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Sustainable plastic waste management: Global practices and perspectives on the case of Kazakhstan

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Abstract

Plastic waste presents itself as a menace that could require a multifaceted approach to eliminate. This article seeks to not only analyze but also expound on the current state of plastic waste residing in Kazakhstan. The first part deals with the issues posed by single-use plastics and evaluates their environmental effects while considering the patterns of overconsumption in Kazakhstan. The paper examines the history of single-use plastics, focusing on the import, export, and production aspects of Kazakhstan. The processes of sorting and recycling plastic waste are investigated, as well as the share of waste sent for reprocessing and the quality of sorting at different levels. It also discusses the current methods and technologies of recycling plastic, as well as the main problems for its effective application in Kazakhstan, among which are a lack of infrastructure, economic challenges, and low awareness of the population about the issue. The uniqueness of Kazakhstan is juxtaposed with that of other countries, and the necessity of creating long-term sustainable solutions to the issue is emphasized. The final section of the article is dedicated to presenting potential recommendations for improvement in waste management alongside conclusions based on the article's premise.

Keywords: Environmental Impact, Kazakhstan, Plastic Recycling, Plastic Waste, Single-Use Plastic, Sustainable Waste Management, Waste Sorting.

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1. Introduction

The issue of reducing plastic waste is at the forefront of the global environmental agenda [1-5]. Traditional polymeric materials used in the production of packaging and short-term goods cause significant environmental damage due to their long decomposition period and difficulty of disposal. Against this background, the introduction of ecodesign principles [9, 10], as well as the development of biodegradable and recyclable materials [11-13], represents important steps toward sustainable development. From 24 to 28 August 2024, intersessional meetings of the UN Environment Programme were held in Bangkok, Thailand, where the delegation of Kazakhstan and Ph.D. in Chemistry Gaini Seitenova from the Petrochemical Association discussed the development of the first legally binding document to combat plastic pollution. The final stage of negotiations took place at the fifth session of IGC-5 from 25 November to 1 December 2024 in Busan, Republic of Korea, where the Kazakh side emphasized the need to develop an international agreement that would ensure the fight against plastic pollution, considering national economic interests, the exclusion of virgin polymers from regulation, and the introduction of a balanced approach to protect the environment and support sustainable development.

Today, waste is seen not only as a problem, but also as a source of economic opportunity. The transition from a linear to a cyclical economic model allows waste to be turned into resources [14-19] which create additional value. Recycling plastics, implementing recycling technologies and developing waste management infrastructure can become drivers of economic growth. Moreover, recycled and sustainable materials open up new markets and attract investment, forming the basis for an environmentally and economically beneficial economy of the future.

Efforts are being made in various countries around the world to implement integrated approaches aimed at minimizing the impact of plastic on the environment [20-22]. The European Union has set high standards for eco-design, for example mandating the use of plastic bottles with integrated lids and the introduction of recycled plastic content standards [23-27]. These measures are included in EU Directive 2019/904 and are accompanied by new initiatives such as digital product passports and requirements for the durability and recyclability of products. China [28-35] in turn, strengthens the standards for labelling and identifying biodegradable materials, introducing updated regulations governing the use of packaging and the production of biodegradable plastics. However, despite the successes, the mass adoption of biodegradable polymers is accompanied by significant challenges, such as high production costs, limited recycling infrastructure, insufficient consumer awareness, environmental and energy costs [36-48]. Key requirements for such materials include maintaining performance properties, safety of additives, absence of toxic decomposition products, and compatibility with existing recycling systems. Environmental risks associated with microplastics are worth considering [9, 19, 49-53] formed during the decomposition of certain types of biodegradable plastics.

Japan is actively developing waste management systems, including plastic recycling. In 2022, the Plastic Resources Circulation Act was passed, requiring citizens to sort all plastic as a recyclable resource, which has stimulated a rethinking of waste management habits [54]. Under Extended Producer Responsibility (EPR), the country places particular emphasis on reducing carbon emissions and optimising recycling processes, including mechanical recycling and waste-to-energy [55-58].

South Korea is one of the leading countries in plastic waste recycling, using advanced technology and strict regulations, such as requiring transparent PET bottles to make them easier to dispose of and recycle [59-63]. Current research on waste management and pollution in Nepal covers a variety of aspects, from assessing micro-plastic pollution in rivers and recycling municipal solid waste to integrating the informal sector and developing sustainable plastic recycling models to support a circular economy [64-68]. Plastic waste management in Bangladesh faces significant challenges including low recycling rates, inadequate infrastructure and high levels of illegal dumping, requiring comprehensive measures to raise consumer awareness and promote sustainable recycling practices [69-73].

This study is devoted to a comprehensive analysis of the problem of plastic waste in Kazakhstan, with the aim of identifying the unique features of the country that can serve as an example for other countries. The review is aimed at assessing the impact of plastic waste, analysing the current situation with its consumption, production, export and import, as well as studying existing recycling methods and technologies. This work seeks to emphasize the importance of creating a sustainable plastic management system and forming a model that can be implemented and adapted in other countries.

Kazakhstan, as the economic leader of Central Asia, also faces the need to actively engage in global environmental initiatives. The development of the processing industry and the transition to sustainable production methods can be an important step towards increasing the country's environmental responsibility. The significant amount of waste generated as a result of the use of plastic products is a challenge that requires systemic solutions. In the context of high urbanization and growing consumption, Kazakhstan has a unique opportunity to introduce advanced technologies and adopt successful international experience to create a sustainable economy.

2. Overview of Plastic Waste in Kazakhstan

2.1. Impact of Plastic Waste

In Kazakhstan, as in most other countries in the world, there is a problem of environmental pollution with single-use plastic [74]. Kazakhstan has accumulated significant amounts of plastic waste that pollutes the soil, water bodies and the atmosphere. Particularly alarming is the fact that only a small portion of the plastic is recycled, while most ends up in landfills or in the environment, where it decomposes over hundreds of years, causing irreparable harm to ecosystems [53, 75, 76].

It is worth paying special attention to the fact that polymers affect the health of humans, animals and plants depending on the type. Table 1 contains examples of the main types of polymers and their impact on human and animal health [6, 9].

Table 1.
Main types of polymers and their areas of application for the manufacture of disposable products.

No.	Type of plastic	Scope of application
1	Polyethylene terephthalate PET or PETF	Bottles with a raised dot on the bottom for water, soda, milk, and oil. Transparent disposable food containers (e.g., cups).
2	High-density low-pressure polyethylene (PEHD or HDPE)	Canisters, bottle caps, cosmetic and household chemical bottles, plastic bags, food containers, and packaging film (such as tape or bubble wrap).
3	Polyvinyl chloride (PVC).	Blister packs, tablets, cake and cottage cheese packaging, shrink film, cosmetic bottles, medical gloves, and masks.
4	Low-density high-pressure polyethylene (PELD or LDPE)	Bags (including garbage bags), film, wrapping paper, and food containers.
5	Polypropylene (PP)	Bottle caps, buckets and pails, yogurt cups, lens packaging, rustling plastic packaging, medical syringes, drinking straws, blisters, and pill bottles.
6	Polystyrene (PS)	Foamed: egg containers, meat trays, and packaging. Smooth: yogurt cups and almost all types of disposable tableware.
7	Other types of polymers (Other)	A mixture of different plastics or polymers not listed above. For example, packaging for cheese, coffee, pet food, and transparent disposable spoons, forks, and knives.

Main problems, associated with the negative impact of polymers [77, 78] and materials used in their production.

