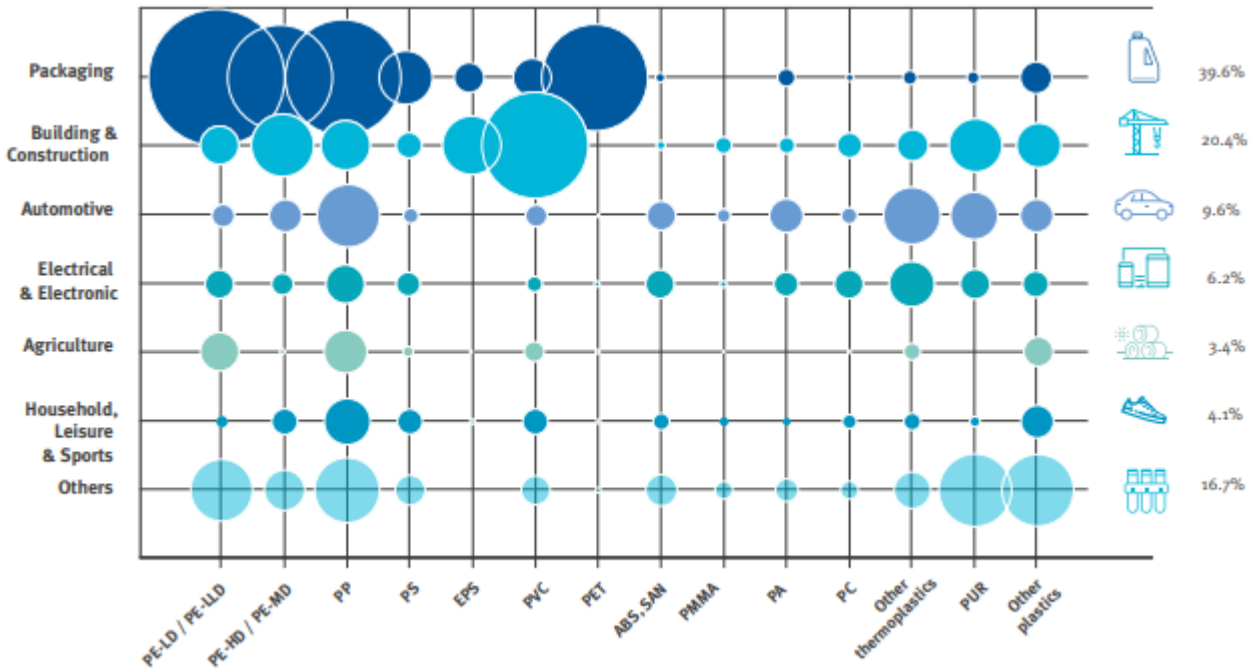

Fig. 1. Plastic distribution in European Union [1]

Resource efficiency requires a sustainable plastic production model and a sustainable plastic waste management plan, especially when talking about recycling. Plastics are produced from petroleum and currently account for about 8% of the worlds' petroleum production, of which 5% is used as a raw material and 3% as the energy for production processes [2].

One of the most important tasks is to reduce the disposal of plastic packaging waste in landfills. Plastic products disposed of in landfills are untapped resources, so this type of waste disposal should be avoided. Recycling of plastics can contribute to climate change and the reduction of water ecotoxicity. Landfilling of plastic packaging affects the environment and wastes local government and household budgets, its negative effect causes unwanted economical and environmental consequences for local authorities and it encourages the search for new waste management systems and recycling technologies. The economic costs of disposing plastic packaging waste are very high, but they can be reduced by optimizing collection systems, recycling technologies, or encouraging packaging reuse [2].

Waste manegement and waste disposal have a negative impact on the environment, and it uses additional resources. Landfills cover land, pollute air, water, and soil. Waste incineration emits

hazardous air pollutants. The goals of the European Unions' waste management legislation are to reduce the negative impact of waste on the environment and health, and to ensure that countries use resources as efficiently as possible. The waste management legislation stipulates that in cases where waste cannot be avoided, the use of waste as a resource should be encouraged, and more waste should be allocated for recycling [2].

In 2019 Lithuania accumulated about 1.3 million tons of municipal waste, of which 23.5% were landfilled, 14.7% were incinerated with energy recovery, 27.5% were recycled, 22.2% were composted, and lastly, 12.1% were temporary stored. Plastic packaging waste accounted for an average of 13% of all municipal waste. These results show that there is a need for collection improvement and citizens education, as in some cities, plastic packaging waste accounted for 26% of all municipal waste [3].

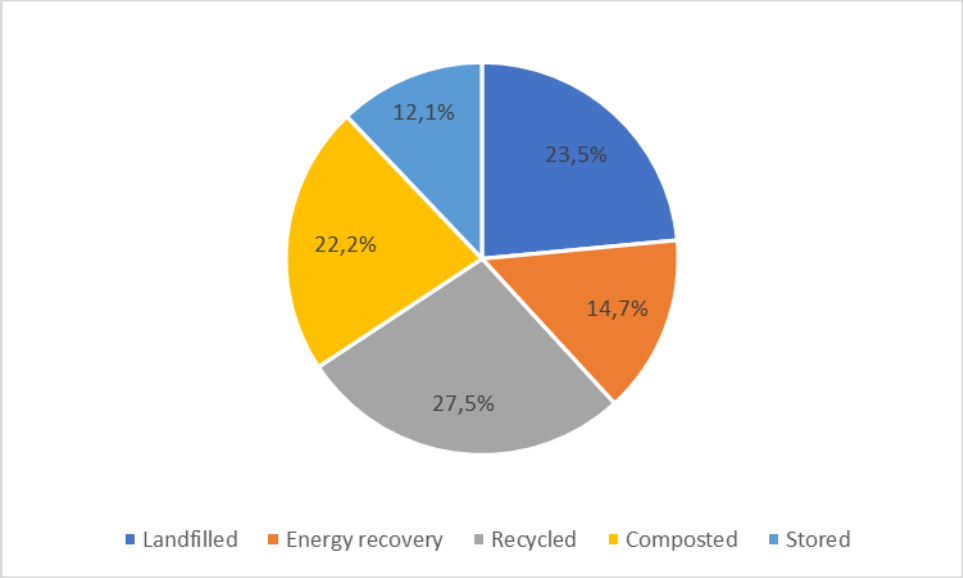

Fig. 2. Methods of municipal waste recycling in Lithuania in 2019 [3]

1.2. Implementation of Circular Economy Measures and Tasks

Plastic packaging waste would pose a much lower risk to the environment if current waste legislation were properly implemented. The European Commission has adopted a circular economy package that aims to use all-natural resources as sparingly as possible, as most of them are dwindling. Therefore, circular economy policy seeks to preserve the value of the products and materials for as long as possible, and to reuse obsolete or damaged products for production of new raw materials. Such a model promotes implementation of innovation, creates new job opportunities, and protects environment and human health [4].

Circular economy package aims:

- To reduce municipal waste disposed of in landfills at least by 10% by 2035.
- To recycle at least 65% of municipal waste by 2035.
- To recycle at least 70% of packaging waste by 2030.
- To prohibit some types of single use plastic on market by July 2021.
- To harmonize and simplify legislation on by-products and waste disposal.

– To establish conditions for extended producer responsibility and to add all of the costs associated with a product throughout the product life cycle [4].

Table 1. Packaging waste recycling targets [5]

	Target	**Year**
All packaging waste prepared for re-use or recycled	65%	2025
Plastic packaging waste prepared for re-use or recycled	50%	2025
All packaging waste prepared for re-use or recycled	70%	2030
Plastic packaging waste prepared for re-use or recycled	55%	2030

Plastic packaging must meet the requirements of the product and consumers, while minimizing the impact on the environment. Throughout the product life cycle, the entire supply chain contributes to the recource efficiency. Packaging must be designed in a comprehensive way, optimizing the negative impact on the environement. It must be made from the responsibly extracted raw materials and develop safe and efficient product lifecycle. Packaging must meet legal requirements of the market and be efficiently recycled or recovered when disposed [5].

1.3. Regulation of Plastic Packaging Waste

Although the impact of plastic waste on the environment is growing, the only Packaging Directive (94/62/EC) sets a specific target for the recycling of plastic packaging. The Waste Framework Directive (2008/98/EC) states that the key point in waste policies should be to minimize the negative effects of the waste management on the environment and on human health. The Waste Framework Directive is also important in some other aspects, such as the wider producer responsibility, which is one of the most important principles of waste management. In addition, it establishes a waste hierarchy that prioritises waste prevention, reuse, and recycling over recovery for energy and disposal [2]. To implement this requirement, Member States must prohibit uncontrolled disposal, draw up waste management plans and set up an integrated and appropriate installations for waste disposal.

1.3.1. Legal Requirements for Packaging and Pakaging Waste Management

European Parliament and Council Directive 2004/12/EC amending Directive 94/62/EC on packaging and packaging waste is the main European Union legislation governing the management of packaging and packaging waste in member countries. The legislation aims to harmonize national legal documents in order to prevent the environmental impact of packaging waste and to ensure its internal functioning. Directive regulates development of pakaging return, collection, recycling, and incineration for energy labeling and identification systems [6].

1.3.2. Packaging and Packaging Waste Directive

The purpose of the Directive is to reduce the amount of packaging waste and the negative impact on the environment and human health. It applies to the packaging manufactured in Lithuania and imported into the country including packaging with product, as well as to the packaging waste. Directive provides:

- General requirements for accounting, labelling, collection and use of packaging and packaging waste.
- Rights and obligations of producers, importers, manufacturers, sellers, consumers, product users and waste managers.
- Packaging and packaging waste management priorities, which must be followed by all economic operators.
- Identifies the possibility to establish organizations.
- Establishes the main requirements for production of packaging.
- Requirements for implementation of deposit system. [4].

1.4. Future Requirements for Plastic Packaging Recycling

The European Commission sets a target for 2025 to reduce pollution related to the plastics industry and to increase the recycling and reuse of plastic waste in the European Union member states. European Commission requirements apply to all stages of the plastic industry, from the processing of the raw material into a product, to the sorting and recycling plastic waste into secondary raw materials. Comon requirements and targets for the plastics industry have been defined and set by the three largest European plastics associations pursuing a sustainable economy strategy. It is the plastics industry that has many issues related to pollution, secondary raw materials, recycling and sorting. They can either deepen global ecological problems or help to solve them. Considerable attention is also paid to waste sorting, collection from landfills and prevention so that the plastic waste does not end up there. Finally, European Commission promote plastics producers to innovate throughout the value chain of the plastics industry, in all its technological processes [3].

1.4.1. Waste as a Resource

Recycling of secondary materials is much easier, cheaper, and less polluting. The higher the amount of secondary materials used, the more saving can be made in natural resources. Environmental requirements are set out in European Union directives and regulations, they determine the general waste management policy and individual waste streams. Recycling of secondary materials accumulates secondary raw materials, saves natural resources and energy, and reduces waste management costs. Waste also has an indirect effect on the environment. Unprocessed or not neutralized materials results in losses of various materials in the chain, during the production, transport, and consumption [4].

1.5. Flexible Packaging

Flexible plastic packaging is used to describe singlelayer or multilayer packaging that is produced out of flexible materials and can be easily formed into preferred shape. Its main use is to protect and distribute food products, beverages, pharmaceutical, beauty and other products. This wide range of use results in flexible packaging representing 40% of the total plastic production in European Union and its growth is estimated to increase from 5 to 7% each year [7].

Flexible packaging is preferred due to its light weight, thin structure, and relatively low costs. It uses less energy and recourses, helps to increase products shelf life, and reduce food waste [7]. However, in order to reach that, there are several mechanical, physical, and biological requirements, that a package must meet [8].

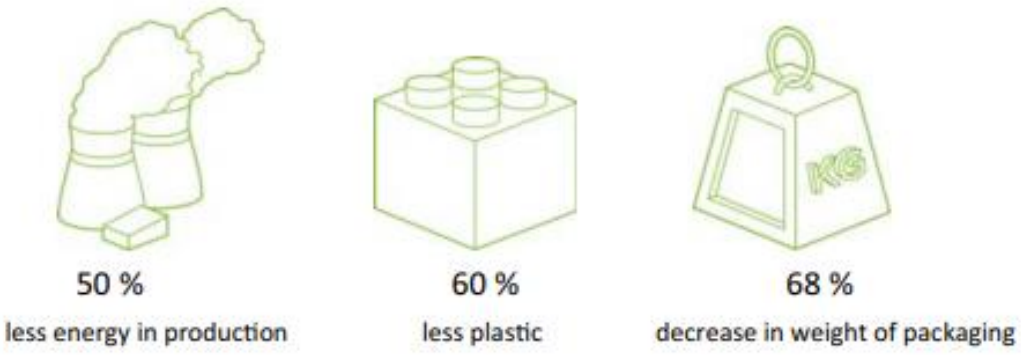

Fig. 3. Flexible plastic packaging material consumption, compared to rigid plastic packaging [9]

1.5.1. Mechanical Requirements

Packaging must be resistant to puncture in order to protect a product from sharp objects as well as, for packaging not to be damaged by the packed product itself. Package also can not be damaged when product is dropped. Packaging resistance to puncture is determined by the structure and the elasticity of the material. Better mechanical properties can be reached using more rigid materials laminated together with more flexible materials [10].

1.5.2. Physical Requirements

Different food products need different conditions to maintain their quality through their shelf-life. Meat, dairy products need protection from UV-radiation as they can have negative impact on their quality. Oxygen can increase products' oxidation processes, while water vapour can impact products texture. These conditions can be reached when the right polymer or their combination is used in flexible packaging [11]. In order to protect food from water vapour, hydrophobic polymer, like PE can be chosen. Oxygen gases penetrate in large amounts through nonpolar plastics, that is why high-density polymers, like HDPE are a good barrier [12]. However, to reach the highest protection, flexible laminates from different polymers should be used. Aluminium layer can provide great barrier to all of the above-mentioned conditions, which is why it is the most popular choice in laminate packaging. Selection of layers can be used to protect products from gas, however, they often have various disadvantages, like the lack of protection from water vapour [13]. Furthermore, sealing quality must be evaluated, when choosing the right packaging. To be able to reach the best sealing quality, it is recommended to use PE and PP materials [8].

1.5.3. Biological Requirements

Besides causing products oxidation, oxygen can also stimulate the growth of aerobic microorganisms. To avoid this growth, packaging in modified atmosphere is used, this process can be high in carbon dioxide and low in oxygen or only low in oxygen. For this packaging technique, flexible laminated films with gas barrier are used. Another process to protect food from microorganism's growth is sterilization, which secures product from oxygen and moisture as well. Flexible laminates can be used during this process, however, only few polymers are suitable [8].

1.6. Types and Forms of Flexible Plastic Packaging

Single-layer flexible plastic film is produced with one-layer film and it can be made from one or several polymer blends. It is commonly used in various types of bags and as a primary packaging for products, for which monolayer packaging properties are enough to protect the product from moisture or gas transfer [8].

Multilayer flexible packaging consists different thickness and polymer layers [14]. Films can be produced during coextrusion or lamination processes from two up to twenty different polymer layers with their thickness reaching up to 10 μm. Additionally, multilayer flexible packaging can have various adhesive layers with a thickness varying from 1 to 3 μm, inks and metals [15]. Variety of materials used ensures the best protection properties to the product [16]. HDPE layer has high tensile strength and overall is stiffer and can be combined with LLDPE layer, which provides higher tear strength. Combination of both films results in mechanically strong packaging and allows to produce thinner films. PE films are often combined with polyamide or EVOH polymers in order to achieve high gas barrier. Polypropylene is often used in packaging, that requires resistance to heat, moisture barrier and high mechanical strength [8]. It is mainly used for food products to extend their shelf-life and reduce food waste. Flexible films are widely used due to their decorative properties and possibility to achieve various forms of packaging [17].

