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PLASTIC WASTE MANAGEMENT IN THE SMART CITIES: POLAND AND TURKEY AS A CASE STUDY

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Introduction/background: Waste in various forms, such as solid waste, gaseous waste, and liquid waste, increases as a result of population growth, urbanization, and industrialization, and has a global impact. Waste management entails activities such as reuse, recycling, and reducing waste generation, as well as other strategies to combat the effect of waste generation caused by increasing population and industrialization. Monitoring is a critical function of waste management because it is required to address waste management issues such as waste generation, waste collection, waste transportation, waste treatment, and waste disposal. The article presents plastic waste management in the context of smart cities.
Purpose: The goal of the article is to present and compare of the production of plastic waste in Poland and Turkey in the context of smart cities. Sustainable and eco-innovation plastic waste management solutions to reduce plastic waste are provided to be implemented in smart cities. In this study, smart cities are explained, how to manage plastic waste by using smart city components, and methods of dealing with plastic waste are explained.
Methodology: The article is based on a review of the literature, own observations and own experience. The currently available plastic waste management solutions were analyzed and examples in the implementation of the technology in a smart city are described.
Findings: The incorporation of smart city technology into waste management practices provides a smart way to solve waste issues. The main of plastic waste management is to develop methods to transform plastic waste into a circular economy. As estimated by 2030 plastic leakage to ecosystems should be 30% reduced, double the global recovery of plastic (collection and recycling), and shift to sustainable inputs for remaining plastic, including recycled content, sustainably sourced biocontent, advanced products and reducing unnecessary plastic through a business model, innovation, reduction and substitution.
Originality: The goal of waste management is to recover as much useful material as possible, including energy. Waste generated in smart cities is a category of municipal waste. Traditional approaches to waste management have failed because they are not reliable or sustainable because they require a lot of input for little or no work output. The incorporation of smart city

technology into waste management practices provides a smart way to solve waste issues. The main of plastic waste management is to develop methods to transform plastic waste into a circular economy.

Keywords: Plastic wastes, waste management, smart cities, eco-innovation solutions.

1. Introduction

Within the scope of research carried out by the United Nations to design a more livable future, it is predicted that approximately seventy percent of the world's population will live in cities by 2030. The United Nations advises member states to take action as soon as possible to establish sustainable solutions for urban life because it forecasts that the population of cities will utilize the world's resources much more in the near future than it does now. The United Nations is also trying to find solutions to increase efficiency and energy savings for complex systems such as waste management, water management, public transportation management, mass lighting and heating management in megacities. At the start of these incentives, basic systems such as street lighting and traffic lights are equipped with more environmentally friendly solutions. Zero waste initiatives seek to unite cities around smart waste management solutions, which, in the eyes of the United Nations, is one of the most critical needs of cities. They are especially supported at the local government level.

2. Smart cities and waste management

2.1. What is smart city?

The same issues have existed since people first started settling in cities more than 6000 years ago: sanitization, crime, traffic, tax collection, upkeep of public infrastructure, and emergency services (Albino et al., 2015) . Infrastructure is also necessary for the development of significant technological advancements, including the electric grid, telephone and cell phone networks, internet (including fiber optic and cable networks), hot and cold running water, water and waste treatment, garbage and recycling collection, public parks and recreation facilities, rail, light rail, and automotive streets, roads, thoroughfares, and rights-of-way (Achmad et al., 2018; Fayomi et al., 2021). The main components of a smart city are presented in the Figure 1.

A smart city, to put it simply, is a place where existing networks and services are improved for the benefit of its citizens by using information, digital, and telecommunication technologies to make them more adaptable, efficient, and sustainable. To put it another way, in a smart city, the utilization of digital technologies translates into improved public services for residents and better resource management with lower environmental effect (Balaban, 2019; Örselli, Akbay, 2019; Baran et al., 2020).

The following is one of the official definitions of the smart city: a city that "connects the social, business, information-technology, and physical infrastructure to exploit the collective intelligence of the city". "A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operations and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, and environmental aspects", states another formal and thorough definition (Mohanty, 2016; Barlow, Levy-Bencheton, 2018; Liu et al., 2020; Singh, Jara, 2022).