- *Penetration of microplastics into the bodies of living beings.* Researchers have documented the presence of micro- and nanoplastics even in regions and ecosystems where plastic use is extremely low, such as the North and South Poles [79-83].
- *Increased consumption of fossil non-renewable hydrocarbons,* used in the production of polymers. According to experts, the production of petrochemical products is a key factor in the growth of oil production volumes [84].
- *Pollution of the World Ocean,* caused by the release of toxic products of polymer decomposition, leads to their spread throughout the Earth's ecosystem. The increase in the amount of plastic and its accumulation in the ocean contributes to the general pollution of sea waters and coasts, as well as the formation of plastic islands, the largest of which is the "Great Garbage Patch" in the Pacific Ocean [28].
- *Long period of decomposition* plastic with its short-term use and the widespread use of products made from polymers leads to an increase in the area of landfills for storing human waste and environmental pollution. The service life of plastic products ranges from less than one year to more than 50 years. The average period of actual use of disposable plastic items is very short; for example, the average duration of use of disposable plastic bags is only 12 minutes. At the same time, the decomposition time of polymers varies depending on the disposal method and the type of plastic. On average, the following data can be highlighted: disposable plastic bag - 20 years, coffee cup - 30 years, drinking straw - 200 years, plastic bottle - 450 years, plastic cup - 450 years, disposable diaper - 500 years, toothbrush - 500 years [85-91].
- *Release of toxic substances* during decomposition and combustion. During the decomposition and thermal processing of polymers, harmful substances such as phthalates, formaldehyde, bisphenol A, dioxins, cadmium, luorene-9-bisphenol, styrene and others can be released into the atmosphere [92, 93].

Plastic waste has a significant negative impact on the environment and health of living beings in Kazakhstan and globally. Despite the widespread use of polymers in various fields and their economic importance, the problems of their recycling, long-term decomposition and release of toxic substances remain a serious challenge. Key issues include limited reuse of plastic, penetration of microplastics into ecosystems, consumption of non-renewable resources for polymer production, pollution of the World Ocean and negative impact on human and animal health. These aspects require urgent measures to reduce the use of single-use plastic, improve recycling methods and introduce innovative technologies aimed at minimizing its impact on the environment.

2.2. Types of Disposable Plastic Products, Their Classification and Impact Assessment Single-Use Plastic on the Environment

The definition of single-use polymer products does not include polymer products that are designed and placed on the market to undergo multiple rotations during their useful life by refilling or reuse for the same purpose for which the products were designed.

Examples of food containers that should be considered as single-use plastic products for the purposes of the EU Directive are:

- Fast food containers
- Containers for food, sandwiches, salads with cold or hot food,
- Food containers containing fresh or processed foods that do not require additional preparation, such as fruits, vegetables or desserts.

The domestic market for polymer products covers various segments, including packaging materials, construction products, automotive parts, household appliances, etc. Table 2 shows that in 2023, the volume of polymer production in Kazakhstan amounted to 300 thousand tons, which is 15% higher than last year's figure [94].

The greatest growth is observed in the production of packaging materials, where polymer products account for 40% of the total production volume.

Table 2.
Production of polymer products in Kazakhstan, 2023.

Type of product	Production volume (Thousand tons)	Share (%)
Packaging materials	120	40%
Building materials	80	27%
Household appliances and goods	50	17%
Automotive parts	30	10%
Other product	20	6%
Total	300	100%

Examples of food packaging that should not be treated as single-use plastic products under Directive EU 2019/904 include food containers containing dried ingredients or cold foods that require further cooking; containers containing food of more than one serving size; or portion packs sold in multiple quantities.

Amid growing concerns about the negative impact of plastic waste on the environment, many countries are taking steps to restrict the use of certain plastic products.

Regulations can range from complete bans on the production and sale of single-use plastic items to taxes or recycling requirements. These measures aim to reduce plastic waste and encourage the use of more sustainable and environmentally friendly alternatives.

Thus, the recycling of packaging and other products made of expanded polystyrene, including foam plastic, was banned for use first in New York City on January 1, 2019, and then throughout New York State on January 1, 2022. This outcome was supported by arguments about "environmental inefficiency" (the environmental pollution from transporting, sorting and disposing of expanded polystyrene waste exceeds its environmental impact during recycling) and the potential danger to employees involved in waste management and disposal [95].

1.3. Analysis of Changes and Consumption of Disposable Plastic Products in Kazakhstan

The volume of plastics presented on the Kazakhstan market fluctuated significantly between 2013 and 2022. The main growth has been observed in recent years, which can be associated with increased consumption of plastic products and active economic activity. The key factors in the growth of RPR volumes are growing consumer demand, an increase in the number of production capacities and the expansion of plastic use in various sectors of the economy.

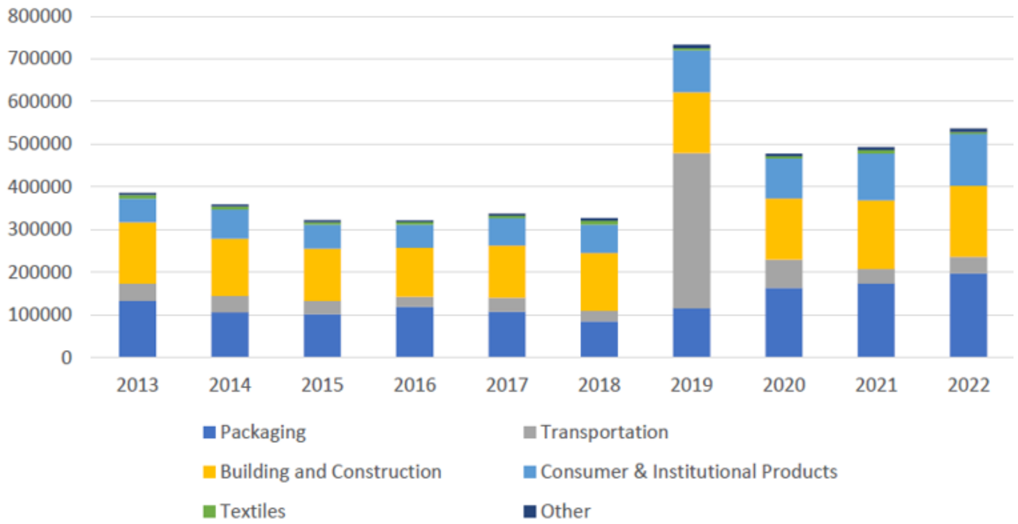

Figure 1.
Plastic products entering the Kazakhstan market by economic sector.

Plastic products entering the Kazakhstan market by economic sectors, shown in Figure 1, visualizes the distribution of plastic product volumes by various industries [96]. This helps to better understand which sectors are most active users of plastic products and how consumption patterns are changing.

Thus, the data confirms the trend of increasing plastic volumes on the Kazakhstan market.

Figure 2 illustrates the volumes of different types of plastic entering the Kazakhstan market [96]. The data show that over the past 10 years there has been a slight but steady upward trend in the consumption of polymer packaging.