Metalized flexible films – to achieve better barrier from oxygen and moisture, plastic films are laminated to the layer of metal, in most cases aluminium. It not only provides great protection but improves appearance of the packaging. It is commonly used in food, pharmaceutical and electronic industry [8].

One of the advantages of flexible plastic packaging is its possibility to be used in many different forms.

- Bags are used for shopping, garbage, and medical waste disposal, frozen or fresh products, agriculture products, etc. They are mostly produced of PP, LDPE, or HDPE materials. They are single-layer flexible packaging, resistant to water. Due to their simple structure, they are inexpensive to produce, and due to their lightweight, bags are easy to transport [8]. However, once used, they often end up in landfills or disposed to incineration. They are one of the reasons of the environment and marine pollution [18].
- Shrink wraps – used to wrap around one of several products to optimize shipping ant palletizing processes. Shrink wrap is produced from LDPE film, that is heat-activated [8].
- Stretch Film – it is commonly used to wrap around and secure products during their transportation and is produced from LLDPE. Cast stretch film excels great transperancy and does not make unpleasant noises when being used. During transportation, product, wrapped with cast stretch film, is more secure due to film two-sided cling. Compared to blown stretch film, it has lower cost, however, it does not have great tear resistance. Blown stretch film is excellent when sharp edged products must be shipped, due to its higher strength. The main disadvantages of this type of film are its price and noise which it causes during wrapping. Lastly, the main drawback of both stretch films is that it can only be recycled in a special process and can not be disposed in the curbside recycling bins [8].
- Bubble wrap – it is used as an additional support and protection for products during transportation. This type of packaging is produced from LDPE and contains multiple various size air pockets. For packaging to be recycled, it must be flattened. When air is removed from

the bubbles, it can be disposed together with other types of stretch films, however it can not be disposed in the curbside recycling bins [8].

- Twist wrap – It is used to wrap small items, like candies, various bars, bottles and candles. Packaging is mostly produced from PP film and must be stiff enough not to crumple or shrink during packaging process, but it should also be flexible enough not to tear at the twisted ends [19].
- Pouches and sachets – these types of packages are used very widely – from food products and beverages to various household and beauty items. They are produced from multiple polymers like PET, BOPP, PE and laminated with other materials like aluminium. Even though, pouches and sachets have many advantages, they are not recycled and have low economic value. As they often are used once, they leak into landfills or oceans easily and cause big environmental issues [20].
- Labels and sleeves are used for marketing and informational purposes on packages. They are mostly produced from PP, OPP, PET-G, LDPE, and PVC. It is important to use label of the same material as the package that it is applied on, because that way, label will be recycled together with the packaging material. If materials differ, it is important to remove label or sleeve before packaging disposal in order to avoid material contaminantion in the recycling stream [21].
- Printed films – it has a wide application range, from construction to food industries, this means, that inks should be suitable for different polymers and provide great printability through low and high printing speeds [22]. The most popular printing technology for flexible packaging is flexography and it can be used for every form of packaging described above and can provide very efficient printing process. However, printed flexible packaging is the source of contamination, reduces significantly quality of recyclates and limits its reuse potential [23].

1.7. Advantages of Flexible Plastic Packaging

Flexible plastic packaging is used for many applications and in various formats – from labels, shopping bags to flexible beverage containers or pouches for cosmetic products. Its wide use is based on its advantages in providing product protection against contamination and UV light, preserving nutritional value and extenting shelf life. Light weight and thin structure benefit in lower energy consumption during production and lower owerall product cost [24]. Flexbile plastic films are preffered options for packaging manufacturers and for producers as it excels great technical properties as strenght, ease of extrusion into sheets, transparency and also, one of the advantages its low production and transportation costs. Films are resistant from punctures and have a good sealability [25]. Flexible packaging films are vital for the economy as it provides food products maximum protection and shelf live at minimum packaging weights and costs. Different plastic types have specific functions in terms of strenght, stiffness, barriers and sealing ability. When different polymer films are laminated, manufacturers are able to provide the best packaging film for producers' product and its equipment [10].

6. Transportation

Flexible plastic, used as primary, secondary, or tertiary packaging helps to protect product from mechanical or environmental damage. Because of its light weight and low volume, this type of packaging reduces transportation costs by minimizing required space for the product [10].

7. Marketing

One of the packaging adtvantages is its transparancy, which can be used for product visualization. Correctly chosen packaging material can also be used for design and communication. It is also important for providing information about brand, product type and all relevant information about the product inside the packaging. Packaging, used as a communication tool can help decide a customer to choose a product [11].

8. Protection

Flexible plastic packaging used for food products, provides great protection for food products, especialy, when laminated with different polymers, moreover, films can have good barrier from moisture, air, odors, UV light and gasses [25]. Food protection results in reduction of food waste, which lowers its negative environmental impact. Different food products have different effect on the environment, thus the packaging should be selected for specific food groups [26]. Product shelf life can be increased by choosing correct packaging material and therefore, food waste can be decreased in supermarkets. However, it may not reduce food waste at households, because food consumption highly depends on human behaviour [27].

9. Material reduction

The introduction of flexible packaging drastically reduced the amount of used packagning material per product unit. It reduced not only costs, but environmental impact between 3 to 8 times [10].

1.8. Disadvantages of Flexible Plastic Packaging

In order to achieve set targets for plastic packaging recycling, focus should be on the improvement of flexible packaging collection. In addition to that, sorting and recycling technologies for various plastic materials should be developed to achieve high quality recycled product, because at the moment, most of the materials are considered as not recyclable in most countries. Regarding multi-material flexible packaging, there is no solution to separate different types of polymer layers, which also results in increased costs of packaging waste hangling and contamination of PE recyclates. Even though flexible packaging made out of PE is widely recycled, current PE recyclate is of low quality and not suitable for most of its applications [28]. Table 1 indicates main flexible film groups and challenges faced through collection, sorting, recycling and recyclated end markets [29].

Table 2. Main flexible plastic packaging groups and their recyclability [29]

Process step	**Material**			
	PE	PP	Other polymers	Multi-layer
Collecting	Included in many packaging EPR collection schemes, though not in all countries or regions.	Collected with other films.	Collected with other films.	Collected with other films.
Sorting	Sorted together into clear and colored PE film stream, small films often lost in mixed plastic or waste streams.	Sometimes sorted into PP streams, but mostly sorted into mixed plastic streams, rejected or inspected as a contaminant.	Due to low quantites not sorted into separate streams, but sorted into mixed plastic streams, rejected or inspected as a contaminant.	Recycled packaging has no value in the market, as a result, sorted into mixed plastic streams, rejected or inspected as a contaminant.
Recycling	Possible recycling into lower quality product due to contamination.	Can be reprocessed into mixed polyolefins.	No excisting recycling process.	No excisting process for layer separation.
End market	Can be used for lower quality products.	Can be used in lower quality MPO products.	Energy recovery or fuel.	Energy recovery or fuel.

Since the implementation of Circular Ecomony Action Plan, several strategies to improve collection, recycling, design, consuption and remanufacturing have been developed, however, there are still challenges with separating different polymer and, especially, separating aluminum from composite packaging [30].

1. Multi-material packaging

Even though multi-material packaging takes a small part in overall flexible packaging waste, it has big impact on recyclate quality. Multilayer flexible packaging can not be recycled into a valuable material as different type of polymer needs different treatment. What is more, it is imposible to send multilayer materials through the same waste flow as single layer packaging, because it is considered to be a contaminant to other materials. Due to technical liminations, its lightweight nature and the lack of economical value, multimaterial and other uncommon material packaging are usually disposed. Additives of polyaminds or EVOH in multi-material flexible packaging can result in unrequired coloring of PET material and change in mechanical, chemical, or physical properties. Multilayer flexible packaging is one of the most challenging packaging categories when talking about achieving circular economy [31].
Flexible packaging, that contains aluminium layer, is considered not only as a contaminant for recycled material, but this type of packaging can cause process issues, such as blockages in melt-filters. However, filter blockage can be caused by films, that have polymers layers with high melting temperature, such as PA and PET. Furthermore, aluminium layer in flexible packaging can cause material loss during metal detection process, as laminate will be rejected from the line before extruders and melt filters [10].

2. Contamination

Presence of food remains degrades the quality of recyclates. Mix of different types of waste in the stream can have negative impact to the quality of recyclates as well as, it can be the cause of inaccurate sorting, as organic, agriculture or different packaging material residues can have an impact on the optical beams. [31] Organic and chemical residues can cause unwanted odour and color of the recyclate. Addition of labels, adhesives or pigments can influence the strenght and quality of recycled material, interfere sorting and recycling and increase the cost of the process. [29]

3. Inks

With optical sorting technology, it is possible to sort several plastics, as long as packaging surface can be reached by the rays. However, dark colors on flexible packaging, absorb rays and materials can not be identified and sorted. The only alternative is to replace carbon black by NIR technology complient detectable black dye [31].

4. Economical value

Landfilling or incineration of flexible packaging is the cheapest method for waste treatment, that is why it is still one of the most popular methods in various European Union countries. However, strict measures regarding landfilling have been proposed by EU legislation, as a result, member states divert waste to incineration with or without energy recovery. Due to different properties of flexible packaging, their waste treatment cots are higher, compared to other material end-of-life treatment. Additionally, costs generated by collecting and recycling packaging materials makes price of the recyclates higher, compared to the price of virgin material. This motivates industry and government to achieve better collection rates and invest in recycling chain to increase the supply of good quality recyclates. As a result, it would help to reduce the price gap or even have it reversed so that the recycled resin price would be lower. However, different studies show, that industry would be willing to pay for high quality recyclates the same price as for a virgin material [31].

2. Collection of Flexible Plastic Packaging in European Union Countries

In different European Union countries different waste collection systems are applied, systems can vary also at regional or municipal levels. It all depends on municipalities, district authorities or EPR schemes implemented [32]. Table 3 shows an overview of the implemented collection systems in different European Union countries by fraction.

Table 3. Collection systems in European Union member states [32]

Collection type	Glass	Paper	Plastic	Metal
Door-to-door	BG, FI, LU, LT, LV, SI, MT	AT, BE, BG, CY, DE, DK, FI, HU, IT, LU, LT, LV, NL, SI	AT, LV, NL, DK	FI, DK
Co-mingled (plastic+metal)			BE, BG, CY, DE, FR, IT, HU, LU, LT, SI	
Co-mingled (paper+plastic+metal)		RO, MT		
Co-mingled (all in one bin)	EL, IE			
Bring-points	AT, BE, DK, CY, CZ, DE, EE, ES, FR, HR, IT, HU, LT, NL, PT, PL, RO, SE, SK	CZ, EE, ES, FR, HR, LT, PT, PL, SE, SK	SE	AT, EE, SE
Bring-points (plastic+metal)			ES, HR, LT, PT, PL	
Civic amenity sites				CZ, LV, NL, SK

In door-to-door collection system bags or bins are collected from the households at the set time. Co-mingled collection is similar to door-to-door collection, however, various types of waste fractions are collected together in one container. Bring-points are used for different types of waste disposal at public places, and lastly, civic amenity sites are used for various waste, as well as hazardous waste, to be brought by citizens from their households. The most popular collection system for packaging waste is co-mingled. Collected waste are then separated in sorting facilities. Countries, that have separate collection system for plastic packaging, collection rates reach 40%, when in countries, where plastic packaging is co-mingled, average collection rate for plastic packaging is around 14% [32].

Implementation of pay-as-you-throw (PAYT) schemes have been noticed to significantly increase collection of different fraction packaging waste. This system is based on waste charge for households according to the amount of waste they generate. Various schemes can be implemented, based on the volume, weight or number of sacks used. It is most often used for mixed residual waste and its purpose is to encourage citizens to separate recyclable materials, like paper, plastic, and metal. Charges based on the residual waste, tends to cover the price for separate waste collection. Even though, there are variation of applied fees for waste collection in different countries, it can be noticed, that collection rates are higher in the countries, that apply PAYT schemes [32].

Implementation of various collection systems reduces waste environmental impact in terms of global warming, eutrophication, photochemical oxidation, and acidification. Various studies have shown that in countries where separate collection systems are implemented, citizens are more aware of

packaging waste impact, importance of recycling and are overall more satisfied with the systems [33]. Further, various collection systems applied in 6 European Union countries are analyzed.

2.1. Collection in Netherlands

In 2009 separate collection system for post-consumer plastic packaging waste was established and companies, responsible for collection, sorting and recycling were contracted by the Dutch organization of extended producer responsibility. It allowed to collect all packaging, that contained product inside before, and was disposed without said products. Other packaging was excluded from this system. From 2015 municipalities received fixed fee for sorted product and became responsible for post-consumer plastic packaging waste recovery, with previously mentioned company monitoring the process. Because of the circular economy policy and the responsibility for the recycling chain, expansion of collected materials was necessary. In 2017 municipalities had expanded collected packaging waste, part of them collected plastic and metal packaging, as well as cartons from beverages, while others chose to not include metal packaging in their collection schemes [34]. However, with expanded collected packaging portfolio risk of contamination and product residues increased.

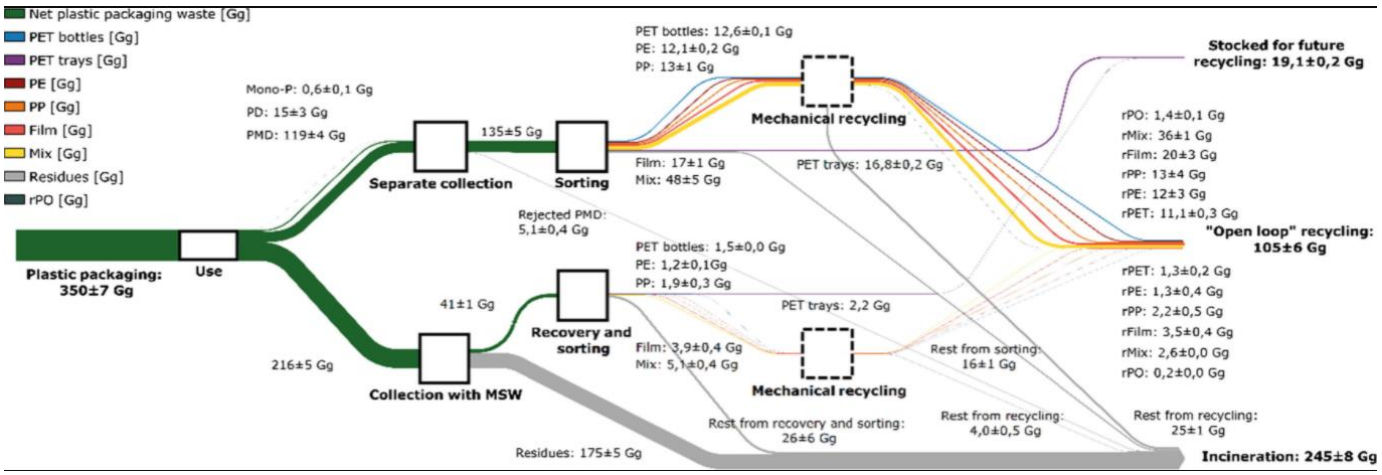

Fig. 4. Plastic packaging waste management system in Netherlands [34]

Brouwer, M., et. al., in their research have compared collection system in 2017 with mono-collection system in 2014 to understand impact of the packaging waste portfolio expansion. Recycling rates have not changed with the improvement of the collection system and was reported as 50% in both years, which was a result of a reduction of recycled packaging [35]. Even though in 2017 post-consumer plastic packaging collection rate was higher and quantity of recycled material increased by 37%, the quality of recyclates remained low. High purity was observed only with the recycled PET material, other recycled materials were insufficient to be used in production of packages or any closed loop application. Recycling yield increased because of the expansion of collected materials, however this resulted in higher product contamination and increase in rejected packaging volume during sorting process [36].