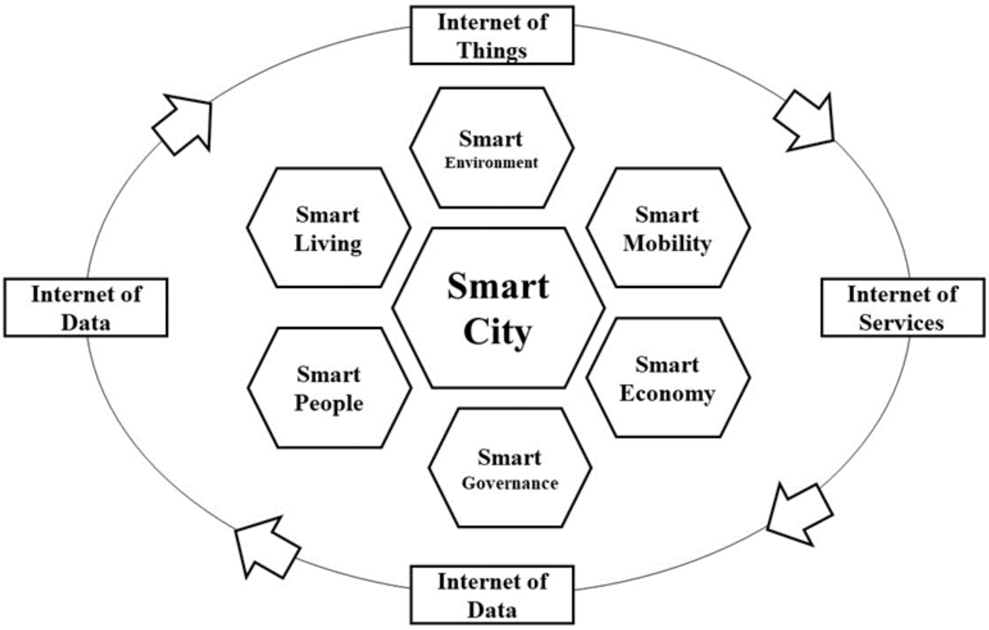

Figure 1. The main components of a smart city.
Source: Modified from Khatoun and Zeadally (2016).

2.1.1. Smart city in Turkey

It is seen that some targets regarding smart cities have been determined in both development plans and programs as well as different policy and strategy documents since the 2000s in Turkey. The following documents: The 10th Development Plan, Annual Programs, National Science and Technology Policies, 2003-2023 Strategy Document-Vision 2023, Information Society Strategy and Action Plans are the ones that draw the most attention. However, the Smart Municipalism Summits, Smart Cities Congress, Smart Cities Transformation Movement Project, Smart City Fair and Smart Cities Automation System are some of the organizations that bring the public and private sectors together in developing of idea of smart cities in Turkey (Adıgüzel, 2017).

The project to establish an eco-tech settlement started in Yalova at the beginning of 2000 is the Informatics Valley Project, which is accepted as Turkey's first smart city application. After this implementation, the Informatics Valley Projects started to be put on the agenda by other cities, especially Bursa, Kocaeli and Ankara. In addition, it is possible to come across municipality-based projects such as three-dimensional street imaging that works in harmony with the GoogleEart program of Fatih and Beyoğlu municipalities. However, the first smart city project, which was prepared as a solution to manage city services as a whole, was started in our province of Karaman. Efficiency will be experienced in all processes in city life with 20 applications integrated with sensors, IoT components, infrastructure, kiosks, touch screens, information screens, mass message systems, smart park and TEDES (Traffic Control Systems), data center and operation center (Bıyık, 2019; Soydan, Benliay, 2020).

It is planned to ensure the sustainability of the city by using smart irrigation, smart lighting, smart meter reading systems and water and energy resources efficiently; thus, it is tried to strengthen the communication between the municipality and the citizens by increasing the quality of service. With the Smart City Automation System project, a knowledge-based management approach and participatory municipalism were aimed as a result of on-site determination of information about the city and its inhabitants on the basis of addresses and real estate. It is possible to mention data analysis center, geographic information system (GIS), traffic control center, vehicle tracking system with GPS, waste management, wifi, central communication, navigation, security cameras and partially renewable energy projects as common points of our major metropolitan cities within the scope of smart city (Dener, 2018; Çetin, Çiftçi, 2019).