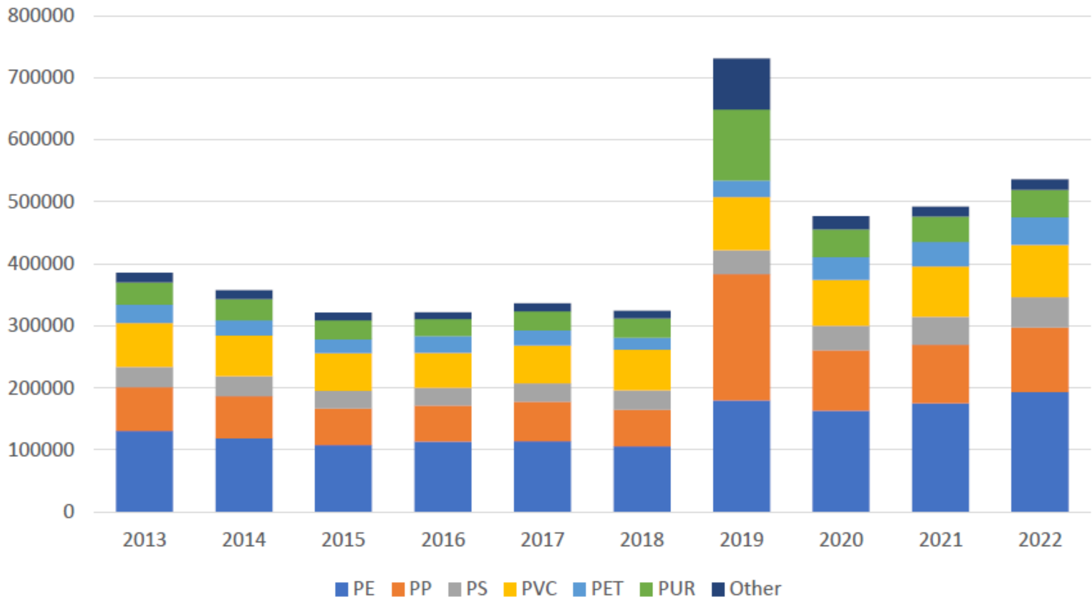

Figure 2.
Different types of plastic entering the Kazakhstan market

This diversity highlights the wide range of applications of plastic materials in different industries. Based on current trends, it is assumed that the trend of growth in polymer packaging consumption will continue in the forecast period. This may require the development of more effective plastic waste management strategies, as well as the active implementation of recycling technologies.

Table 3 presents the forecast for polymer packaging consumption in tons for the period from 2021 to 2030 [97]. The data shows a steady increase in consumption, indicating an increase in demand for polymer packaging materials in the country.

Table 3.
Forecast of polymer packaging consumption in the Republic of Kazakhstan, tons.

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Polymer packaging	176750	178518	180303	182106	183927	185766	187624	189500	191395	193309

The actual data in Table 3 forecast trend of polymer packaging consumption visualizes the dynamics of changes in consumption volumes. The graph highlights the upward trend, which can be attributed to the increase in production and consumption volumes of packaging in various industries, such as the food industry and retail. The steady growth in polymer packaging consumption also points to the need to develop effective disposal and recycling strategies to minimize the negative impact on the environment.

1. *Economic growth*. Increased production and consumption of goods leads to an increase in the use of plastic materials.
2. *Technological development.* Improvements in plastic production technology make it more accessible and popular.
3. *Political and regulatory changes.* Introducing new standards and regulations to improve the quality and safety of plastic materials and to support the recycling and use of biodegradable plastics.

RNR analysis shows that the packaging sector is the main user of plastic materials, driven by the increasing consumption of consumer goods and increasing standards for packaging materials. The transportation and construction sectors also contribute significantly to POM volumes, driven by the widespread use of plastics in the production of automotive components and building materials. The consumer goods and textiles sector also shows significant increases in POM volumes, reflecting changing consumer preferences and increasing demand for synthetic materials. The main polymers used in these sectors include polyethylene, polypropylene, PET, PVC and polystyrene, with volumes steadily increasing in recent years [96].

1.4. Assessment of the Impact of Single-Use Plastic on the Environment in Kazakhstan

The main negative impact of disposable polymer products on the environment is related to their long period of decomposition. The average decomposition period of plastic products created using various technologies is from 400 to 700 years.

Thus, the entire volume of plastic produced by mankind still remains on the planet. In the process of destruction of such products, they disintegrate into small particles, which can lead to the release of chemicals, including toxic ones, used in the production of polymers. Chemical additives are included in plastics for many reasons. To give flexibility to the material, plasticizers are used, for example, phthalates. To improve the heat resistance of products, flame retardants are added.

There are also other components that ensure durability, water repellence, or colour. There are more than 4,000 chemical compounds used in plastic packaging. While not all of these substances are hazardous, at least 63 of them have been identified as harmful to human health. Many of the substances also reduce the recycling potential of plastic products, such as certain dyes. At the same time, there is no information about the presence of specific chemicals in specific products [98].

Complete destruction of plastic waste is only possible through destructive thermal treatment, such as incineration or pyrolysis. When some plastics are burned, toxic substances are released into the air, causing atmospheric pollution. These substances may include chlorine or carcinogenic flame retardants. When released into the ground, these chemicals may leach into groundwater or nearby water sources.

The greatest negative impact of plastic is due to the fact that a significant portion of disposable products is not properly buried in modern landfills and is not recycled. Consequently, they end up in the environment, polluting storm drains and other natural areas. When placed in modern landfills, the negative impact of plastic is limited, as the engineering systems of landfills prevent pollution of soil and groundwater with plastic waste. A huge amount of plastic materials ends up in the world's oceans.

Every year, 5 to 12 million tons of plastic end up in the ocean. The most environmentally friendly types of packaging are paper and cardboard and aluminium packaging. Paper and cardboard packaging is 75% cellulose, which is obtained from a renewable raw material - wood.

Table 4 divides plastic waste into three categories based on their recyclability. The first category, non-recyclable, includes the most problematic types of plastic that are difficult or impossible to recycle. These include polyethylene (LDPE, HDPE, PE), polypropylene, and polyethylene terephthalate. These materials often end up in landfills or in the environment, which creates environmental problems. The second category includes materials that can be recycled, but with restrictions. This includes polyvinyl chloride. Partial recycling may be due to technological difficulties or economic inexpediency, which makes it difficult to effectively manage this waste. The third category is fully recyclable and consists of plastic materials such as polystyrene, polyurethane, and others that are easily recycled and can be reused. This makes it possible to reduce waste volumes and use resources efficiently [99].

Table 4.
Identification of problematic sectors of plastic waste generation

Not recyclable	Partial recycling	Subject to recycling
1. Polyethylene 2. Polypropylene 3. Polyethylene terephthalate	1. Polyvinyl chloride	1. Polystyrene 2. Polyurethane 3.Others

Thus, single-use plastic products cause significant damage to the environment of Kazakhstan due to the long period of decomposition, the release of toxic substances, and improper disposal. Many types of plastic are difficult to recycle, which aggravates the problem of waste and pollution in natural ecosystems. The solution requires the introduction of effective recycling and waste management technologies, especially for the most problematic materials.

1.5 Volume and Structure of Export and Import and Production of Plastic Products in Kazakhstan

Export and import of plastics are of great importance for the economy of Kazakhstan. The country actively participates in the international market of plastics and plastic products.

Kazakhstan exports large volumes of polyethylene, polypropylene, polyvinyl chloride and other types of plastics and products made from them. The main export destinations are Central Asian countries, Russia and other CIS countries, as well as China.

Kazakhstan imports various types of plastics and plastic products, most often from Russia, China, Turkey, the European Union and other countries. Important imported goods are specialized plastics, raw materials for production and high-quality products.

In Kazakhstan, the production volume of rubber and plastic products for the period from January to October 2023 amounted to 367.7 billion tenge (about 1 billion dollars). This indicates significant development of the industry, which plays an important role in the country's economy [99].

1.6. The Main Share in the Production of Rubber and Plastic Products

1. Plastic plates, sheets, pipes and profiles (43.1%). This category includes a variety of products used in construction and other industries, highlighting the importance of plastic in modern construction technologies.
2. Construction plastic products (19.8%). Plastic components in construction are becoming increasingly popular due to their lightness, strength and resistance to environmental influences.
3. Other plastic products (15.7%). This category includes various products used in everyday life, production and other areas, which indicates the wide range of applications of plastic.
4. Plastic packaging for goods (15%). Packaging materials remain an important segment, particularly in the food and retail industries, reflecting market needs for convenient and efficient solutions.
5. Other rubber products (6.3%). This category includes products used in various industries such as the automotive and household goods industries.

Thus, the plastics industry in Kazakhstan demonstrates sustainable growth and diversity, which underlines its importance for the economy and the needs of society. The development of this industry also requires attention to environmental issues and waste management, which will be a key factor in the future.