In the project, performed by the Collectors it was observed, that the implementation of separate collection system for different types of waste helped to lower the waste fee from 60% to 32%. Incineration revenue decreased from 13% to 3% and extender producer's responsibility fee increased from 26% to 53%, which resulted in lowered costs for citizens. Benefits of separate collection system

was noticed in lower residual waste, which quantities decreased by 65%. This resulted in lower costs for residual waste collection and processing. Lastly, improved system increased plastic packaging waste collection by 24% [37].

Thoden van Velzen, et.al. have performed an exploratory study of the collection behavior in Dutch municipalities to determine possibility to have wider portfolio of collected lightweight packaging waste. For mixed municipal solid waste, they have PAYT system which is based on the annual fees for each household, which depends on registered waste weights. For lightweight packaging waste, they have separate curbside collection system. Households collect plastic, metal packaging and beverage cartons together in bags for small-rise buildings. High-rise buildings have drop-off parks for both, municipal solid waste, and lightweight packaging waste, which are operated by an identification cards and registers disposed waste weight. For this study, researchers have collected waste from the 21 households as well as, waste from drop-off stations to determine its composition. Analysis showed that collection yields for desired plastic packaging from individual households was between 57% and 99%. Analyzed waste from drop-off station resulted in 73% of desired plastic packaging collected with lightweight packaging. Additionally, it was observed that some types of plastic packaging were collected by all households. This could lead to the hypothesis, that some type of packaging could be collected separately. However, analysis have not showed if different collection system would increase collected waste [34].

Expansion of collected materials portfolio have not increased total collected plastic packaging waste rate, as seen in the Figure 5, in 2017 amount of collected waste have even decreased, compared to collected waste in 2006, however separate collection system was only introduced in 2017 and it is possible to assume that results in 2018 could be better. Even though collection rates have not showed positive results, plastic packaging recycling rates have increased by 8.9%, which is a result of less other packaging contaminants in disposed material.

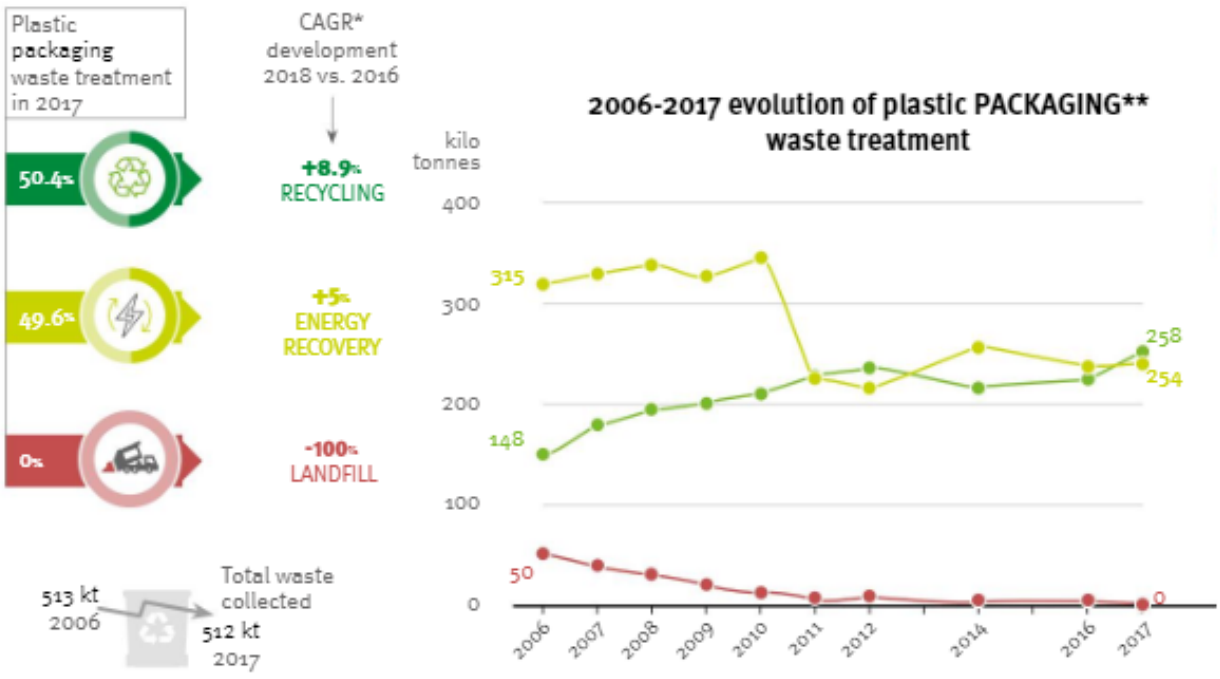

Fig. 5. Plastic packaging waste treatment in Netherlands [8]

2.2. Collection in Germany

In Germany there are officially established collection systems: collection for mixed residual waste, deposit system for bottles made from PET and Dual System for collecting plastic, paper, metal packaging and non-packaging waste. Flexible plastic packaging is collected through Dual System to be transported together with other materials to the sorting facilities. Figure 6 shows packaging life cycle [38].

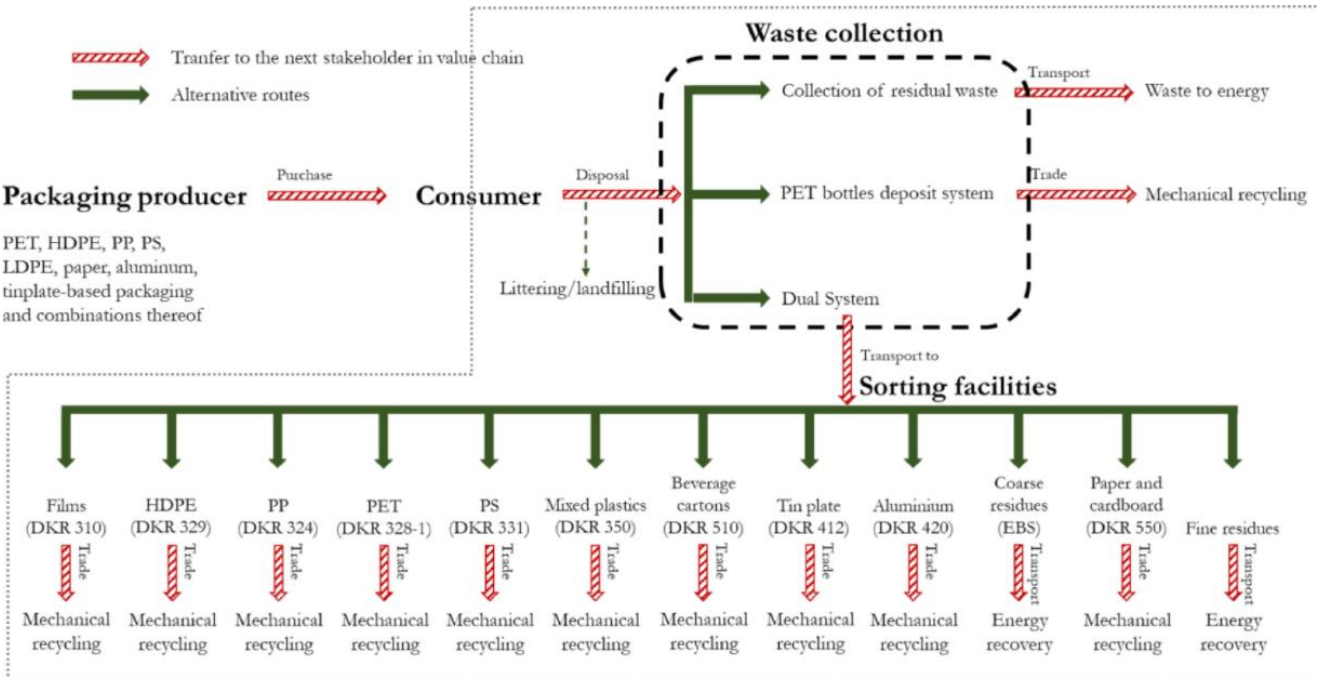

Fig. 6. Plastic packaging life cycle in Germany [38]

Since 1991 German packaging manufacturers and distributors are fully responsible for their generated waste and must finance operations related to packaging recovery and recycling [39]. This led industry to develop Dual System to collect all packaging from the households in parallel to the collection system for residual waste. System connected all packaging industry to take responsibility to provide collection of packaging waste and fulfill taxes related to recovery of produced packaging. Applied fees for product weight and used material encouraged manufacturers to implement more environmentally friendly designs and rewards if company seeks innovation during product development [40]. Since the implementation of Dual System and investment in various educational campaigns, Germany was able to significantly increase plastic packaging collection and recycling rates.

Azevedo, B., et. al., in their research have analyzed waste collection system in one of the cities in Germany. Collection was separated into two different service types. Door-to-door system was described as an active collection, and system where citizens were taking their waste to central collection centers, was described as passive collection. However, waste must be separated and stored in households for both systems [41].

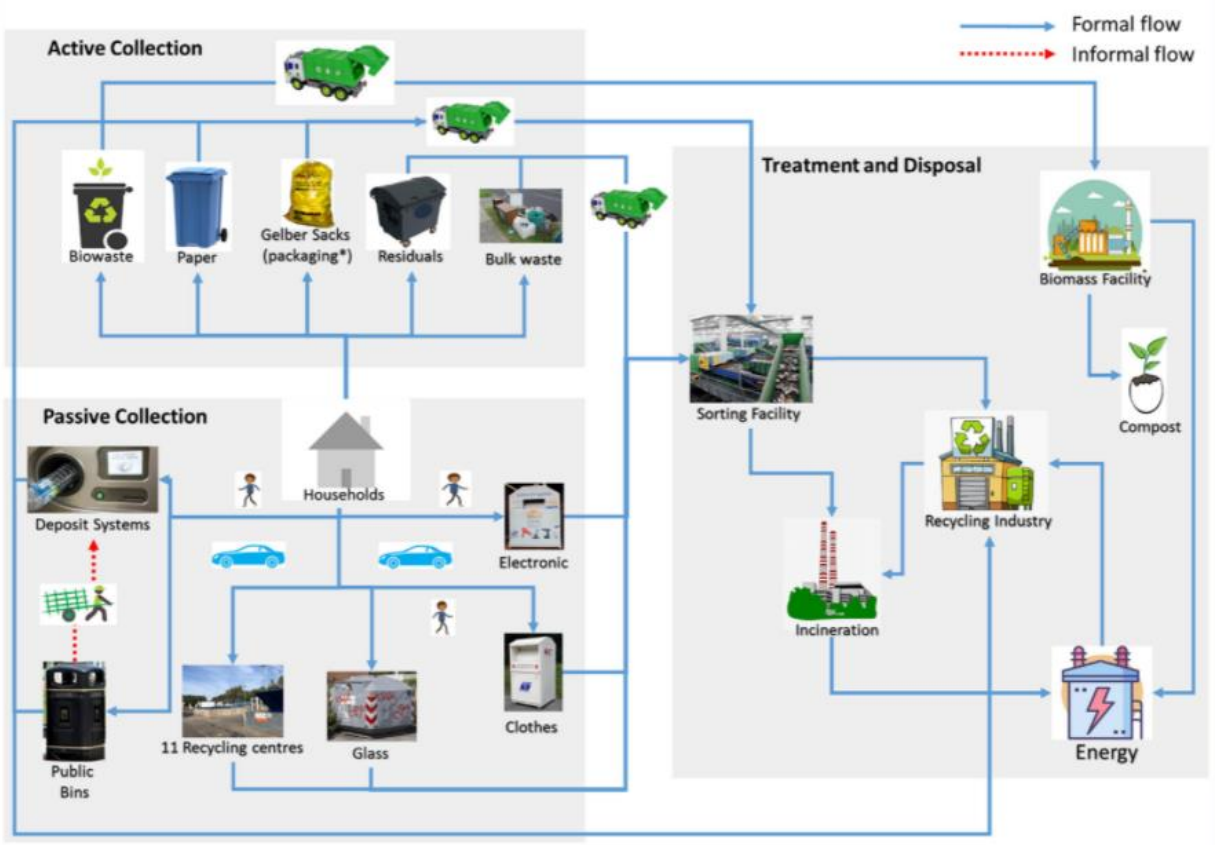

Fig. 7. Waste collection systems in Germany [41]

For active collection, companies provide different colored containers near homes for different type of waste. For passive collection, responsible company throughout the city provides collection banks, recycling centers and containers for various types of waste. Furthermore, stores have installed deposit systems for bottles and cans [41].

Together with the industry payments, households must comply with usage and performance fees according to PAYT system [42]. Each household have set annual fee, additional fees depend on the size of used waste bins and the frequency of collection. If household would like to have waste collected every weak instead of the two weeks, annual fee can double [43].

Implementation of separate collection, PAYT and Dual systems, have significantly increased plastic packaging collection rates. It can be seen in Figure 8, that the total waste collection from 2006 until 2018 have increased by 47%. Plastic packaging recycling increased by 2%, which is a result of separate waste collection systems and less contamination in collected plastic packaging waste.

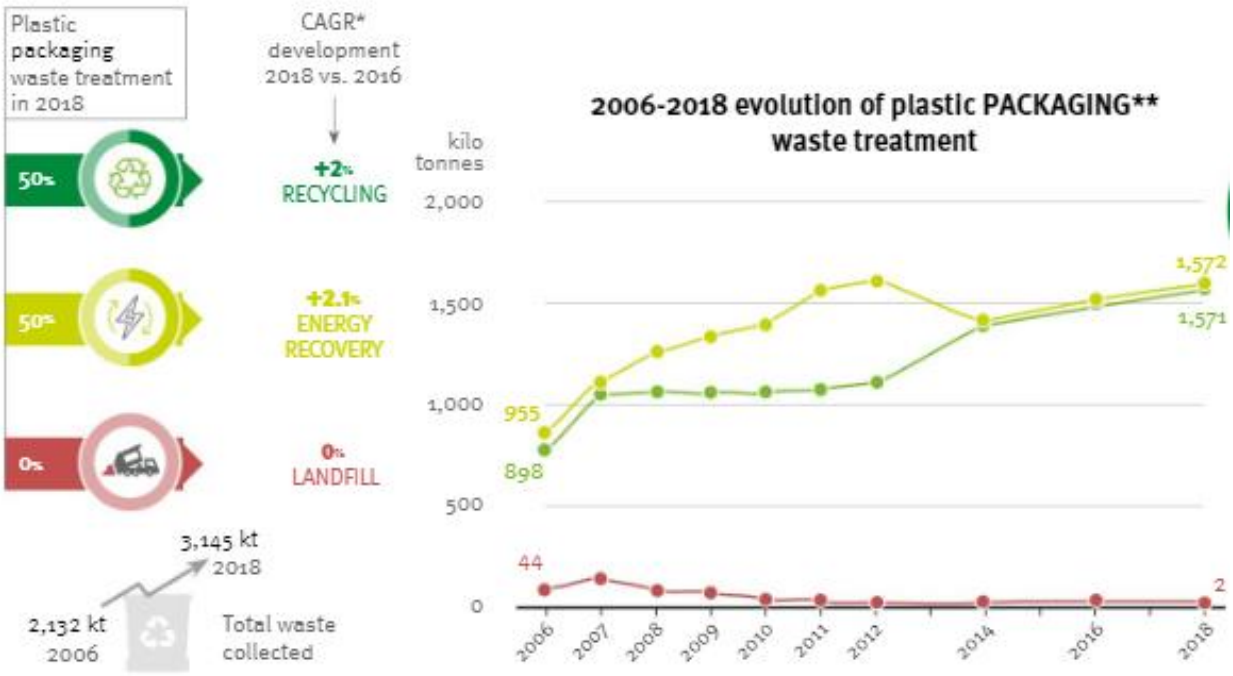

Fig. 8. Plastic packaging waste treatment in Germany [8]

2.3. Collection in Italy

In 1997, when first regulation of waste management was adopted in Italy, collection rate was 9.4%, around 10% of waste was incinerated and 80% of municipal solid waste was landfilled. In 2017, when collection have shifted to separate, this resulted in increased collection rate by 15.5% and only 25% of waste was landfilled [43]. Italy was able to achieve these results by implementing door-to-door collection [44]. This adapted collection system not only increased collection rate, but also increased material recovery and minimized environmental impact. Door-to-door collection separated waste streams, which allowed to collect higher quality packaging waste. In this collection system, every household use bins or plastic bags that are placed in front of the house.