With the Istanbul Fatih Municipality web-based GIS project, for the first time in the world, floor sections and independent sections can be interrogated and analyzed in three dimensions with a sketch-based field study and compared with existing projects. Fatih Municipality has also included the Augmented Reality application into Smart City projects. With the "FatihAr" application, historical, cultural, public areas and parcel information in Fatih can be displayed verbally, picture, audio and video in four different languages. When the image of any building in Fatih Municipality is taken and sent to the relevant service center with 3G-4G communication technology, the information about that building can be transferred to the user immediately from the information center. In addition, approximately 20 different cleaning activities carried out in the field are monitored with the ÇEVKO mobile application, and data is entered into the system instantly.

Izmir Metropolitan Municipality, while trying to reduce carbon emissions with its projects of environmentally friendly ships, tram, subway, suburban and electric bus fleets, also provides the electricity required for the vehicles in the fully electric bus fleet with the 10 thousand m^2 solar power plant installed by ESHOT on the roof of the workshop buildings in Buca. In addition, in order to meet the electricity needs of Ekrem Akurgal Life Park, the roofs of the gym and parking areas in the park have been converted into energy facilities. With solar panels, 45 thousand kilowatt hours of electrical energy was provided in three months, preventing 19 tons of carbon dioxide emissions.

2.1.2. Smart City in Poland

In Poland, the idea of the smart city is gaining popularity. The National Urban Policies 2023, the fundamental document outlining the functions of the Polish government administration in the area of urban development, first introduced the idea of the smart city. The standard PN-ISO 37120:2015 03 Sustainable social development - Indicators of urban services and quality of life, which is a part of a set of ISO standards presenting an integrated approach to sustainable development, was also published by the Polish Committee for Standardization. Thirdly, initiatives and conferences like the "Smart City Forum," the biggest conference in Poland entirely devoted to the subject of smart cities, which was attended by local government representatives, presidents of major corporations, and international experts, demonstrate interest in the idea of the smart city.

In 2020, only two Polish cities - Warsaw and Wrocław - were included in the IESE Cities in Motion Index ranking the most smart cities in the world. However, other largest Polish cities, as well as much smaller centers, have already entered the road to being a smart city. In the IESE Citis in Motion Index for 2020, Warsaw was ranked 69th and Wrocław 95th. Both cities also took two leading places in the "Polish Cities of the Future 2050" ranking prepared by Saint Gobain. In both rankings, both Warsaw and Wrocław were recognized for their transport investments. In Wrocław, most projects related to the smart city project concern getting around the city. One of the key projects was the launch of the Intelligent Transport System (ITS) in 2014, under which 1,285 cameras were installed at 159 Wrocław intersections. Additionally, nearly 650 trams and buses were equipped with on-board computers and detectors cooperating with the software.

The ITS system is also coordinated with the Dynamic Passenger Information system. For the majority of people traveling in the largest Polish cities, but also in smaller towns, electronic boards informing about directions and real times of departure of buses and trams are almost the norm. Moving around the city by public transport, both in Wrocław, in Gdańsk, they also have the opportunity to see where the bus or tram they are waiting for is located. All they need to do is install the appropriate applications on the phone.

Since 2018, in Wrocław, in addition to traditional paper tickets available in stationary machines at stops, there are also virtual ones available in machines installed in trams and buses. The Urbancard system automatically assigns the purchased ticket to the number of the payment card with which the passenger makes the purchase. For the 8.5-year contract under which the system will operate, the city paid almost PLN 174 million.

Systems that allow residents to report problems also help to increase safety on city streets. As long as, like Big Brother, they are supported by a camera system.

According to the authorities of Katowice, the local Intelligent Monitoring and Analysis System consisting of 300 cameras scattered over more than 160 square kilometers of the capital of the Silesian province. The number of car thefts decreased over four years - from 337 in 2016 to 79 in 2020. On the other hand, police data show that from 2017 to 2020 the number of crimes is decreasing, and their detection rate constantly exceeds 65%.