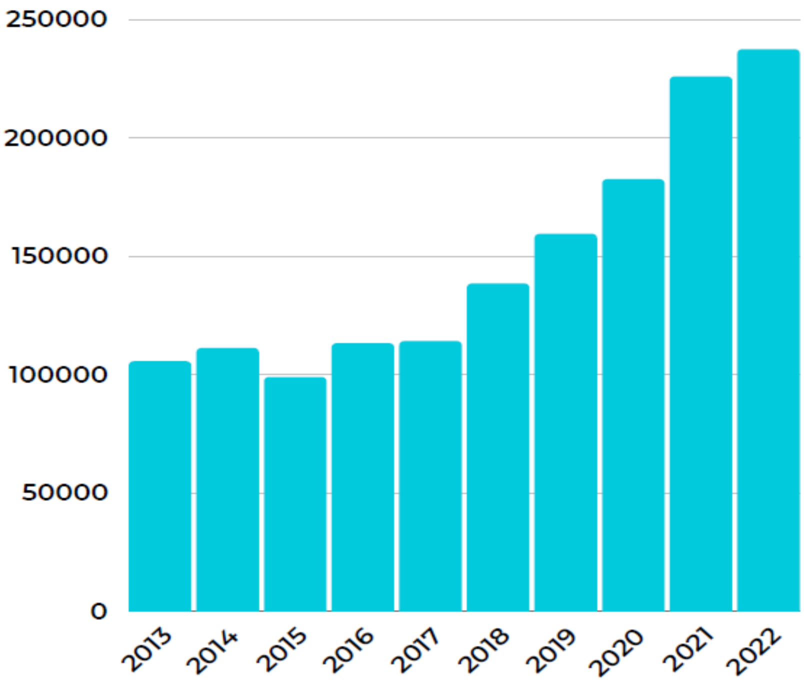

Figure 3.
Domestic production of plastic products (2013-2022).

Figure 3 illustrates the dynamics of domestic production of plastic products in Kazakhstan for the period from 2013 to 2022 [99].

Overall, the data shows a positive trend in production, indicating growth in the industry. Production increased from 105,571 tons in 2013 to 237,408 tons in 2022.

Particularly significant growth was observed from 2017 to 2021, where production increased by 14-23% each year.

Largest increase: The largest percentage increase occurred from 2020 to 2021 (23.8%).

Figure 4a illustrates the dynamics of plastic product exports from Kazakhstan for the period from 2013 to 2022. Data analysis shows a general upward trend in export volumes, indicating the growth of the country's export capabilities in this area [99].

During the analysed period, the volume of plastic product exports showed a steady positive trend, especially starting from 2018. After stable export levels in 2019 and 2020, a significant jump in export volumes has been observed since 2021.

The average export volume for the entire period was approximately 22,718 tons. In 2022, plastic product exports accounted for about 20% of the total domestic production. This highlights that a significant portion of the manufactured products finds its application in international markets, which in turn contributes to the country's economic growth.

Thus, the positive trend in the export of plastic products from Kazakhstan emphasizes the importance of developing export potential for sustainable economic growth and diversification of sales markets.

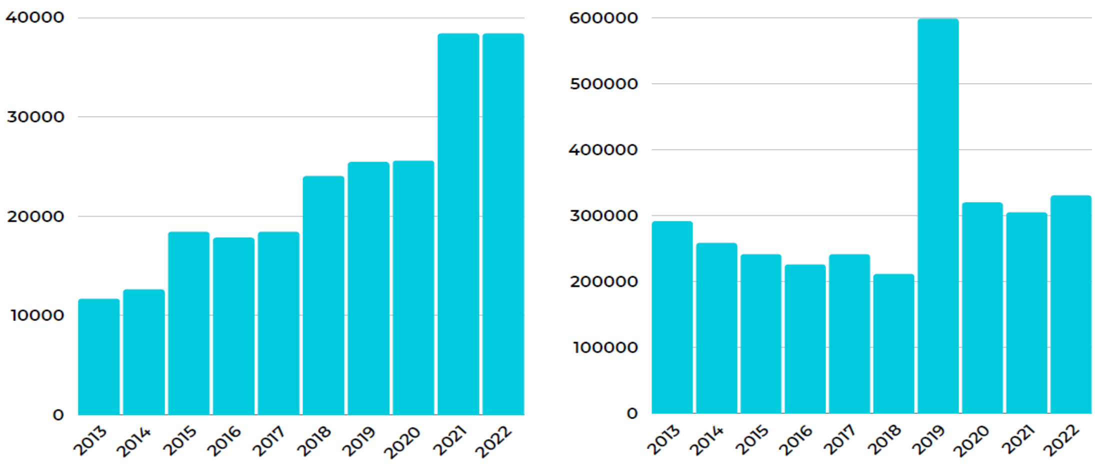

Figure 4.
a) Export and b) Import of plastic products (2013-2022).

Figure 4b illustrates the dynamics of plastic product imports to Kazakhstan for the period from 2013 to 2022. The data shows several key trends reflecting changes in the plastic product market. There is a general downward trend from 2013 (291,481 tons) to 2018 (211,565 tons).

A significant jump occurred in 2019, when import volume reached 598,562 tons, significantly higher than other years. This sharp increase in 2019 was due to fleet modernization programs and increased demand for cars and spare parts.

After 2019, import volumes declined again and stabilized at around 300,000 tons since 2020. The average import volume over these years was approximately 282,932 tons.

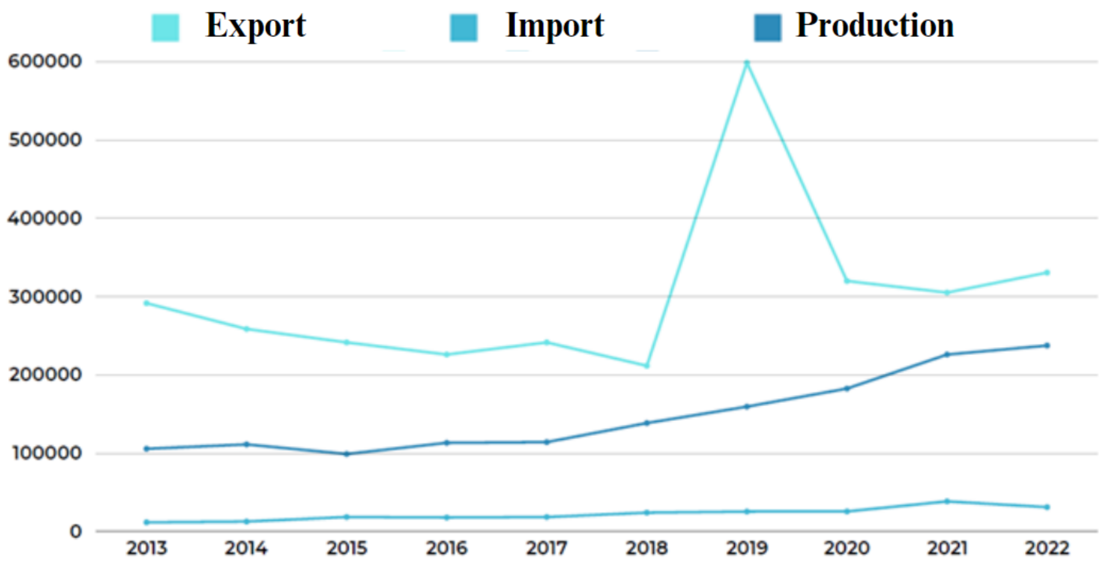

Figure 5.
Summary chart of imports, exports and domestic production.

Figure 5 shows the dynamics of imports, exports and domestic production of a certain product (or group of products) from 2013 to 2022 [99].

Production has shown growth throughout the period, with a particularly significant jump in 2018. Imports gradually declined from 2013 to 2018, peaking in 2019 and then declining sharply. Exports also show some stability and have generally remained relatively stable.