Calabro, P., et.al. in their research have analyzed the implementation of door-to-door collection system in Reggio, town in Italy. Citizens were able to separately dispose organic, mixed, plastic and metal packaging and glass waste. Before 2017 separate collection reached only 10%, at the beginning of the implementation of the door-to-door system it has increased to 40%. In addition to that, higher collection efficiency was a result of the application of the national regulations and higher landfill fees for municipalities with low separate collection rates. With the experience and expansion of door-to-door system, Reggio town was able to reach 55% of the separate collection efficiency in 2018 [45].

Laurieri, M., et.al. in their research have investigated implementation of door-to-door collection system in Altamura town in Italy to understand citizens' behavior when managing different waste. Before 2018 for waste collection town was using community bins in the fixed points, near the streets, where residents would bring their garbage. Even though community bins were designed for separate waste collection, implementation of door-to-door system increased collected separate waste from 25% to 70% [46].

Fig. 9. Separate waste collection rate in Italy [46]

An on-line survey showed that with improved collection system, citizens would like to receive more educational programs and information campaigns to motivate them to separate waste correctly and reduce its environmental impact. Additionally, survey results showed the high amounts of usage of plastic packaging in the households with their recommendation to evaluate the possibility to install separate plastic packaging collection system for the main plastic materials [47].

Implementation of separate Door-to-door collection system in Italy, total collected waste has increased by 6% from 2006 until 2018. It has decreased landfilled plastic packaging waste by 2.4% and increased recycled packaging rate by 7%.

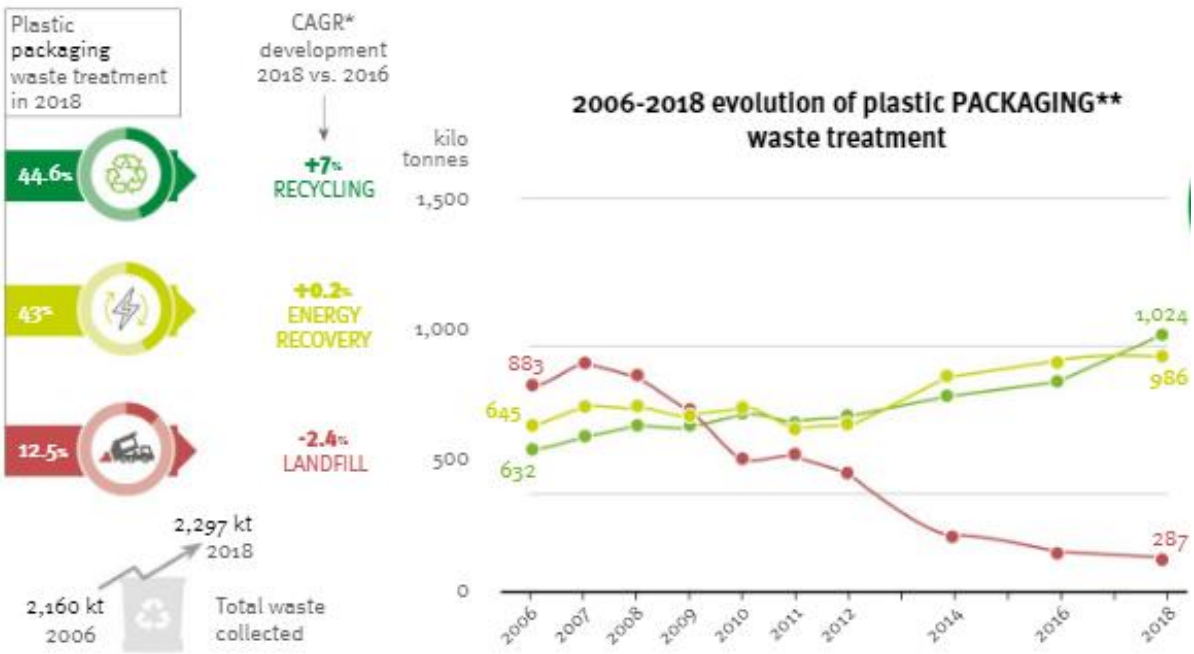

Fig. 10. Plastic packaging waste treatment in Italy [8]

2.4. Collection in Spain

In Spain there are three ways to collect packaging. The first being selective collection from municipalities using specialized containers for paper/cardboard, plastic and metal, and glass, which goes to the transfer plants. Separate collection is organized by the authorized managers and waste is transported directly to the sorting plants. And lastly, bulk collection, where waste goes to the transfer plants first [48].

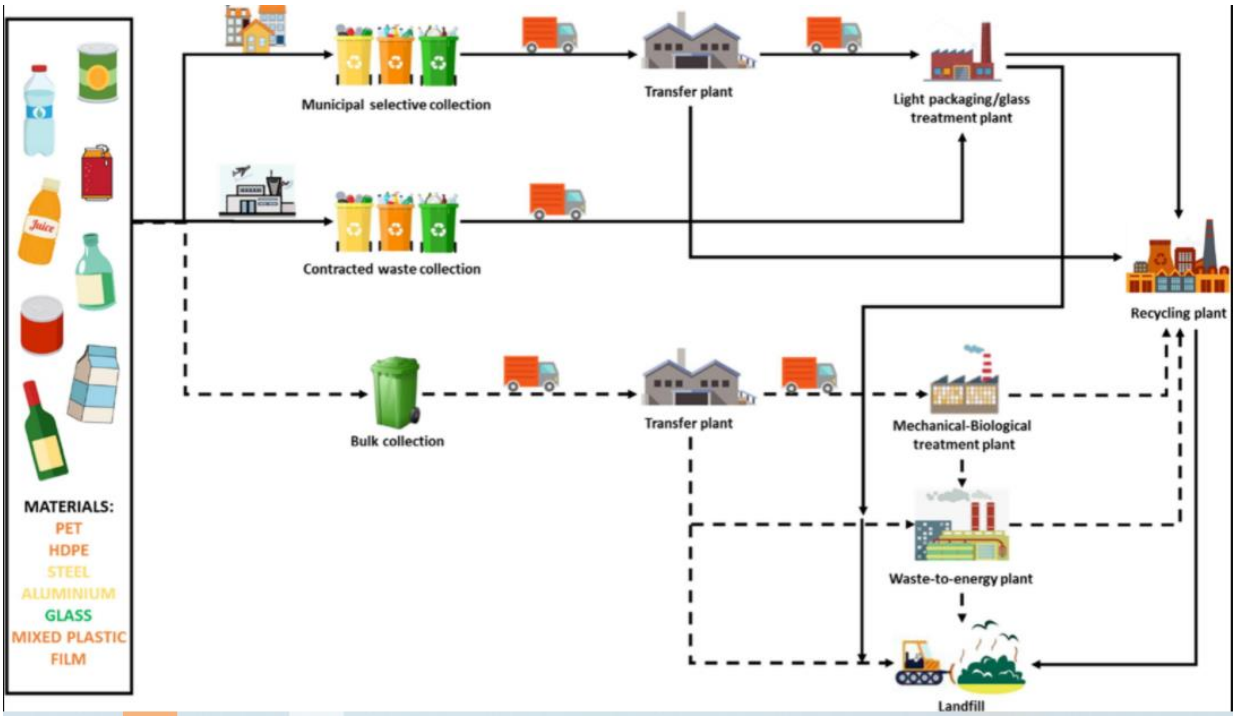

Fig. 11. Waste collection schemes in Spain [48]

In Spain in 2016 38.2% of plastic packaging waste was landfilled [8]. In order to reach targets, set by European Union and national regulations, it was necessary to design efficient collection methods. Spanish regulations included obligatory separate waste collection for towns with more than 5000 inhabitants [48].

Gallardo, A., et.al. have analyzed various collection systems available in Spain to identify the amounts of waste collected through each system. Eight different collection systems were described [49]. Table 4 shows the portfolio of the systems in Spain and composition of lightweight packaging found.

Table 4. Collection system portfolio in Spain [49]

System	Number of towns using	Collected plastic, %
Four fraction collection. Curbside bins for mixed waste. Drop-off points for paper/cardboard, glass, and packaging.	52	50.83
Four fraction collection. Curbside bins for mixed waste and lightweight packaging. Drop-off points for paper/cardboard, and glass.	21	49.14
Four fraction collection. Curbside bins for mixed and organic waste. Drop-off points for paper/cardboard, and glass.	7	-
Five fraction collection. Curbside bins for mixed and organic waste. Drop-off points for paper/cardboard, glass, and lightweight packaging.	16	56.19
Five fraction collection. Curbside bins for mixed waste. Drop-off points for paper/cardboard, glass, and lightweight packaging. Door-to-door collection for organic waste.	2	56.34
Four fraction collection. Curbside bins for mixed and organic waste. Drop-off points for multiproduct (paper/cardboard and plastic), and glass.	2	37.08
Four fraction collection. Door-to-door collection for mixed, organic waste, and multiproduct (paper/cardboard and plastic). Drop-off points for glass.	2	37.08
Five fraction collection. Mixed, organic waste, paper/cardboard, glass, and lightweight packaging are collected at the curbside.	1	56.19

From the collected information, it can be seen, that first collection system is the most widely implemented system in Spain. However, if compared found plastic packaging part in collected waste, the most efficient systems are the ones, that have wider collected materials portfolio. The lowest amount of plastic was observed in the systems, where multiple products were collected. From analyzing this report, it could be stated, that with wider range of collected materials it is possible to achieve higher collection rates for each type of packaging [49].

Figure 12 indicates that implementation of different waste collection systems in Spain have only slightly increased (by 0.6%) total collected waste, however it has increased by 10% collected plastic packaging waste recycling, as separate collection systems ensured higher quality and lower contamination in packaging waste. Furthermore, implemented collection systems have reduced landfilled plastic packaging by 2%. These results indicate that efficient collection systems have positive effect on environmental and it helps to reach plastic waste targets set by the European Union.

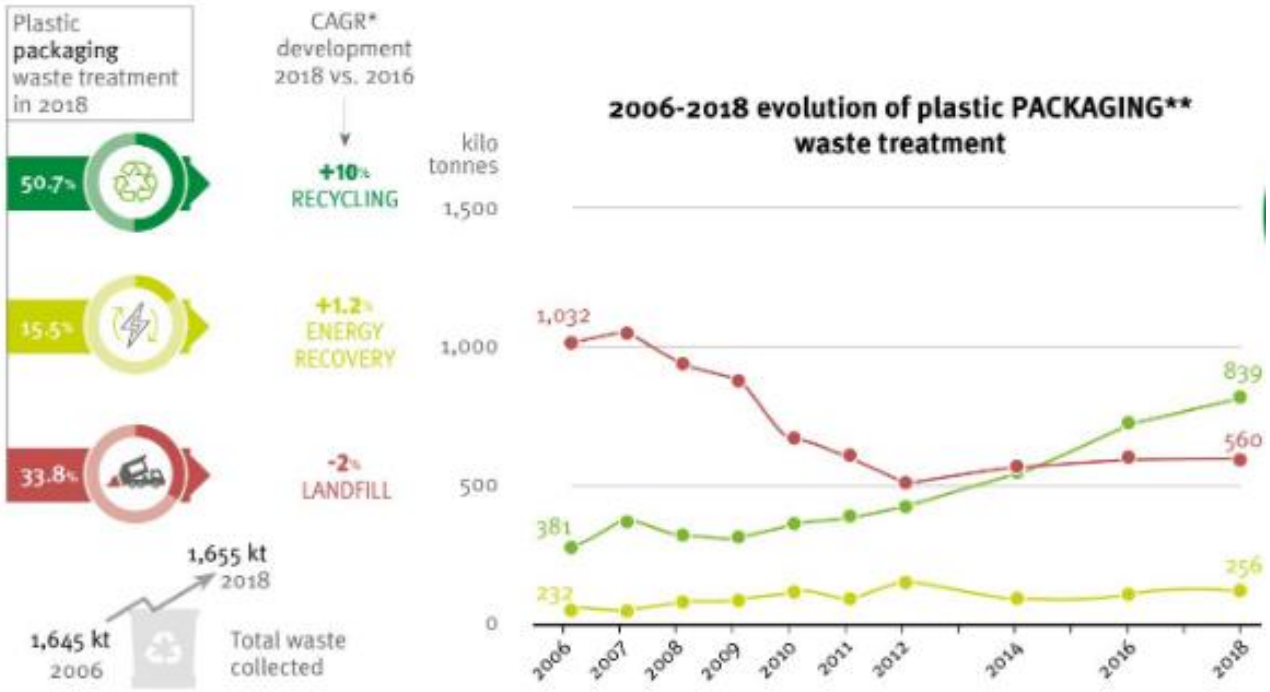

Fig. 12. Plastic packaging waste treatment in Spain [8]

2.5. Collection in Sweden

Over the years, Sweden have achieved effective waste management system as only 1% of household waste is landfilled. In Sweden waste collection and recycling are covered by the producer's responsibility [50]. However, municipalities are responsible of informing households about collection systems and supervising them [51].

In Sweden, as well as in all the Nordic region, plastic packaging waste collection is based on three principals. First is curbside collection in multi-compartment bins, in separate bags and containers and in colored bags. Second collection option is bring-system, and the last is curbside collection for mixed waste. In Sweden near apartment buildings, the most common collection is separate container or underground container system, that is shared among several households for plastic packaging waste. Citizens collect plastic waste in clear plastic bags and dispose them in containers. In some municipalities, they are using colored bags for easier source sorting. Plastic packaging waste has dedicated one color plastic bag, that is disposed in the same container with other waste. Up to six different plastic packaging fractions can be collected [51].