2.2. What is waste management?

Reuse, recycling, and other waste management practices reduce trash production while also reducing the impact of waste generation brought on by industrialization and population growth. One of the most important tasks in waste management is monitoring, since it is necessary to deal with the problems that arise during the processes of trash generation, waste collection, waste transportation, waste treatment, and waste disposal (Saleh, 2020). To manage the trash effectively and attain zero waste, it is crucial to characterize garbage. Recent studies on intelligent waste management have come down to achieving zero waste, which is motivated by resource and raw material conservation and lowering municipal waste problems in smart cities (Fayomi, 2021). By reusing, recycling, composting garbage, and minimizing waste, we can address these problems, which include the production of toxic gases and air pollution through incineration, as well as land pollution and contamination that can cause disease outbreaks through landfilling (Figure 2). In other words, collection, storage, transportation, and disposal of garbage are all included in waste management. It depends on a collection of integrated resources and procedures used in the proper management and disposal of these wastes. This entails correctly classifying wastes, maintaining disposal trucks, maintaining dumping sites, and establishing a system that complies with environmental requirements. The complete management system should be planned to guarantee effective waste disposal while avoiding health risks and safeguarding the environment. Because different regions are obligated to abide by the rules and environmental restrictions put out by their governments, waste disposal practices may vary from one location to another (Adeniran et al., 2017).

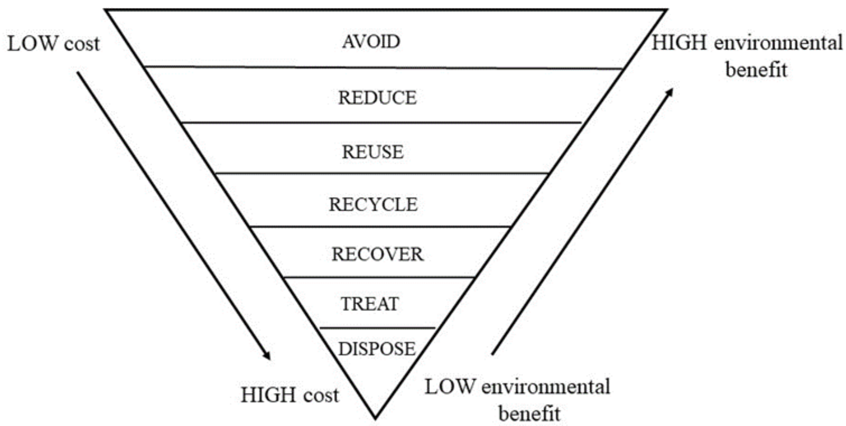

Figure 2. The strategies in waste management.
Source: Modified from Fatimah et al. (2019).

Effective waste management is a crucial prerequisite for ecologically sustainable development in many nations. In today's world, efficient garbage sorting is a significant problem. The consumption society in Europe has contributed to an ever-increasing amount of trash creation. This is a result of consumer behavior that is made worse by packing. It is demonstrated that western Europe produces close to 1.2 kilograms of garbage each day per person (Glouche et al., 2015).

Contrarily, the same consumers who care about environmental protection frequently express opposition to increasing land-filing or incinerators. As a result, garbage should be appropriately disposed of and managed to minimize its influence on the environment. The market for waste management services is expanding, and for the service providers, however the garbage collection procedure is a crucial component. The following are the key objectives: 1) reducing waste generation, 2) ensuring that waste is disposed of properly, 3) recycling and reusing discarded goods (Bolivar, 2015; Fayomi et al., 2021).

Regulations and taxes are being put in place to reward moral behavior in order to accomplish these goals. There is a growing tendency toward individual billing, where people are paid according to how much rubbish they dispose of, specifically to reduce waste creation.

2.3. The significant of waste management

One of the most important public causes is waste management. The main fraction of waste management is solid waste management (Figure 3). According to the UNEP, annual urban waste generation in OECD countries ranges between 7 and 10 billion tons. While waste is conceptually collected, segregated, recovered, and disposed of by a landfill or incineration process, the majority of waste typically accumulates at the landfill stage (UNEP, 2015; Mokale, 2019). Scheme of waste management in smart cities is presented in the Figure 4.