Thus, the plastic industry of Kazakhstan demonstrates sustainable growth, confirming its importance for the national economy and meeting the needs of society. Despite positive trends in production and export, the industry faces a number of environmental challenges related to waste disposal. The growth of plastic product exports highlights the strategic need to develop export potential to strengthen the economy and diversify markets. However, for the sustainable development of the industry, it is important to pay attention to the introduction of environmentally friendly technologies, increasing the recyclability of plastics and reducing their negative impact on the environment.

Based on the data presented, some conclusions can be drawn.

1. *Growth of domestic production.* Kazakhstan has demonstrated the ability to increase domestic production of plastic products, which is a positive trend for the industry. This helps create new jobs and reduce dependence on imports.
2. *Dependence on imports.* Despite the positive developments in production, the country remains heavily dependent on imports of plastic products. The significant volume of imports indicates that local production does not fully satisfy domestic demand, especially during periods of increased demand.
3. *Export opportunities.* Moderate growth in plastic exports indicates that Kazakhstan is gradually developing its export capabilities. However, this process is slower than the increase in domestic production, which highlights the need for further development of the manufacturing sector to enter foreign markets.

2. Sorting, Recycling of Plastic Waste and Modern Technologies in Kazakhstan

2.1. The Share of Plastic Waste Received for Sorting and Recycling.

The problem of plastic waste has become one of the most acute environmental problems of our time, affecting not only the environment but also human health. In Kazakhstan, as in many countries, there is an increase in the volume of plastic waste, which emphasizes the need for an effective sorting and recycling system.

Figure 6, which reflects the interim results of the inventory of plastic waste in Kazakhstan for the period from 2013 to 2030, demonstrates the dynamics of the receipt of this waste for sorting and recycling, and also emphasizes the importance of increasing the level of recycling for sustainable waste management [99]. Data analysis will help to understand current trends and identify areas for improving the environmental situation in the country.

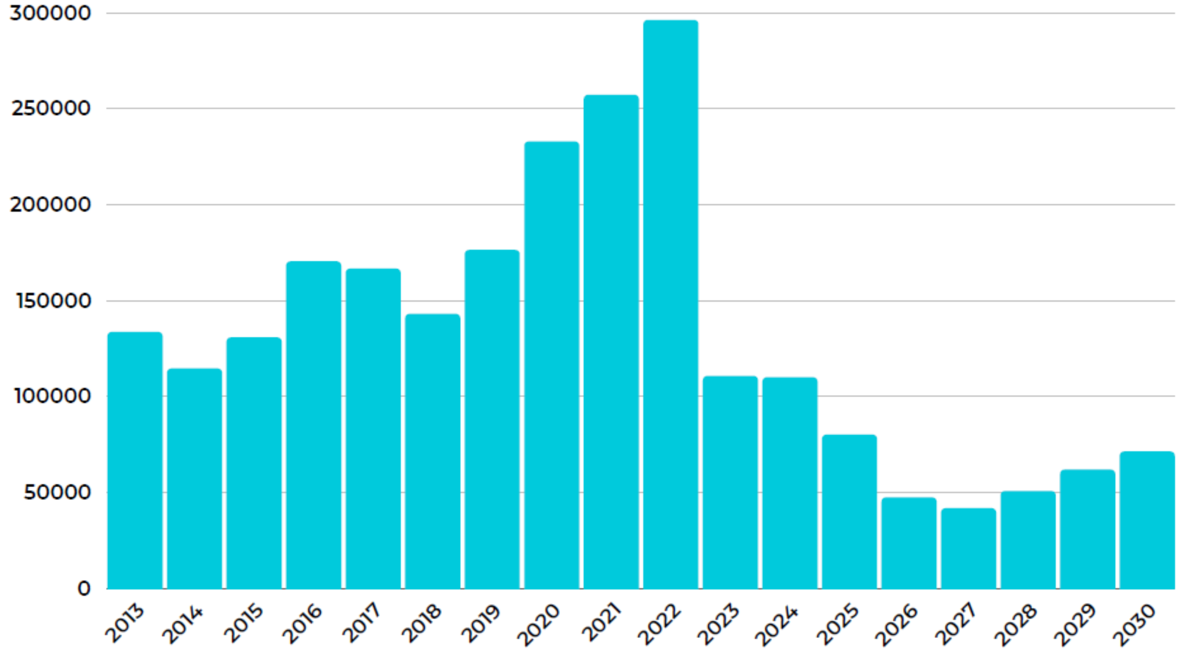

Figure 6.
Interim results of the inventory of plastic waste in Kazakhstan (2013 - 2030).

The amount of plastic waste in 2019 was 176,337 tons, and in 2020 it was 232,847 tons. This may be due to the COVID-19 pandemic, which has increased the use of single-use plastic products such as medical masks, gloves, packaging and delivery of food and other goods.

The average shelf life of packaging is very short - from a few minutes to a few days. In 2013 it was 132,679.37 tons, and in 2022 it was 196,989.60 tons.

In the transport and other sectors, plastic is used in more durable products such as car parts, containers and other durable products. In 2013, it was 0.90 tons and in 2022, it was 6,027.17 tons.

With the increase in consumption of plastic products in recent years, the problem of plastic waste is becoming increasingly urgent. Figure 7, which shows the formation of plastic waste by type of plastic, shows a clear dynamic of the accumulation of plastic waste in Kazakhstan for the period from 2013 to 2022. It is especially worth noting the sharp increase in waste volumes, which highlights the need for more efficient sorting and recycling systems [99].

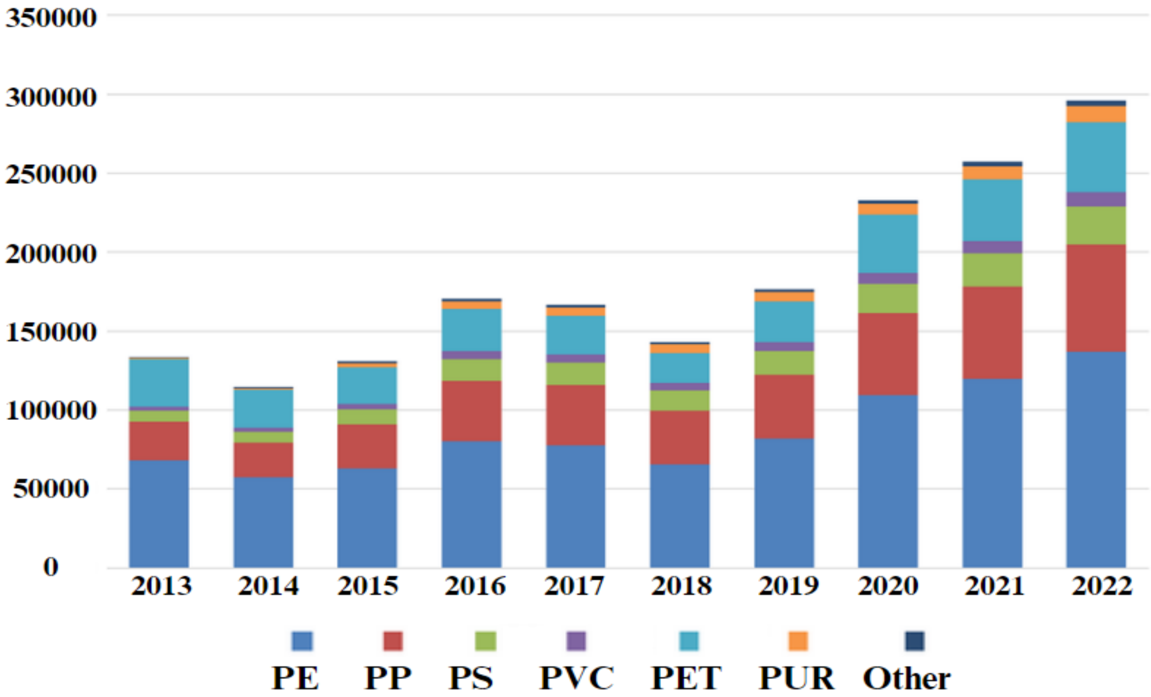

Figure 7.
Formation of plastic waste by types of plastic.