Drop-off points are one of the most widespread collection systems, however, here plastic packaging waste is collected with other packaging materials. This system can be used by both, single family homes and people living in apartment buildings [51]

Sweden is concentrating on providing simple and convenient sorting and collection, they are focusing on providing information about collection importance, which allowed to increase recycling rates in some of the cities to 70% [52]. Takahashi in his research also emphasizes importance of consumer-friendly system. He states that implementation of multiple compartment bins improved curbside collection system, increased recycling rate for separated materials [49]. In majority of municipalities volume-based pricing is used, where residents can choose whether to have longer or shorter collection

intervals, whether to share bins with other residents or not and what size of container to use. All these options impact on final price. Small percentage of municipalities have weight-based pricing, which may not be an attractive solution for residents, however, this fee system increases recycling rates [50].

Takahasi in his study compared single compartment and multi compartment cart impact on collection rate. Results showed, that sorting rate increased from 55% to 67%. Packaging waste collection increased from 28% to 44%, while other mixed waste decreased by 12% [52].

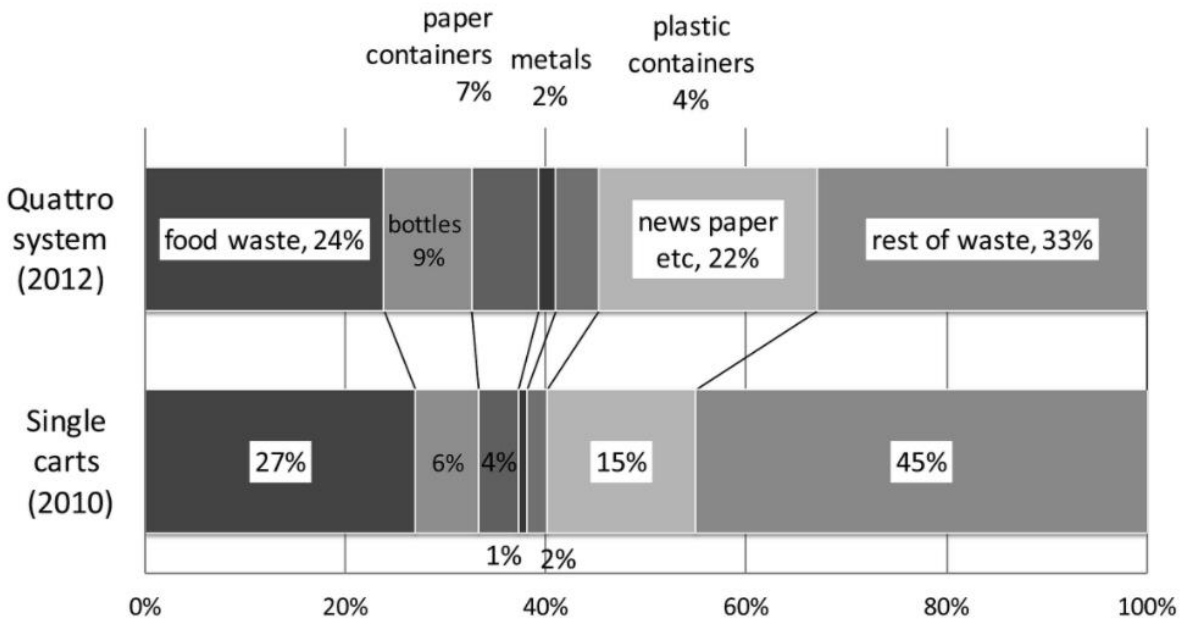

Fig. 13. Waste collection system comparison in Sweden [52]

Hage and others in their study have find out, that more impact on plastic packaging collection have policy variables, for instance, implementation of weight-based collection system. In addition to that, increase of curbside collection in municipalities have also showed positive outcome in collection rates. However, it is important for municipalities to weight collection fees before implementing any collection system [50].

2.6. Collection in Lithuania

The main documents that promote waste re-use, prevention and recovery in Lithuania are the Law on Waste Management of the Republic of Lithuania and the National Strategic Waste Management Plan. These legal acts set up requirement for separate collection of municipal, hazardous and non-hazardous waste. Waste management plans and rules are developed, approved, and implemented at the municipal level [3].

Table 5. Collection schemes in Lithuania by waste fraction [3]

Collection type	**Paper**	**Glass**	**Plastic**	**Metal**	**Bio-waste**
Door-to-door collection	For individual households	For individual households	For individual households	Very rare	Very rare
Co-mingled door-to-door collection			For individual households		
Bring points	For apartment buildings	For apartment buildings	For apartment buildings (co-mingled)		
Civic amenities	Additional collection for all streams on top of other waste types				
Bring back	Scheme for cardboard drink packages	Scheme for glass bottles	Scheme for plastic bottles	Scheme for metal tins	

Collection of residual waste is charged by the system based on a fixed and a variable fee, according to pay-as-you-throw schemes, based on waste volume. However, collection and management of recyclables is free of charge and is partly financed by EPR schemes. For collection of plastic and glass bottles and metal tins, deposit refund scheme is implemented since 2016. With all implemented waste collection systems, landfilled waste rate has decreased significantly, and recycled waste rates proportionally increased [3].

Table 6. Formed waste and its treatment in Lithuania 2015-2019 [3]

Year	**Waste formed, t**	**Treatment**				
		Landfilled, %	Energy recovery, %	Recycled, %	Composted, %	Remaining untreated waste, %
2015	1299998	51.01	11.53	22.99	10.18	1.29
2016	1272061	29.82	17.36	24.55	23.48	4.80
2017	1286434	32.70	18.32	24.16	23.94	0.86
2018	1300527	24.62	12.52	24.25	28.33	10.26
2019	1318626	23.28	14,75	27.51	22.19	12.08

Table 7 shows investigation of municipal waste fractions in 2020. It can be seen, that even though, various separate collection schemes are implemented, from total collected municipal waste, only 50.2% of them are municipal biodegradable waste. Other almost 50% are unwanted waste fractions, that should be disposed in separate waste streams, the highest amount, almost 13% is plastic and plastic packaging waste. These rates show the need of improvement of waste collection systems [3].

Table 7. Investigation of munipical waste composition in Lithuania 2020 [3]

Different waste fractions in municipal waste	**Average, %**
Paper and paper packaging waste	6.22
Green waste	4.66
Wood and wood packaging waste	0.94
Biodegradable food waste	15.40
Textile waste	7.73
Other municipal biodegradable waste	15.25
Plastic and plastic packaging waste	12.96
PET packaging waste	0.74
Combined packaging waste	1.30
Metal and metal packaging waste	1.96
Glass and glass packaging waste	4.63
Inert waste	8.26
Other non-hazardous waste	8.70
Electrical and electronic equipment waste	0.39
Batteries and accumulators waste	0.01
Other hazardous waste	0.25
Other municipal waste	10.62
All municipal biodegradable waste	50.20
The total amount of investigated mixed municipal waste	100

Table 8 shows generated plastic packaging waste in analyzed European Union countries and its treatment in 2018 (available data from Netherlands is from 2017) [52]. Even though Lithuania has the highest recycling rates regarding plastic packaging, the high rate is mostly because of implemented deposit system for plastic bottles, problem with flexible plastic packaging remains as it is seen from Table 7, almost 13% of plastic packaging waste still ends up in general waste containers. It indicates the need of improved collection systems and waste treatment methods, as well as citizens education.

Table 8. Generated plastic packaging waste and its treatment rates [52]

Country	**Wate generated, t**	**Treatment**		
		Energy recovery, %	Recycling, %	Other, %
Germany	3235800	52.8	47.1	0.1
Spain	1655189	15.4	50.7	33.9
Sweden	245934	1.2	50.1	48.7
Italy	2292000	43.1	43.8	13.1
Netherlands	512000 (2017)	45.6	50.4	4.0
Lithuania	75857	2.8	69.3	27.9

It is imposible to determine, which collection system is the most efficient, as there are a lot of variables, that it depends on. However, it can be stated, that countries, that have implemented separate collection systems, have reached higher collection rates for all fractions of waste. With implementation of door-to-door collection it was noticed that the highest recycling rates were reached and recyclates were high quality. In order to have lower collection costs and still achieve high collection and recycling rates, countries implement two fraction co-mingled collection [32].

3. Plastic Packaging Waste Recycling Methods

There is still a lack of technologies for plastic packaging recycling. Even though it has been over 20 years since the implementation of Packaging and Packaging Waste Directive, European Union is still facing plastic packaging waste issue. However, not only lack of technology can be described as an issue, but recycled material quality as well. Currently, most of the plastic waste is being downcycled, which means, that recycled materials quality becomes lower, compared to the virgin material. Additionally, implementation of recycled material into virgin material can decrease products original properties drastically. What is more, risk of transfer of hazardous components increases. Lastly, use of recycled material in production of new products increase is financially unprofitable [53]. Figure 14 shows waste treatment technologies. Different recycling technologies, and risks are reviewed bellow.

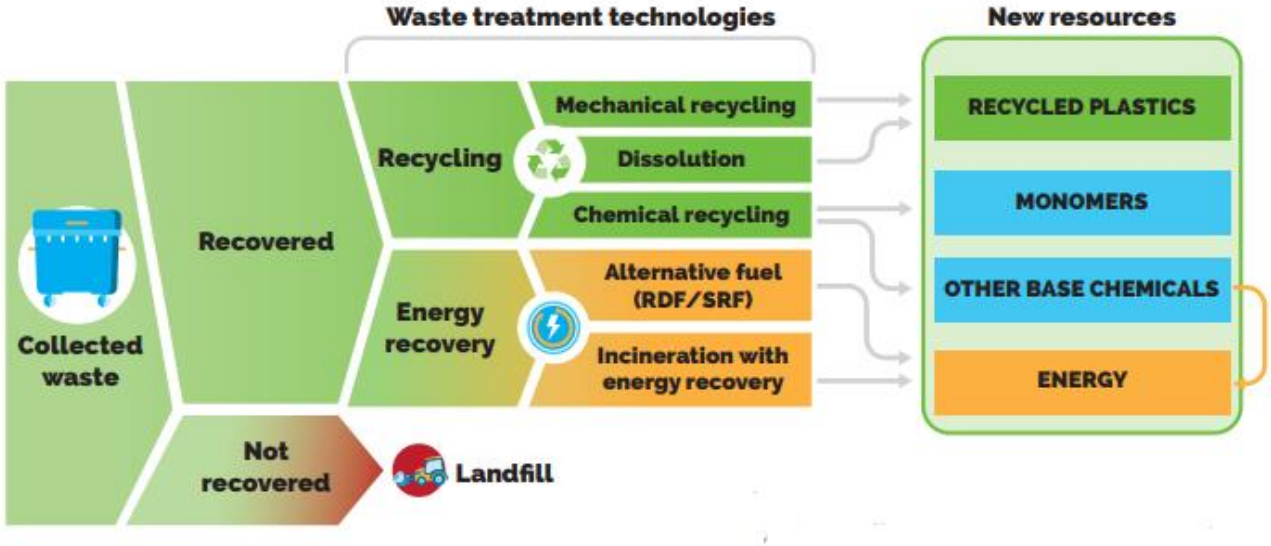

Fig. 14. Waste treatment methods [54]

The main types of plastic recycling:

1. Mechanical recycling, which results in original quality product (closed loop).
2. Mechanical recycling, which results in downgraded product with lower quality (open loop).
3. Chemical recycling, which results in original quality product as it breaks product into monomers.
4. Recycling, during which product is burned and the end product is energy [55].

3.1. Mechanical Recycling

Mechanical recycling process consists of waste sorting, washing, grinding into flakes or granules and extrusion. Flexible plastic packaging is being processed dry. Mechanical recycling can be closed or opened loop and the end product of the process is raw material, that can be used in various applications, depending on its quality and parameters [55]. Open loop recycling provides wider application and more possible recycling cycles [56].

There are different waste sorting techniques:

1. Electrostatic separation – based on polymers different electric field deflection [56]. Received plastic waste is washed to eliminate organic contamination and then dried at 25 ºC temperature for 24 hours. After that, plastic waste goes through milling process, where they are shredded into flakes and transported to separator, where they are separated by particle size in order to reduce electric field needed. Separated flakes are then washed and dried at 60 ºC temperature for 2 hours, in this process particles charges are neutralized. Lastly, particles go through tribo-electrostatic separator, where positively, negatively, or neutrally charged polymer particles collide and are separated from particles, that have different electric field [57].

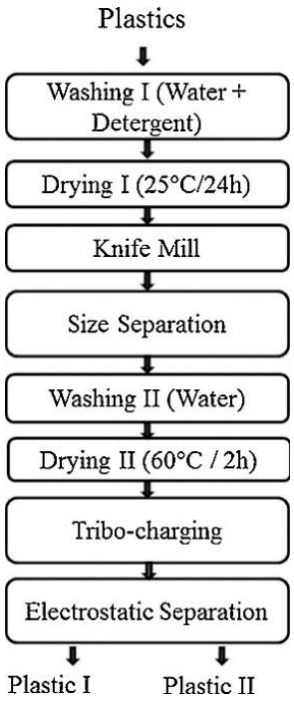

Fig. 15. Process of electrostatic separation [57]

2. Froth flotation – process based on polymer density. Before separation, polymers are mixed with water to avoid contamination, then cell is filled with water, impeller starts, air bubbles are formed, and polymer particles are placed into the cell. After that, froth agent and depressor are introduced. This way different density particles are collected and dried [58].
3. Magnetic separation – process uses magnetic liquid with added iron dioxide and gravity. It changes density of liquid and allows separation of different polymers [59].

3.2. Mechanical Recycling Challenges

During melting process, because of high temperatures and mechanical processes, thermal-mechanical degradation is formed. During this process, during covalent C-C bond hemolytic decomposition, free radicals are formed. Such radicals can be a cause of the decomposition of the chain if affected by chemical reactions. This results in material with lower mechanical, rheological, physical, thermal properties, and changes in its molecular weight [59]. However, addition of heat stabilizers or modifiers during waste recycling can compensate material properties loss. Figure 16 shows decrease of polymer molecular weight, increase of polydispersity, which is caused by degradation. As molecular weight decreases, melt flow index (polymer mass, flowing through a capillary in 10 minutes) increases [58].

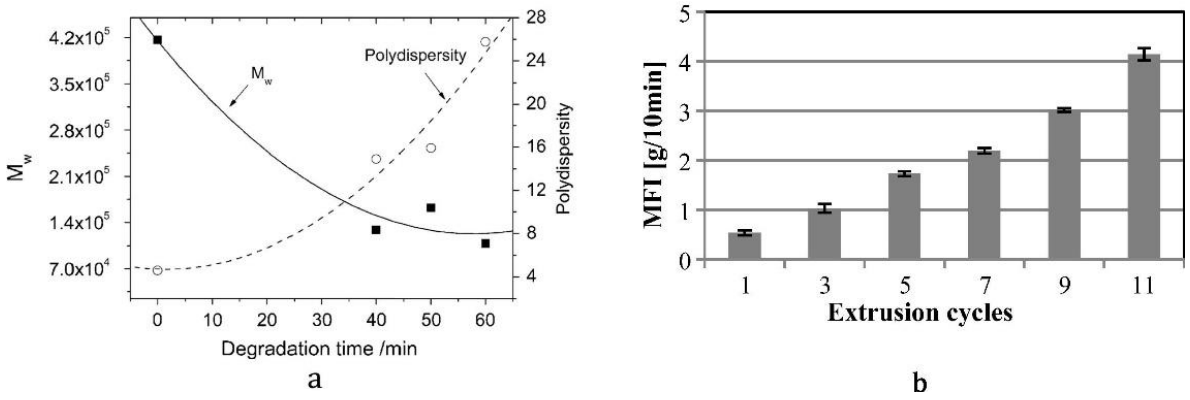

Fig. 16. Thermo-mechanical degradation influence to molecular weight [56]

In addition to thermal-mechanical degradation, plastic degradation could be influenced by light, moisture, and oxygen. Photo-oxidation causes changes in polymer properties as well as forms oxygenated groups, which can cause issues to the equipment [56]. Different analytical technologies can be used to detect oxygenated groups [55].