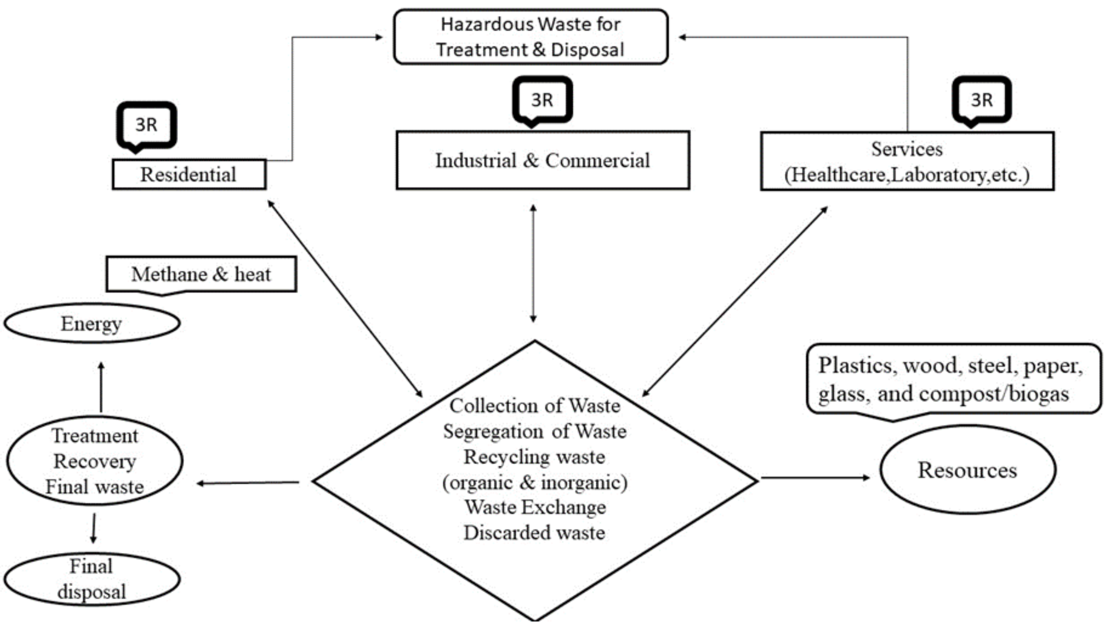

Figure 3. Solid waste management diagram.

Source: UNEP (2015).

Developing countries are particularly vulnerable due to a lack of collection coverage and controlled disposal. While municipal budgets for solid waste management range from 20 to 50%, the World Bank estimates that 30 % to 60 % of urban solid waste in developing countries goes uncollected (Gade et al., 2021). Uncontrolled landfill is especially common at the municipal level, and untreated waste on open sites frequently causes public health concerns as well as environmental pollution. As a result, preventing this accumulation through proper waste management will improve global competence in addressing the world's current environmental challenges (Esmaeilian et al., 2018; Cesconetto et al., 2020).

The ASEM Eco-Innovation Index (ASEI), developed by the ASEM SME Eco-innovation Center, is also linked to the concept of adequate waste management (ASEIC). The ASEI fundamentally assesses Asia and Europe's sustainability, and it is a comprehensive index comprised of four main categories: capacity, supporting environment, activity, and performance. Among those categories, supporting the environment and performance are particularly relevant to the issue of waste management (Surapaneni et al., 2018).

Despite global efforts to manage waste, it is especially difficult to dispose of nonbiodegradable waste because its innate character is not decomposable over time.

Figure 4. Scheme of waste management in smart cities.
Source: Modified according to Mahajan and Quazi (2017).

3. Plastic waste management

3.1. Plastic and microplastic waste

In 1972, the world became aware of the presence of micro-sized plastic particles in the aquatic environment for the first time, when it was reported for the first time that a large number of small floating plastic particles were found in the surface water of the Sargasso Sea. In 2004, these small particles were defined as microplastics. Later, plastics smaller than 5 mm were accepted as microplastics by the Steering Committee of the National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program. In the future, plastics of different sizes were standardized. Accordingly, Macroplastic ≥ 25 mm, Mesoplastic 25-5 mm, Microplastic ≤ 5-1 mm, Mini-microplastic <1mm-1µm and Nanoplastic < 1µm (Faraca, Astrup, 2019). Although the main source of microplastics in the aquatic environment is microplastics formed as a result of the breakdown of larger plastic parts, microplastics are also produced industrially for different purposes (https://mikroplastik.org/...)