In 2013, the amount of polyethylene (PE) waste was 68,045.85 tons, but by 2022 this figure had doubled, reaching 136,985.77 tons. Such a significant increase indicates that PE remains one of the most common types of plastic, actively used in packaging and other areas. The increase in the volume of PE plastic waste requires attention to the development of effective strategies for its recycling and disposal.

A similar trend is observed for polypropylene (PP). In 2013, the amount of PP waste was 24,645.69 tons, and by 2022, this figure has increased to 67,938.09 tons. The increase in PP waste generation also highlights the need to optimize recycling processes, as polypropylene is widely used in the production of various goods, from packaging to textiles.

Thus, analysing the graph allows us not only to record changes in the volumes of plastic waste, but also to identify key areas that require attention to improve the environment and develop sustainable waste management practices.

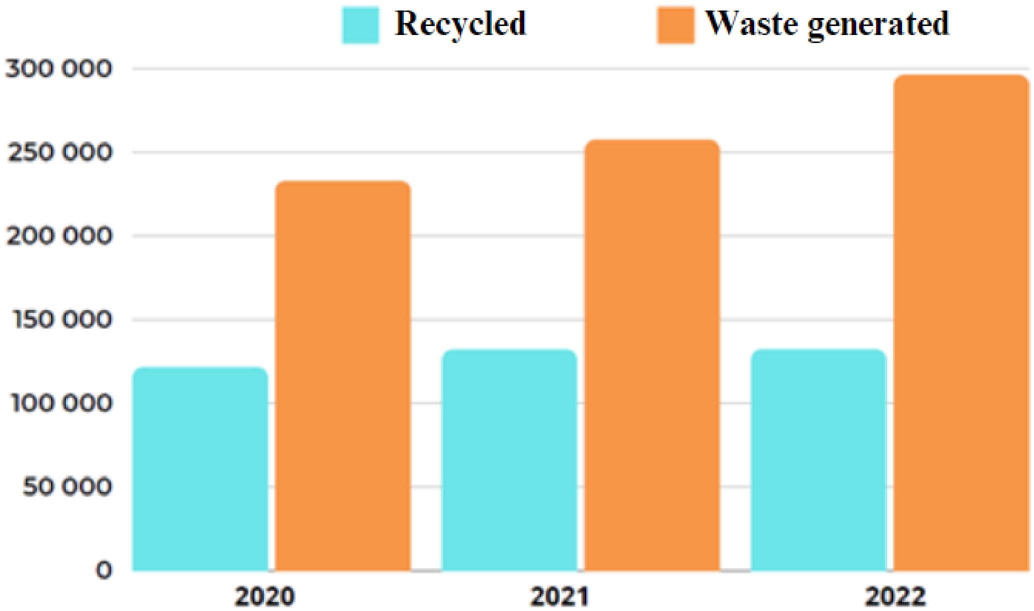

Figure 8.
Share of plastic waste recycling (2020-2022).

In Kazakhstan, about 30-40% of generated plastic waste is recycled annually. This figure indicates the stability of recycling processes, but also indicates the presence of a significant volume of waste that remains unrecycled. It is important to note that the increase in recycling levels is directly related to the development of infrastructure, public awareness, and the effectiveness of state recycling programs.

A comparison of three years of data shows that despite the positive dynamics, efforts to increase the share of recycling must continue. The development of recycling technologies, incentives for the use of secondary materials and active public involvement in environmental initiatives can be key factors in achieving higher rates of plastic waste recycling in the future.

2.2. Level and Quality of Sorting at Different Stages

Every year, Kazakhstan generates about 4.5 million tons of municipal waste. In 2023, 4.135 million tons were accumulated, of which 23.8% were recycled and disposed of (in 2022 - 25.4%). For reference, according to official information from the Astana city administration for the 1st quarter of 2023, the volume of waste generated in the city amounted to 72.9 thousand tons, of which 75.2% were recycled and disposed of (this figure did not change from 2021 to the 1st quarter of 2023). However, in May of this year, the Astana city administration presented official data on the revision of the waste recycling figures and reported a recycling rate of 17% of the total volume. This fact affected the decrease in the strange waste recycling figure.

Since the beginning of the current year, as of May 1, 71.1 thousand tons of waste have been accumulated, of which 12.1 thousand tons were sorted (separated) and sent for recycling. This includes 17%, where the share of selection for recycling of sorted waste is 75.2%.

Below is a Figure 9 of recycled and recycled municipal waste by region [100]. The regions of Kazakhstan are arranged by decreasing population density from left to right in the graph.

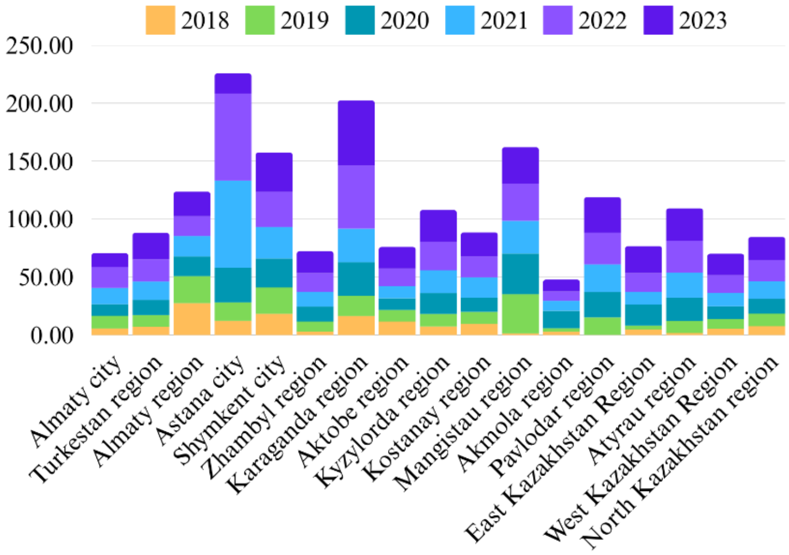

Figure 9.
Data on recycled and disposed municipal waste by region.

2.3. Separate Collection and Sorting of Solid Waste

In the republic, out of 207 cities and districts, separate collection at various stages has been introduced in 130, and sorting in 103 populated areas.

Figure 10 summarizes the implementation of separate collection at different stages and the sorting of municipal waste by region.

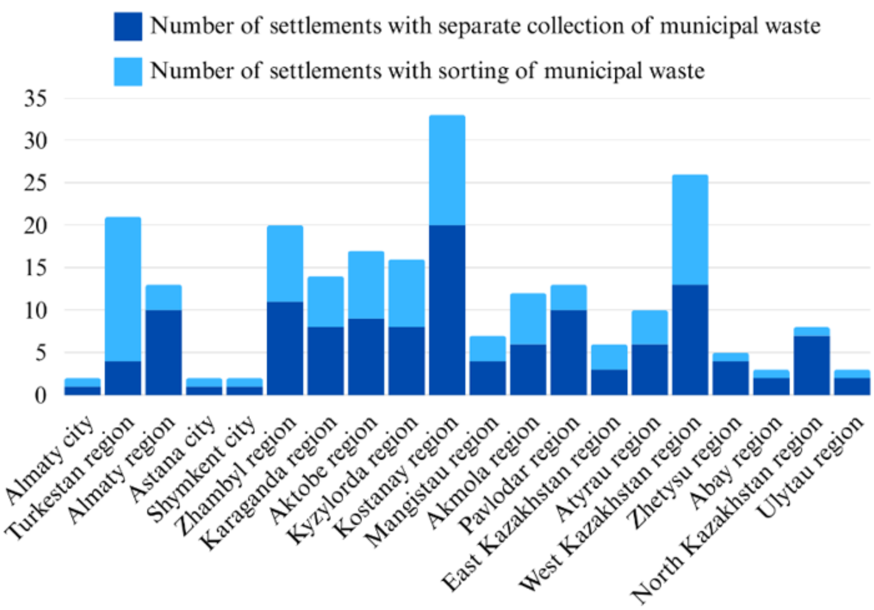

Figure 10.
Data on the implementation of separate collection at different stages and sorting of municipal waste by region.