Lastly, mixed plastic waste is an issue in plastic recycling. Different polymers have different melting temperatures. During recycling, temperature is selected depending on the polymer with highest melting temperature, which results in drastic changes of material properties [56]. Table 9 indicates melting temperature ranges for different materials.

Table 9. Plastic melting temperature ranges, ºC

Material	**Melting temperature, ºC**
ABS	190-270
HDPE	210-270
LDPE	180-240
PET	260-280
PP	200-280
PVC	160-210

3.3. Chemical Recycling

Chemical recycling is the solution for plastic to become circular. During this process valuable products are received such as monomers, polymers, or petrochemicals [55].

1. Pyrolysis – during this process polymers are broken into molecular level. Conventional pyrolysis is mainly used for multilayer plastic packaging that is not contaminated. Process temperature is between 300-700 ºC, pressure 1-2 atm and it is necessary to provide absence of oxygen. Process products are pyrolytic oil, gas, and char. Plasma pyrolysis advantages are low levels of emission, its process temperature is between 1730-9730 ºC and it lasts around 0.01-0.5 sec, during which polymers are fully degraded. Process products are gasses, that are used to generate electricity. Microwave-assisted pyrolysis process is easily controlled as heat distributes evenly, but it can face difficulties if different types of polymers with different properties are mixed together. During the process plastics are mixed with dielectric material [55]. Figure 17 shows pyrolysis process [56].

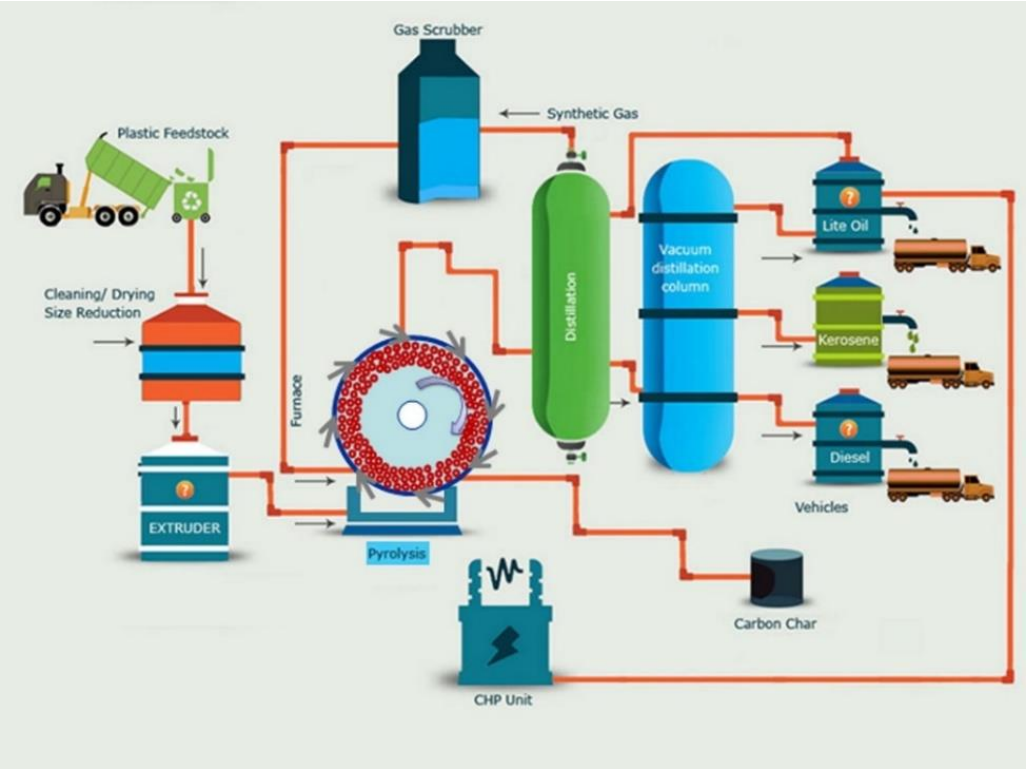

Fig. 17. Pyrolysis process flow diagram [56]

2. Catalytic cracking is a pyrolysis with addition of catalyst, which reduces process temperature and time. This process requires less energy and results in products with similar parameters. However, this process requires additional waste treatment before its start [55].
3. Hydrocracking produces high quality products and is performed at high pressure, using low temperature and hydrogen. Plastic waste firstly goes through pyrolysis, after that catalyst is added and hydrocracking process begins. The biggest drawback of this process is high price of hydrogen [55].
4. Gasification process requires temperature between 700-1200 ºC and one of the agents – steam, air, or plasma. During this process sub-products are formed and in order to receive high quality end products, additional chemical recycling processes are needed. End products of gasification are carbon dioxide and carbon monoxide, hydrogen, and energy [55]. Gasification process is showed in Figure 18 [56].

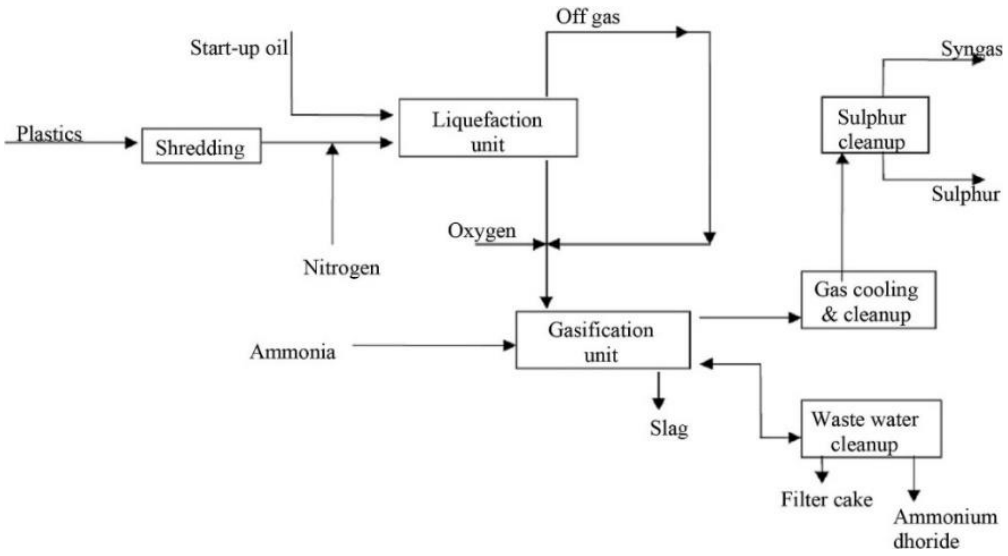

Fig. 18. Glasification process flow diagram [56]

Summary of main chemical recycling processes, their parameters and maturity level are shown in Table 10 [55].

Table 10. Main parameters and technologies level of maturity [55]

	Process temperature	**Sensitivity to material**	**Operational maturity**
Conventional pyrolysis	300-700 ºC	High	Commercial
Plasma pyrolysis	1800-10000 ºC	Low	Laboratory
Microwave-assisted pyrolysis	Up to1000 ºC	Medium	Laboratory and pilot
Catalytic cracking	450-550 ºC	High	Commercial
Hydrocracking	375-500 ºC	High	Pilot
Conventional gasification	700-1200 ºC	Medium	Commercial
Plasma gasification	1200-15000 ºC	Low	Commercial

In European Union, only two countries are starting to use chemical recycling for plastic waste recovery. In Germany 38.6% of post-consumer plastic waste is recycled, of which 0.2% is recycled chemically. In Italy 31.4% of plastic waste is recycled, of which 0.1% is recycled chemically [8].

4. Feasibility Study of Flexible Plastic Packaging Collection

4.1. Assessing Method

Survey is one of the most popular quantitative research methods, widely used in both scientific and applied research, when it is not possible to find out otherwise about the research object or its features. Survey research is often used when the phenomenon under study is related to people's attitudes, needs, interests, motivation and so on. Survey is used as a mean to gather information from respondents on pre-defined questions. Quantitative research does not seek to find out unknown truths, but rather confirms or refutes theoretical reasoning or insights in practice. Surveys are usually performed to obtain information about the studied target groups, as well as to find out the correlation between the different test parameters. The accuracy of the results obtained using this method depends on respondent's willingness to cooperate and tell the truth to the questions asked. A typical feature of quantitative research is a developed questionnaire that helps to systematize the information received from respondents. The content, number and order of the questions depend on the objectives of the study. The main task of the questionnaire is to ensure proper communication between the interlocutor and the respondent. The quality of the questionnaire is determined by the questions it contains, which helps to determine the nature, phenomenon, or connections of the research. Long questions are more reliable when motivated respondents are interviewed, while short questionnaires are less reliable but more suitable for finding a common opinion in practice. It is wrong to collect information that will not be used at any stage of the study, the questions should not be biased, deliberately directing the respondent in the desired direction. The undoubted advantage of questionnaires is that the collection of information takes less time, and the questionnaire does not require that many resources compared to the interview, and its reliability can be assessed by mathematical-statistical methods. As the reliability of the study also depends on subjective answers to the question asked, it is very important that the questions asked are optimal and their wording is understandable and focused on the target groups, as the results themselves depend on both, the questionnaire and the respondent's willingness to participate. The questionnaire first determines what information will be needed. Which topics should be included, which of them are the most important, critical to find out a particular attitude or opinion? Each question in the questionnaire performs a specific function, so all questions must contain some information related to the purpose of the study.

There are many methods used in the literature to sample a quantitative study. Each respondent is treated as a separate research unit and together they form a general research set. The researcher randomly selects only a part of the general set for the study – a certain number of test units. He then collects data from them, analyzes and summarizes the general aspect of the questionnaire. In the literature, sampling methods are divided into two methods. Probability sampling is when the elements are selected at random and the probability of each element entering the sample is the same. The essence of probability methods is knowledge about the probability of including each unit of the general population in the research sample. Non-probability sampling is when we cannot calculate the probability of an item being included in the sample and cannot estimate the accuracy of the survey. This selection may be based on one purpose or another. For example, some elements of the study population may be easier or cheaper to achieve. For this research, non-probability sampling method was selected.

4.2. Materials and Methods

The aim of the study is to analyze the rate of citizens that separate waste in their households, as well as, to understand their willingness to collect wider portfolio of packaging waste, specifically, flexible plastic packaging and what would motivate them in doing so.

The sample size of the users was calculated using the "Select Statistical Services Limited" statistical analysis companies sample size calculation for the population proportionality range.

$X = Z\alpha / 2^2 * p * (1-p) / MOE^2$, where,

X – is the sample size, Zα – is the critical value of the normal distribution α / 2, p – is the sample proportion and MOE – is the margin of error. According to the already analyzed statistical data, 2.8 million people live in Lithuania, of which 82% (2.2 million) uses the internet. In order to obtain as many answers as possible, which would reflect the general opinion of the whole, a confidence level of 90% was chosen. In this case, we believe that if we conduct the same survey 100 times, 90 times out of 100 the survey will give the same results. In order to obtain the largest possible sample size, a standard 50% proportion is used. Estimating, that we may not receive a large number of respondents, we use margin of error of 6%. According to the above formula, the sample size is estimated at 188 respondents.

The questionnaire consisted of 12 closed and 1 open questions with single answers possible. It was live for two weeks, from 12th of April until 26th of April 2021. During this period, 188 responses were collected. Questions were divided into three parts. First part consisting of questions to determine gender, age, education, and monthly income. Second part questions were used to understand respondents recycling habits and last part, was to determine their willingness to collect wider portfolio of packaging waste and incentives that would motivate them to participate in such packaging waste collection.

4.3. Results

The demographic profile of the questionnaire participants has been collated and shows a bigger female participation (64.9%) compared to male (35.1%). Participants aged 18-29 formed the largest group within the same population (68.1%), followed by the 30-49 group (25%) and with only 6.9% of the sample representing age group 50 and more [Table 11].

Table 11. Respondents age and gender

		Age			**Altogether**	**%**
		18-29	30-49	50 and more		
Gender	Woman	84	29	9	122	64.9
	Man	44	18	4	66	35.1
Altogether		128	47	13	188	100
%		68.1	25	6.9	100	

80.9% of the participants had a higher university education with bachelor's or master's degree. 10.1% of respondents had a college degree, followed by 6.9% with secondary education and 2.1% of respondents with other education [Table 12].

Table 12. Respondents education

Education	Respondents	%
Secondary	13	6.9
Higher collegiate	19	10.1
Higher university	152	80.9
Other	4	2.1

36.2% of respondents' monthly income is between 1000 and 1500 Euros, followed by 31.9% with monthly income between 500 and 1000 Euros. Smaller group of 20.7% of participants have monthly income more than 1500 Euros, and lastly, 11.2% respondents receive less than 500 Euros per month [Table 13].

Table 13. Respondents monthly income

Monthly income	Respondents	%
Under 500	21	11.2
500-1000	60	31.9
1000-1500	68	36.2
1500 and over	39	20.7

The first questions in the questionnaire sought to summarize what characteristics could change consumers perceptions regarding recycling and because of that, more attention was paid to the respondents age, education, and monthly income.

When asked, if participants recycle their waste at home, only 54 of them (28.7%) recycle all types of waste, of which 64.8% were in the age group of 18-29, 24% being in age group of 30-49 and 11.2% being 50 and above. 108 of respondents (57.4%) said that they recycle only some type of waste, of which 70.3% were in the age group of 18-29, 24% being in age group of 30-49 and 5.7% being 50 and above. Lastly, only 26 participants (13.9%) stated that they do not recycle at all. 65.4% of them were in the age group of 18-29, 30.7% being in age group 30-49 and 3.9% being 50 and above [Figure 19].

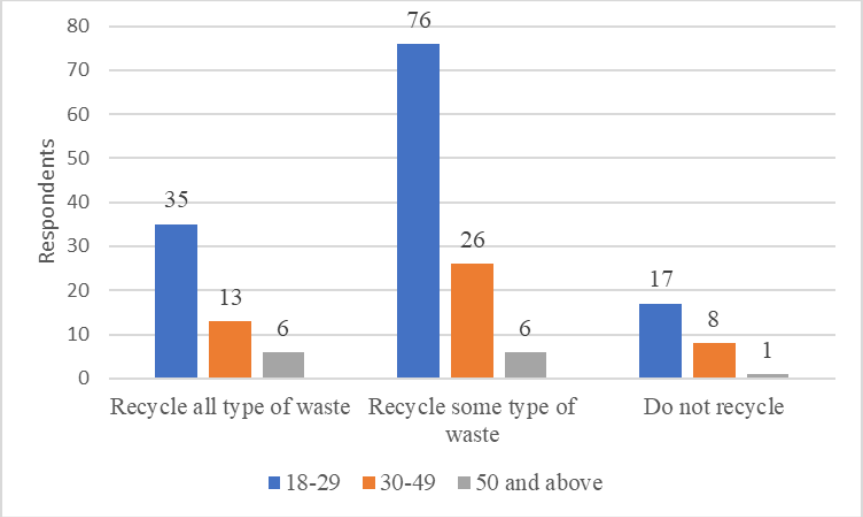

Fig. 19. Correlation between respondents age and recycling behaviour

When analyzing respondents recycling behavior dependence on their education, it can be noticed, that majority of respondents that have university degree have stated, that they recycle all types of waste (92.6%), followed by the participants with college degree (5.5%) and lasty, participants with other education (1.9%). However, similar situation can be noticed with other two options. Implication can be made, that neither age, nor education of respondents have impact on their recycling behavior [Figure 20].