Plastic waste mainly includes macroplastics with a diameter ≥ 5 mm such as bags, balloons, bottles, or straws, most of them cause serious harm to habitats and wildlife. Now, there is growing research focused on the widespread presence and impacts of microplastics particles with a diameter < 5 mm (Koelmans et al., 2017; Piehl et al., 2018). Microplastics consist of plastic fragments, flakes, fibers, or pre-production pellets.

Plastic is everywhere and is unquestionably the foundation of globalization. There is an increasing need in packaging, agriculture, autos, and biomedical fields due to the fabrication of desired shapes and specifications appropriate for future clients. Due to the development of information technology and smart packaging systems, they are crucial to the modern world. Globally, critical waste management issues have arisen as a result of rapid urbanization, population growth, and industrial expansion. Environmental issues frequently come into conflict with concomitant economic progress and modernization. According to the US Environmental Protection Agency, since the 1960s, the usage of plastic has increased significantly, and as a result, the percentage of plastic trash in the overall municipal solid waste stream has climbed from 1% to roughly 13% (Ritchie, Roser, 2020). The using of plastics in various industrial activities is presented in Figure 5.

According to research by the United Nations Environment Programme, some 400 million tonnes of single-use plastic (SUP) waste is produced annually (47% of all plastic waste), and roughly half of this amount is used for disposal, or purchases that are thrown away within a year.

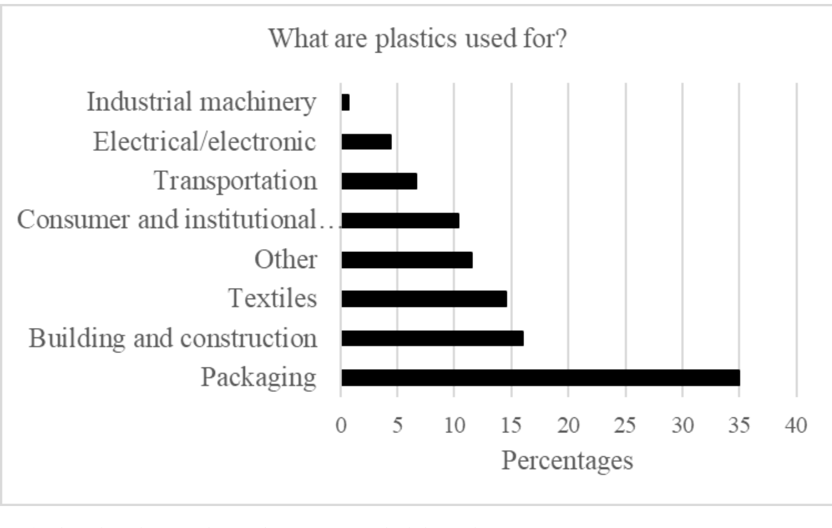

Figure 5. Using of plastics in various human activities (in %).

Source: Modified from Singh and Trivedi (2020).

Bakelite, the first synthetic material, was created in 1907, marking the beginning of the world plastics industry. However, it took until the 1950s for the exponential development in worldwide plastic manufacturing to be understood. Plastics production has more than doubled in the last 200 years. This is roughly equivalent to the mass of the entire world's population (Lombardi et al., 2012).

While concerns regarding the viability of reuse, recycling, and disposal are on the rise, so are the usage and consumption of plastic. Plastics are becoming less recyclable due to changes including the increase in chemicals used to change their strength, texture, flexibility, color, resistance to microorganisms, and other properties. Additionally, some plastics have a very limited market value, which forces communities to landfill or burn plastic as waste. The Environmental Protection Agency estimates that just 8% of plastic supplies are recycled (EPA, 2020).

The lifespan of plastics and the lack of clarity surrounding their biodegradation raise serious concerns about their disposal in the waste stream.