2.4. Solid Waste Landfills

In 2023, the number of solid waste landfills in the republic amounted to 3016 units, of which 624 (20.7%) were in accordance with environmental and sanitary standards. It is noted that according to information from the Akimat of the North Kazakhstan region, 3 landfills were closed (liquidated). In the Kostanay region, for the current quarter, the permits and decisions on the allocation of land for storage and disposal of waste have expired for 10 solid waste landfills.

Currently, work is underway to prepare the necessary documents for the specified landfills. Also, in the West Kazakhstan region, for 5 landfills, and in the Karaganda region, for 5 landfills, all permits were prepared. The smallest share of landfills that meet environmental and sanitary-epidemiological standards was recorded in Pavlodar - 5 (1.56% of the total number of landfills), North Kazakhstan regions - 11 landfills (2.4%) and Abay region - 5 (2.9%).

Figure 11 shows the number of solid waste landfills in Kazakhstan, indicating their compliance with standards.

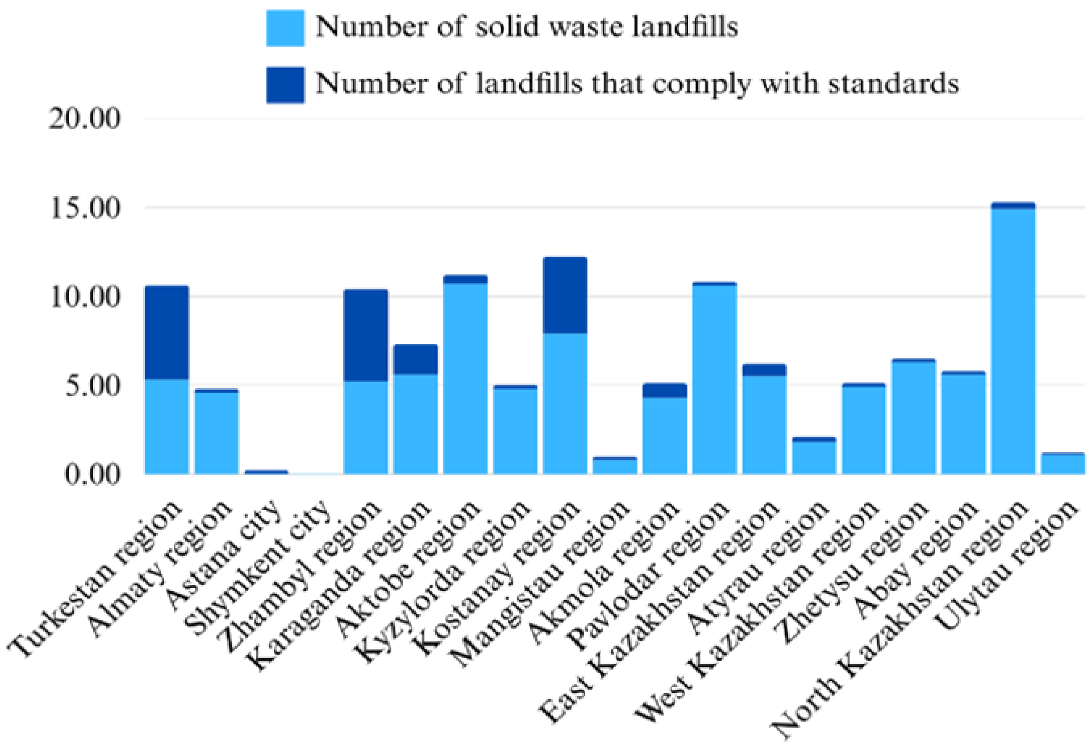

Figure 11.
The number of solid waste landfills in Kazakhstan, indicating their compliance with standards.

2.5. Liquidation Of Illegal Dumps

In addition, space monitoring of waste disposal sites is carried out annually jointly with JSC NC Kazakhstan Gharysh Sapary; according to the results of 2023, 5,534 (2022 - 5,683) unauthorized landfills were identified as part of space monitoring, the liquidation level was 86% (2022 - 77%) or 4,716 objects (2022 - 4,331). Figure 12 shows data on the number of landfills in the country.

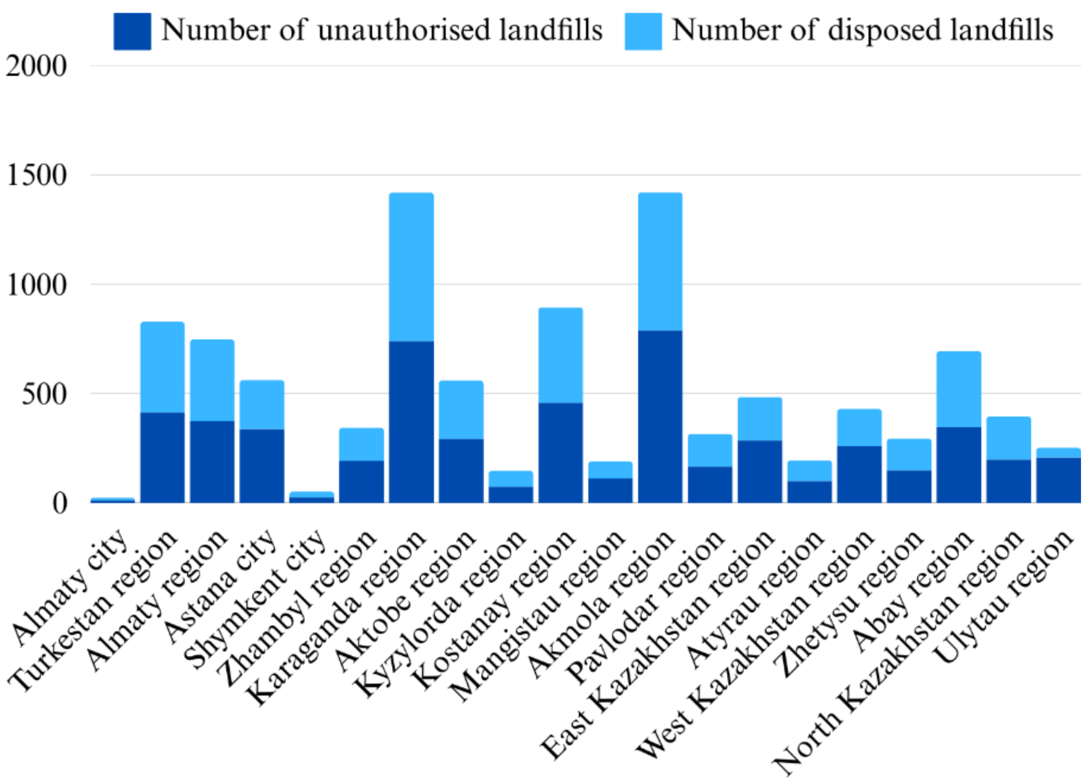

Figure 12.
Data on the number of landfills in the country.

The largest number of illegal dumps identified are in Akmola region – 789 (80% eliminated), Karaganda region – 739 (92% eliminated); weak work on elimination was carried out in Ulytau region [101].

In 2021–2022, three new waste sorting complexes (WSC) with a total capacity of up to 300 thousand tons of waste per year will be gradually launched: in Semey, Ust-Kamenogorsk, and Aktobe [100].

At specialized sites and solid waste landfills, solid waste is sorted both mechanically and manually.

In the cities of Kostanay and Tobyl, there is one complex and three lines for waste sorting. Manual waste sorting is carried out at solid waste landfills in cities such as Rudny, Lisakovsk, Zhitikara, Arkalyk, as well as in Auliekolsky, Amangeldy, Karasu, Kostanay, Mendykarinsky, Sarykolsky and Fyodorovsky districts, as well as in the B. Mailin district.