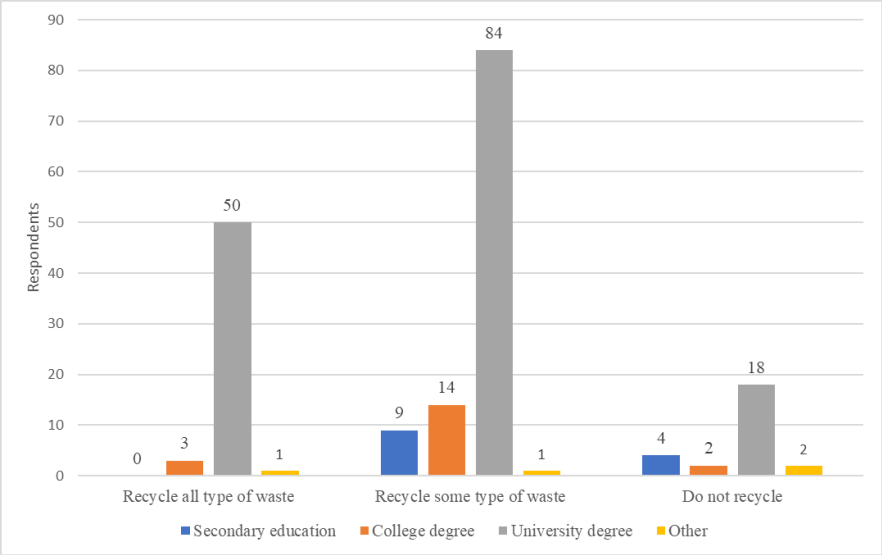

Fig. 20. Correlation between respondents education and recycling behaviour

When asked if respondents think they recycle correctly, 60 participants were positive (31.9%), of which 56.6% stated that they recycle all type of waste, 41.6% states that they lack information to recycle correctly and 1.8% do not recycle. However, it is only 63% of all respondents that have indicated recycling of all type of waste, other 37% of them think, that they need more information in order to recycle better. Overall, 106 respondents (56.4%) have indicated, that the lack of information can lead them to incorrect recycling, majority of them (77.3%) recycle some type of waste. Lastly, 11.7% of participants do not recycle. It can be concluded that lack of information in society leads to incorrect disposal of waste and lack of motivation to participate in recycling processes at all [Figure 21].

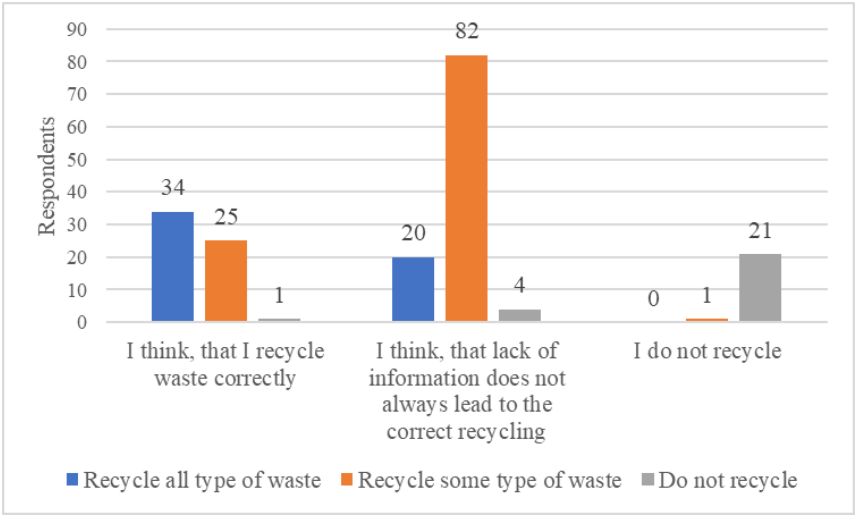

Fig. 21. Respondents recycling behaviour

To the question how participants recycle their packaging waste, 58% of them have selected, that they remove product residues from the packaging and dispose it in a special container. This is a better result, keeping in mind, that only 31.9% respondents before have stated, that they think they recycle correctly. 18.6% of respondents stated, that they dispose packaging waste in a special container together with product residues. 12.2% of participants dispose their used packaging in general waste container together with the product residues and, lastly, 11.2% of them remove product residues and only then dispose packaging waste [Figure 22]. This quite high rate of incorrect packaging waste disposal can be linked with the information that respondents feel they lack, regarding correct recycling.

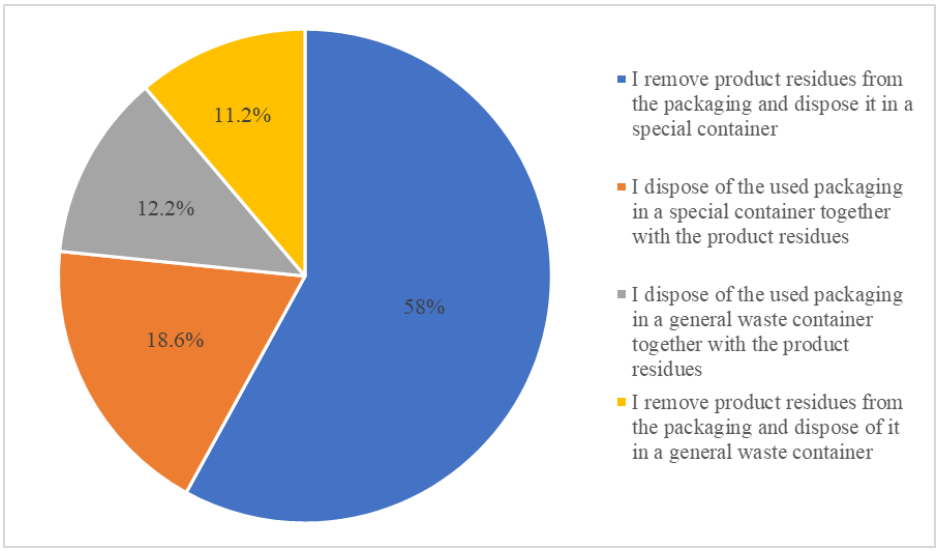

Fig. 22. Respondents disposal of packaging waste

28.7% of all respondents have agreed, that plastic packaging waste and what effect it has on the environment, concerns them, 57.4% have stated, that it concerns them a little, and 13.9% of them do not think about impact, that packaging waste has [Figure 23]. From these results, we could also make a solution, that there is a need of more educational compaings, as well as more information on the media, in supermarkets or on the billboards.

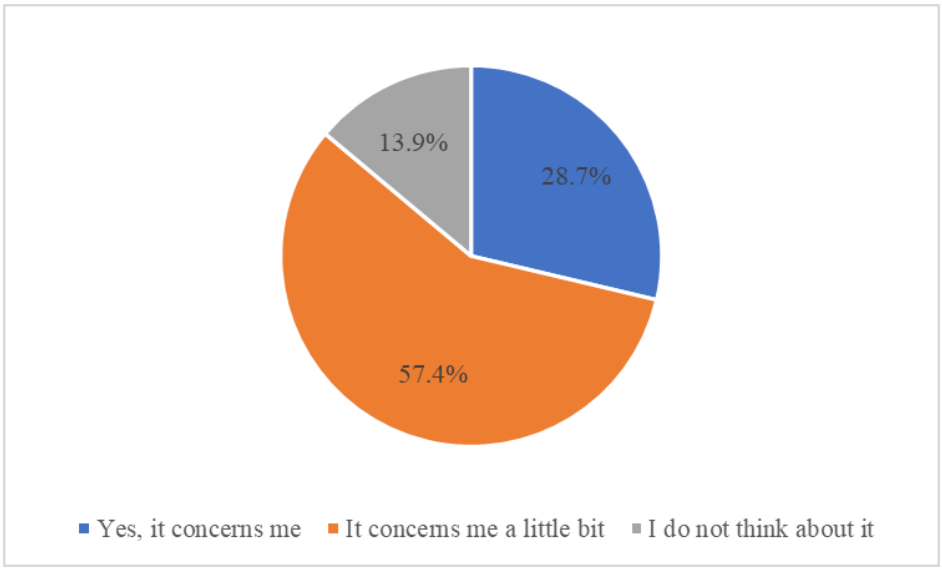

Fig. 23. Respondents concern on plastic packaging impact on the environment

There was no big deviation between the respondents' opinion regarding current plastic packaging recycling suitability. Equal number of respondents (31.9%) have stated that recycling system is appropriate and not appropriate, 36.2% of participants have stated, that they do not have an opinion [Figure 24]. This could be again related to the need of statistical data of collected and recycled packaging waste rates and impact that it has on the environment.

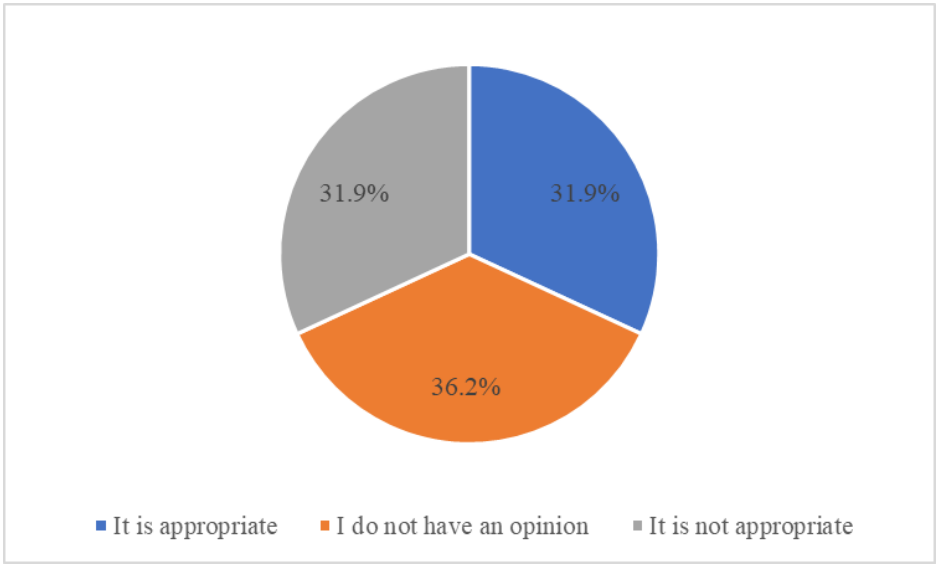

Fig. 24. Plastic packaging recycling system suitability

When asked to express their opinion about need of separate collection streams for flexible and rigid plastic packaging, 75 respondents (39.9%) declared, that separate recycling system is needed, of which 50.6% have previously declared, that current packaging recycling system is not correct. 61 respondents (32.4%) do not have an opinion if separate collection is needed, 54% of which have previously also declared, that they do not have an opinion if current plastic packaging collection system is appropriate. And lastly, 52 respondents (27.7%) think, that separate flexible plastic packaging collection is not needed, of which 50% have previously stated, that current plastic packaging collection is appropriate [Figure 25].

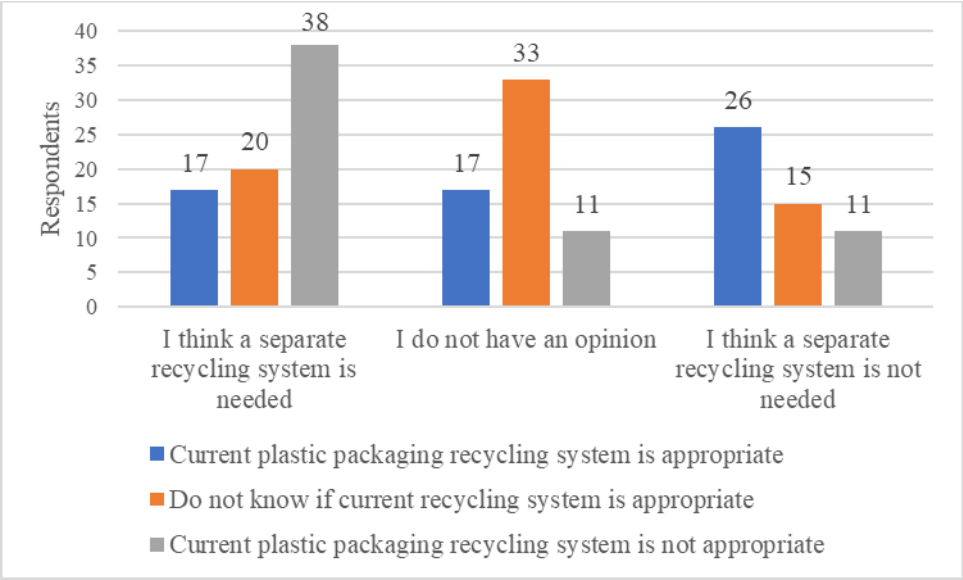

Fig. 25. Requirement of separate flexible plastic packaging collection scheme

55.8% of respondents would choose so separate flexible plastic packaging waste in different color bags and disposing them in the plastic waste containers. 26.6% of them would bring separately collected flexible plastic packaging waste at store drop-off points and 17.6% of participants would not agree to separately collect flexible plastic packaging [Figure 26].

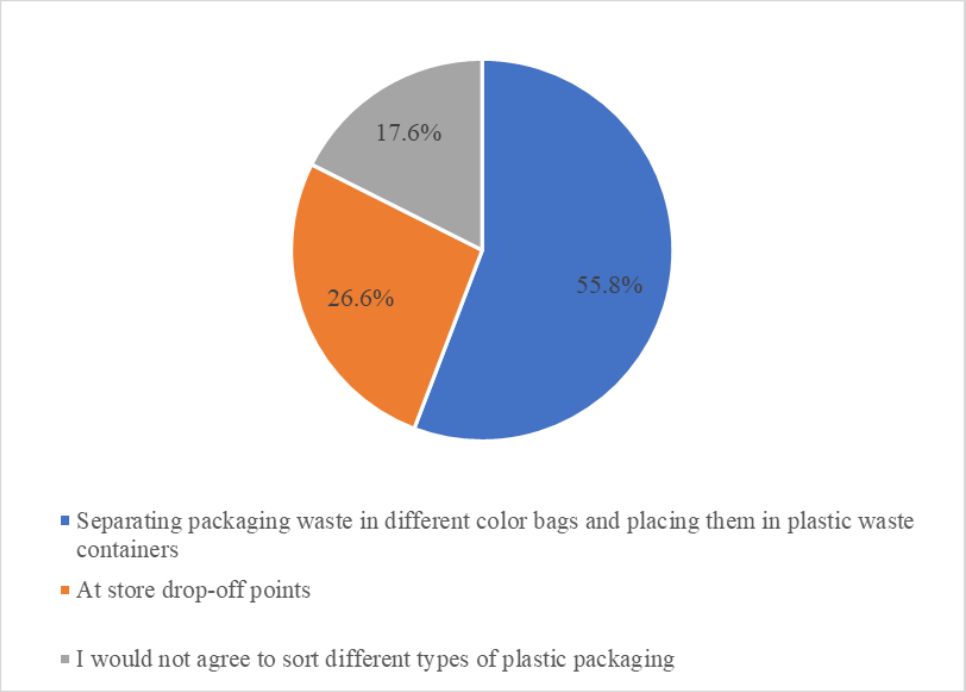

Fig. 26. Flexible plastic packaging collection schemes

Respondents were asked to rate if proposed factors would motivate them to collect separately flexible plastic packaging. When assessing the average response rate, it was observed that clear recycling information on the packaging would motivate them the most. Second most motivational factor was deposit system with additional charges for packaging. Phone applications with possibility to accumulate bonuses or applications, that would scan code and inform about correct packaging sorting were not rated as highly motivational factors. It is seen as well from the standard deviation, these two variables had big deviations, which means, that respondents either found these options very motivational, or not motivational at all. Standard deviation for clear recycling information on the packaging variant is the smallest, which means, that respondents have agreed on it quite equally [Table 14].