It is estimated that the majority of plastics will take between 500 and 1000 years to totally break down into organic components. Due to its durability and low recycling rate, the majority of our plastic trash is disposed of in landfills or as litter. It is undeniable that plastic garbage has an impact on living things across the ecosystem, either directly or indirectly. This impact on aquatic life, both at the macro and micro scales, is disturbingly large. In fact, the United Nations estimates that plastic makes up over 80% of marine waste (Dąbrowska et al., 2021).

3.2. Popular ways to deal with plastic waste

Landfills and Incineration

One of the following approaches is typically used to control waste: Incineration simply involves transporting substantial amounts of waste to facilities for waste management, where it is burned to produce carbon. In addition to being buried underground in landfills, a significant amount of the rubbish we produce also frequently ends up being dumped in open areas, leaving streets and rural areas littered (quite unfortunately). Despite the fact that these techniques are frequently used, they nonetheless have drawbacks. The majority of the waste we produce is disposed of by incineration or landfilling. Building landfills can be challenging, and burning waste produces a lots of greenhouse gases that are released into the environment. These problems cause both techniques to have a detrimental environmental impact (Mahajan, Quazi, 2017).

What are the differences between these approaches, which is more efficient, and what are the repercussions? As garbage decomposes in a landfill, methane is produced. It is possible to recover this gas and use it to produce electricity. In this regard, landfilling is a successful technique of disposing of certain municipal solid waste (MSW), although plastic trash remains an ongoing issue. Plastic garbage decompose very hard or change composition as it sits in landfills. It is just unsustainable for plastic garbage to accumulate in landfills.

When plastic is burned, a significant amount of fossil carbon is released as CO2 into the air. It is possible to reduce the amount of greenhouse gases discharged into the atmosphere by using plastic separation techniques prior to incineration, but this is easier said than done. The management of waste involves several aspects. However, increasing the effectiveness of plastic separation may be less harmful to the environment. Even though incinerating wastes a lot of energy, some of it can be recovered. Although removing plastic trash from the equation lowers greenhouse gas emissions, there is a significant decrease in the amount of energy that can be obtained from incineration without plastics. The goal of waste management is to recover as much useful material as possible, including energy. Thus, a variety of elements are involved.

Techniques for recycling plastic waste

Plastic waste material that would otherwise become solid garbage is collected, segregated, processed, and then put back to use through a process known as recycling or reprocessing. Collecting, sorting, cleaning, and ultimately reclamation are steps that must be taken in order to develop an effective and affordable method for recycling waste plastics that have completed their intended function, removing them from the waste stream, and getting them back into the manufacturing process. Recycling via mechanical (or physical) processes is the economically preferable form of recovery for homogeneous plastic waste streams. However, chemical and thermal procedures are more effective at handling or treating heterogeneous plastic waste streams in order to recover essential chemicals and/or energy.

Some recycling methods can be listed as follows: mechanical recycling, monomerization, blast furnace feedstock recycling, coke oven, chemical feedstock recycling, gasification, liquefaction and thermal recycling (Mahajan, Quazi, 2017; Köseoğlu, Demirci, 2018).

3.3. Importance of plastic waste management

There is only one environment, and it ought to be respected as such. It makes sense to reuse raw materials that have already been mined whenever possible. As a result, reserves will be more durable in the future. Recycling plastic garbage also helps protect natural resources, notably raw materials like energy and oil. Natural resources will last longer for future generations if more is recycled. It indicates that activities like mining, quarrying, drilling for oil and gas, clearing forests, and the like have less of an impact on the environment. Less of these operations will protect the ecosystem from ongoing deterioration and damage.

Recycling may also reduce atmospheric emissions of pollutants like carbon dioxide (CO_2), which is a benefit to the environment. From "life-cycle" analyses of raw and reprocessed plastics, it is known that recycled plastics emit significantly fewer CO_2, SO_2, and NO_X (NO and NO_2) emissions than virgin materials. Therefore, if recycling is practiced on a wide scale, the environment will be better protected from air pollution and global warming. Groundwater and surface waters will both be protected from pollution by recycling plastic trash. This is due to the fact that, if disposed of carelessly, they clog gutters and may even find their way into bodies of water that supply towns and cities with drinking water. Additionally, they contribute to the development of leachate, which can contaminate groundwater resources when it seeps into the ground.