Most large cities and regional centers have plastic waste recycling plants that produce products such as PET flakes and PET granules, which are then used to create finished products, usually intended for home use.

In 2018, a plastic recycling plant with a capacity of 40 thousand tons per year was opened in the south of the country, near Shymkent; similar enterprises exist in Almaty (Qazaq Recycling), Petropavlovsk and Pavlodar. In the Almaty region, KazPetPolymer LLP is engaged in the processing of polymer waste [102].

Thus, municipal waste recycling in Kazakhstan remains low — only 23.8% of waste was recycled in 2023. The implementation of separate collection and sorting is actively developing, but the results vary by region. Some regions, such as Zhambyl and Turkestan, show good results, while others, such as Pavlodar, require improvement. It is important to continue building waste sorting complexes and eliminating illegal dumps, which generally helps improve the waste situation.

2.6. Methods of Plastic Recycling

There are several reasons why plastic waste needs to be disposed of using specialized equipment.

Thus, the following reasons can be noted.

- Plastic does not decompose under atmospheric conditions;
- Decomposes, but over a very long period of time;
- Releases carcinogenic or toxic substances at high temperatures.

Plastic, as a synthetic material, either does not decompose due to its structural features, or decomposes, but very poorly. The period of complete decomposition of, for example, a plastic bottle can reach 150 years. There are several ways to recycle plastic waste. The choice of one or another method depends on the characteristics of the plastic, economic feasibility and other factors. For example, some types of waste cannot be burned due to air pollution with toxic substances.

Below we will highlight the main modern methods of plastic recycling [60, 70, 78].

1. Burning. It is the cheapest method of recycling. It is suitable for burning polyethylene (PP) and other plastics, the burning of which does not result in the release of toxic substances. Residential buildings are heated in this way, since thermal energy is released during the recycling process. Emissions of substances into the atmosphere are controlled [103-107].
2. Pyrolysis. It is a fairly new technology. During the polymer processing process, the material is decomposed into molecules, which are then used as synthetic fuel [108-111].
3. Mechanical processing and granulation. The method is much more complex and expensive. In the process, the plastic is processed into granules or crushed, and the particles are then reused. Thus, this method is only economically feasible for the mass production of plastic items. The method can be used to process polymer mixtures that cannot be burned [112-115].
4. Chemical method. This method of processing involves changing the structure of the material at high temperatures. It is used to obtain valuable chemicals and thermal energy, while the structure of the plastic is completely destroyed [116, 117].
5. Burial. Still used as a recycling method for some types of plastic, such as PVC [118-122].

There are also other technologies for recycling plastic, the main ones are presented above. Plastic waste is one of the environmental problems of the modern world. The goal of all production should be the correct and timely disposal of waste with minimal emissions [123].

1. The following technology is used to extract plastic from waste for subsequent recycling [115]:

- Plastic waste is mainly delivered to the recycling plant by companies specializing in waste collection from individuals and legal entities, as well as solid waste landfills.
- The company stores waste, sorts it by type (PET, PP, PS, etc.) and colour of plastic, cleans it from labels, metal and other “foreign” elements for each type of plastic.
- The waste is crushed, washed with hot water and a soda solution (disinfection), and finally dried and packaged, followed by sending as an intermediate product for the manufacture of final products.

At the beginning of the development of the plastic waste inventory, there was a choice between two methodologies: The Material Flow Analysis (MFA) approach and the Product Lifetime Methodology (PLM). In order to conduct an effective and accurate inventory in Kazakhstan, the Product Lifetime Methodology was chosen for several reasons. PLM allows for an accurate assessment of the volume of plastic waste, considering the duration of use of plastic products. It tracks the flow of materials from production to disposal, predicting waste generation. MFA, unlike PLM, focuses on current flows and recycling, but does not consider the service life of products, which limits its effectiveness in predicting waste volumes.

The choice of the product life cycle methodology is explained by the need to forecast in detail the volumes of plastic waste and create effective management strategies. This approach provides a deep understanding of the life cycle of plastic products and their impact on the environment [96].

A significant portion of plastic labelled 7 (other types of plastic) and biodegradable plastic is almost not recycled in the world. The only way to dispose of it is to burn it R on the Implementation of Research Work for Official use by the E E Commission [102] Plastics marked 3 and 6 are rarely accepted for recycling due to the labour-intensive nature of the process and their high toxicity.

In hazardous waste incineration plants, solid residues are partially melted and are slags. In waste incineration plants, inorganic residues are often in the form of ash due to lower temperatures.

Waste pyrolysis and gasification, also referred to as "alternative" thermal treatments, have been around since the 1970s. Alternative processes are characterized by fairly complex system design.

Equipment manufacturers claim that, compared with waste incineration, alternative processes show the advantage of higher electrical efficiency and/or produce higher quality products such as liquid energy to replace other fuels or vitrified slag with very low leachability.

Despite a number of failures, alternative thermal processes are not very relevant in the EU, but are still being considered in other countries, for example, due to the long-term experience of operating such plants in Asia, especially in Japan.

Both pyrolysis and gasification differ from incineration in that they can be used to recover the chemical value of waste (instead of its energy value). The resulting chemical products can in some cases be used as feedstock for other processes. It is possible to extract N_2O from processes with sub stoichiometric oxygen supply, such as gasification and pyrolysis. It should be noted that thermal processes require significantly more processing efforts compared to traditional waste incineration [124].

Thus, plastic waste requires specialized recycling methods such as incineration, pyrolysis, and mechanical recycling, each of which depends on the type of plastic. Product life cycle methodology (PLM) helps to accurately estimate waste volumes, considering the lifespan of products, and to develop effective waste management strategies.

3. Conclusion

The problem of plastic waste is one of the main environmental challenges in Kazakhstan and the world. The increased use of plastic materials leads to a rise in waste volumes, which negatively affects the environment and health. Disposable plastic products, which take a long time to decompose and are often not recyclable, are especially dangerous.

Despite the growth of plastic production in Kazakhstan and the development of export opportunities, waste recycling remains an unsolved problem. The introduction of effective recycling technologies and an increase in the share of secondary materials can help address this issue. For a successful resolution, measures to improve the recycling infrastructure, strengthen control, and involve society in environmental initiatives are important. An integrated approach, including innovative technologies, legislative changes, and increased environmental awareness, is key to reducing the plastic waste burden and ensuring the sustainable development of the country.

3.1. To Achieve Your Goals, You Must Adhere to the Following Recommendations

1. *Tightening of legislation*. It is necessary develop and implement regulations that limit the use of single-use plastic. It is also necessary to introduce a system of fines and incentives to stimulate environmentally responsible behaviour of producers and consumers.
2. *Development of processing infrastructure.* It is necessary and invest in the creation of modern plastic recycling plants, including thermal and chemical recycling technologies. The next step is to improve the logistics of collecting and transporting plastic waste.
3. *Increasing the level of sorting.* Installation of additional waste collection and sorting points in cities and rural areas. Organization of educational campaigns to increase environmental awareness of the population will significantly help the current situation.
4. *Promoting sustainable alternatives.* Support the development and use of biodegradable and reusable materials as replacements for single-use plastics. Provide subsidies for producers of environmentally friendly packaging.
5. *International cooperation.* Attract international investment and expertise to improve recycling technologies. Participate in global initiatives to reduce plastic pollution and exchange best practices.
6. *Support for scientific projects* aimed at finding and scientifically substantiating the content of environmental risks.

The implementation of these measures will significantly reduce the negative impact of single-use plastic on the environment, as well as increase the sustainability of ecosystems and improve the quality of life of the population of Kazakhstan. This will not only strengthen the environmental safety of the country but also strengthen its position in the regional and global context as a leader in environmental transformations.

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