Table 14. Motivational factors for separate collection schemes

Factor	Minimum	Maximum	Average	Standard deviation
A phone application that scans the package code and informs how to sort it properly	1	5	3.63	1.35
Clear recycling information on the packaging	1	5	4.52	0.85
A phone application where you could accumulate bonuses for properly sorted packages	1	5	3.79	1.38
Deposit system with additional charges for packaging	1	5	4.16	1.19

Lastly, respondents were asked to identify, what other factors would motivate them to participate in separate plastic packaging collections. Almost 55% of participants have indicated the lack of education and information about plastic packaging life cycle. Several respondents stated that public information with statistical data about collected, sorted, and recycled plastic packaging would motivate them to participate more in collection. Another factor could be advertisements and documentaries, showing what impact plastic packaging waste has on the environment, they have stated that visually presented facts and figures are stimulating to think about importance of correct sorting. Education from early years was also mentioned, as several respondents have stated, that it is important to firstly change human perception on pollution. Participants have also noted the need of clear information on how to recycle each product. From these results it is possible to form a solution, that in lack of information in general leads to incorrect plastic packaging recycling or it frustrates consumers and leads to disposal of packaging residues in general waste bins. 30.7% of participants have indicated that changes in waste collection system would motivate them to separate different types of plastic packaging waste. It could be either improvement in current collection system, additional containers in the suburbs and wider spread of containers in cities as well. Several respondents indicated that monetary system would also motivate them, where packaging would be charged additionally or if packaging waste would be charged depending on its collected weight. 7.6% of respondents indicated that to minimize plastic packaging impact on the environment it is necessary to use less plastic to pack products and to provide consumers option to choose product without plastic packaging, when possible. Lastly, 6.7% of participants indicated, that if packaging could be disposed without cleaning them first, it would motivate them to sort waste more.

From the collected results of the survey, it is seen, that the collection behaviour is evenly distributed between diffent age groups, and between different participants education. The highest amount of respondents collect only some type of waste, which can be a result of poor collection infrastructure and lack of information about importance of proper waste disposal. The lack of information is noticed from the majority of the survey results, almost half of the participants do not separate waste correctly, or they do not have any concerns regarding plastic packaging impact on the environment. Even though, part of the respondents have indicated the need of separate flexible packaging collection system, it is clear, that it is necessary, firstly, to invest in education and to increase dissemination of information in order to reach required collection rates.

5. Collection System Improvement in Lithuania

Literature and statistics analysis have showed, that even though Lithuania is a leading European Union country regarding plastic packaging recycling rate, there is still a lot of place for improvement. A study of the composition of municipal waste showed, that almost 50% of collected waste is unwanted waste, of which almost 13% is plastic packaging waste. These results indicate the need of collection system improvement. Additionally, survey results have also showed the need of infrastructure change. Several respondents have indicated that weight-based collection system would motivate them to separate their waste more. Taking into consideration all collected information, implementation of weight-based pay-as-you-throw collection system could be an option for Lithuania to increase separate collection rates. This system has been implemented in several European Union countries and showed positive results.

Pay-as-you-throw (PAYT) approach in waste management uses the polluter pays principal, where citizens are charged according to the amount of waste they have generated. This approach is based on identification of waste generator, measurement for the amount of waste generated, and pricing system. In most cases, when implementing PAYT system, countries choose to charge fixed and variable waste fee, this way illegal dumping is avoided. Volume based pay-as-you-thow system can be a disadvantage to people living in densely populated cities, because of shared waste bins. It can lead to citizens not minding how much waste they are generating and what impact it has on the environment. Weight-based pay-as-you-thow system is linked to single household and for every generated waste kilogram they have to pay set waste fee. This system encourages citizens to separate their waste and reduce their consumption.

5.1. Pay-As-You-Throw Weight-Based System

To implement weight-based pay-as-you-throw system a lot of effort is needed to process data for billing, accounting, and optimizing the whole system. For system to work, various equipment improvements are needed. Waste bins should be coded either with barcode, 2D code and identification number, additionally they should be equipped with a chip and lock system. Lastly, bins should be equipped with a sensor weighting system to record the quantity of waste by every user. This system would be more applicable to areas, where several households are sharing the same bin. Users could be identified by using magnetic or radio frequency identification based smart cards, that would be used as a key. Another identification system could be mobile program with installed Near Field Communication technology. This system would require direct mobile contact with the collection bin. For single-use containers this system could be too expensive, so weight sensors could be implemented in the trucks. Additionally, collection trucks should be also equipped with a reading device to collect data from the bin codes. Collected data would be transferred to a central facility, where it would be processed, accounted and bills would be formed. Possible PAYT system process flow diagram is showed in Figure 27.

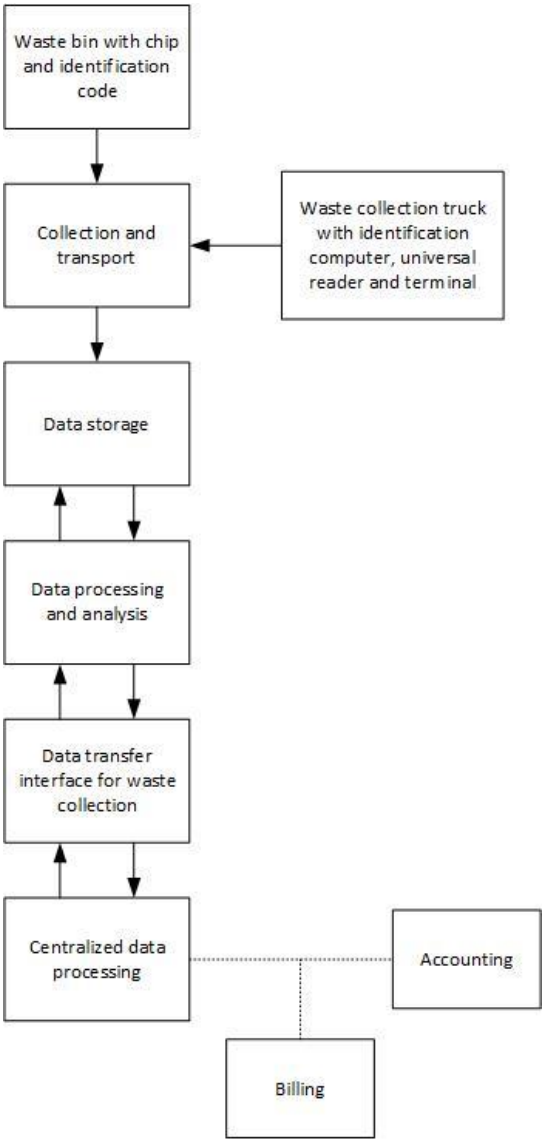

Fig. 27. PAYT weight-based schematic process

5.2. SWOT Analysis

SWOT (strengths, weaknesses, opportunities, and threats) is used to develop awarness of the factors that are involved during decision making. Analysis is used to identify streghts and opportunities in order to overcome threats and weaknesses.

PAYT scheme-based SWOT analysis was performed to develop an action plan. It aimed at identifying internal and external factors, their advantages and disadvantages, that might have an impact on the proposed PAYT concept. SWOT analysis of this project was intended to maximize both strengths and opportunities and minimize the external threats. SWOT is a tool designed to be used in the preliminary stages of decision-making.

Table 15. SWOT analysis

Internal	
Strengths	Weaknesses
1. Decreased environmental impact. 2. Fair allocation of costs to the citizens. 3. Transparent waste management costs. 4. Reduction of waste in bins. 5. Increased sorting of recyclables. 6. Decreased administration.	1. Increased investment cost for implementation and for further operation. 2. Illegal dumping of household waste in other collection points. 3. Increased rate of contaminated recyclables. 4. Technical operating problems. 5. Lack of ecuation and awareness regarding environmental among the society.
External	
Opportunities	Threats
1. Various funding schemes from European Union, national or private sector. 2. New employment opportunity. 3. Education, environmental awareness with implemented new rules.	1. Lack of interest from citizens. 2. Vandals. 3. Improper recycling behavior. 4. High costs of transfer and disposal. 5. Increased littering.

The results from the performed SWOT analysis showed that a PAYT weight-based concept provides various strengths and opportunities but may face risks as well. However, the true list of risks and opportunities would be generalized during the implementation of a PAYT scheme. Advantage of this analysis is that identified risks and weaknesses can be minimized and some actions can be done before the project start. Pilot application should be provided, in order to identify the reliability of the proposed scheme and to also identify potential ways and methods of reducing the investment and operation costs and optimising the overall process. Community awareness and support is a key to the ultimate success of PAYT concepts.

6. Recommendations

Even though weight-based pay-as-you-throw waste management system could be used to improve collection and possibly increase plastic packaging collection rates, this system requires a lot of investments and could take a longer time to implement. Literature analysis and survey results have showed that there are a lot of other factors that are important to investigate in order to reach circular economy goals.

6.1. Waste which ceases to be waste

In order to increase plastic packaging recycling rates, it is important to establish criteria for plastic packaging waste that ceases to be waste. Waste ceases to be waste, when it undergoes a recovery operation, including recycling and meets specific criteria to be prepared in accordance with several conditions, like material is used for specific purposes and it has a market and demand. What is more, material fulfills the technical requirements for the product and complies with legislation and standards applicable to it. Currently, in European Union, criteria are set only for iron, steel, aluminum and copper scrap, and broken glass. Only Italy is planning to implement national criteria for plastic packaging waste [60]. The demand for implementation of post consumer recycled plastic into new material is increasing and many companies are including this pledge in their sustainability plans. Currently, recycled material reuse for production of new packaging material is cost inefficient, however implementation of criteria could encourage industry to take more action regarding improvement of waste treatment methods.

6.2. Labeling and dissemination of information

One of the most important factor is changing people's behaviour and attitude towards plastic packaging waste and the impact that it has on the environment. In order to increase the awareness and involvement of the population, it is important to increase various social initiatives. The main focus should be on the target groups, that are least informed or least interested to be involved in waste management programs. That is why it is necessary to involve younger population to educate elderly population. Government should focus on solving fundamental problems, providing higher quality education, develop general skills for self-interest. Information should be short, concise and encourage to expand the further knowledge independently. Surveys should be performed in order to identify, what better communication tools would be and what type of information would make the biggest impact on people's behaviour.

What is more, improvement of packaging labeling is necessary. Various studies have indicated positive consumers behaviour towards clearly labeld packaging. In addition to that, survey results have showed, that clear packaging labeling would motivate respondents to collect different type of waste separately. Good example is packaging labeling system developed in the UK, which helps consumers to reuse and recycle packaging correctly and increases materials recycling rates. Designed labels are simple and indicated information is clear. The system encourages innovation regarding collection systems and recycling technologies and protects quality of currently recycled material. Various surveys could be developed, and pilot applications could be performed to investigate the potential of such type of labeling.

Fig. 28. Example packaging recycling labeling

6.3. Life cycle assessment

Life cycle assessment of different packaging types and used materials can be used in the industry, to focus on more sustainable packaging solutions. Life cycle assessment measures environmental footprint of various material packaging and determines its impact on the environment through its life cycle from the raw material phase, production and up to disposal. There are various softwares created for the industry to assess environmental impact of various processes. A few of the sofwares could be Umberto LCA+, SimaPro or OpenLCA. These tools could be used by the companies during packaging design and decision phase to compare different possible packaging solutions for their product and to understand which solution would be the most environmentally friendly. Performing such analysis could indicate, that not in every case replacing flexible plastic packaging with an alternative solution would be the most sustainable option. The design of packaging ensures the longest possible service life of products and the subsequent reuse or recycling of their materials. For example, halving the amount of materials used to make the packaging and doubling life and reuse of the materials at the same time would increase the efficiency of natural resources significantly.

Conclusions

1. Flexible plastic packaging collection and recycling methods in European Union countries were investigated to understand how different collection methods impact citizens behaviour towards recycling. Weight-based pay-as-you-thow waste management system was proposed as a possible way to increase recyclability in Lithuania.
2. Flexible plastic packaging advantages and disadvantages were analyzed and it was noted that plastic products are particalarly important for many industrial processes and are used for a variety of industrial applications. In modern society, plastic is considered as a cheap disposable single-use material with high protective barrier, but its recycling rate is very low. One of the most important tasks is to reduce the disposal of plastic packaging waste in landfills. Plastic products disposed of in landfills are untapped resources, so this type of waste disposal should be avoided. Recycling of plastics can contribute to climate change and the reduction of water ecotoxicity.
3. Collection systems in different European Union countries were analyzed and it can be stated, that countries, that have implemented separate collection systems, have reached higher collection rates for all fractions of waste. Lithuania, compared to other analyzed countries, in 2018 was able to reach the highest recycling rate for plastic packaging, which was around 69.3%, Spain, Sweden and Netherlands where second with around 50% recycling rate, Germany was third with 47.1% and Italy was last with 43.8%. Even though Lithuania managed to reach the highest recycling rates for plastic packaging, it was mostly due to deposit system. There is still an issue of flexible plastic packaging being disposed incorrectly, as almost 13% of plastic packaging is found in municipal waste stream.
4. Questionnaire on possible flexible plastic packaging collection methods was developed. From the collected results of the survey, it is seen, that there is no correlation between respondents age, education and their collection behaviour. 57.4% of respondents collect only some type of waste, which can be a result of poor collection infrastructure and lack of information about importance of proper waste disposal. The lack of information is noticed from the majority of the survey results, as 42% of the participants do not separate waste correctly, and only 28.7% stated, that plastic packaging impact on the environment concerns them. Even though, part of the respondents have indicated the need of separate flexible packaging collection system, it is clear, that it is also necessary to invest in education and to increase dissemination of information in order to reach required collection rates.
5. Performed analysis showed the need of collection system improvement. Respondents have indicated, that weight-based collection system would motivate them to participate more in separate waste collection. Literature analysis have showed, that countries, which have implemented weight-based pay-as-you-throw system were able to reach higher recycling rates and increase citizens awareness. According to that, weight-based PAYT system was suggested as possible improvement in Lithuania. Schematic process was presented and SWOT analysis performed. The results from the SWOT analysis proved that a PAYT concept provides a lot of strengths and opportunities but may face critical risks. As far as the weaknesses and threats of PAYT concepts are concerned, some actions can be proposed in order to minimize them.
6. Even though weight-based pay-as-you-throw waste management system could be used to improve collection and possibly increase plastic packaging collection rates, this system requires a lot of investments and could take a longer time to implement. Pilot application would be necessary to identify the reliability of the proposed scheme. Additional improvements could be people's education and better dissemination of information as well as improved packaging recycling

labeling. Implementation of criteria for waste, that ceases to be waste could motivate industry to invest more in plastic packaging recycling technologies to ensure high quality recycled material. Lastly, implementation of LCA analysis during product design stage, could significantly reduce environmental impact of the packaging.

7. For the future research, more in depth survey could be proposed to gain insight on citizens attitude regarding proposed collection system and to identify more internal and external risks that it may face.

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