3.4. Plastic waste management in Europe

Unfortunately, energy recovery accounts for 41.6% of all disposal methods for plastic trash in the EU. Only slightly more waste is recycled (31.1%) than is dumped in landfills (27.3%). Poland's (27%) rate of plastic trash recycling is lower than the EU average. 44% of Polish plastic trash is landfilled. One of the major issues is that a lot of the plastic is made to only be used once before being thrown away. Therefore, around 60% of the plastic trash is made up of single-use plastic packaging (EPRO, 2018). Ireland, Estonia, and Luxembourg are the EU nations that produce the highest plastic packaging waste per person (58 kg, 50 kg, and 58 kg, respectively). The nations with the lowest rates, on the other hand, are Croatia, Bulgaria, and Greece.

Poland generates less trash from plastic packaging than the EU as a whole (Figure 6). There are notable variations among member states, although the EU's recycling rate for packaged plastic waste is slightly greater than that for other plastic trash (42%). The three newest members, Lithuania (74%), Bulgaria (65%), and Cyprus (62%), have the highest recycling rates for this kind of garbage. The nations with the lowest rates, in comparison, are Malta (24%), Finland (27%), and France (27%). Poland recycles plastic packaging waste at a rate of 35% versus 42% for the EU as a whole (Ritchie and Roser, 2020). As a result, Poland is far from meeting the EU's goals, and there is a chance that they won't be accomplished by the end of 2030.

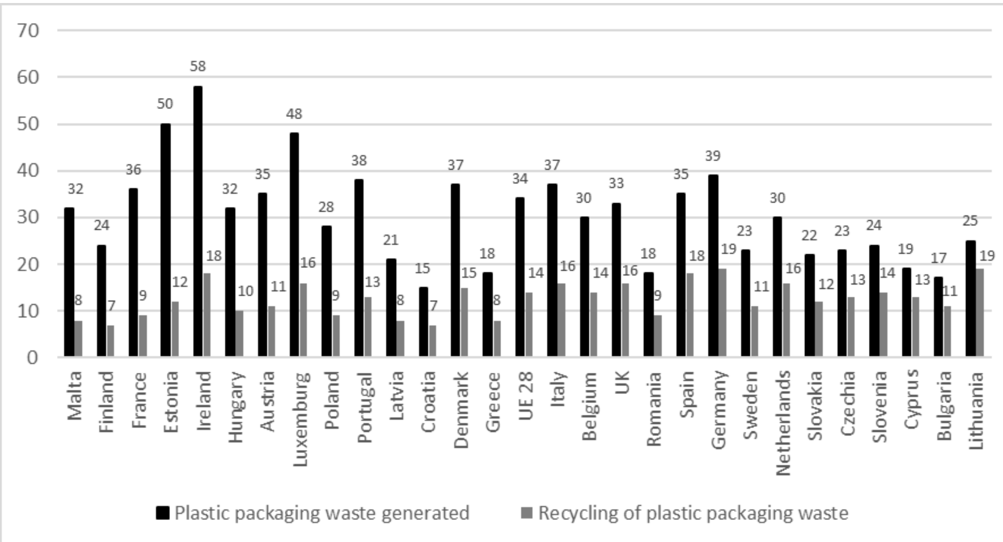

Figure 6. The rate of plastic packaging waste generated and recycled in EU countries (in %).
Source: own calculations based on EPRO (2018).

3.5. Plastic waste management in Poland

Poland produces a comparable quantity of rubbish each year (110-130 million tonnes). There were 128 million tonnes in 2018, and 10% of that was municipal garbage. Poland produces 325 kg less municipal garbage per person than the EU avarage (486 kg) and other countries (including Denmark, which produces 781 kg, Germany, which produces 633 kg, and Luxemburg, which produces 607 kg).The poor rate of recycling, however, is the issue. Only 57% of the municipal waste that was collected in 2018 was intended for recovery, of which 26% was recycled mechanically and chemically and 23% was recycled for energy (EPRO, 2018).

Poland produces less plastic garbage than the other EU-15 countries, but its recycling rate is below the EU average. Plastic waste recycling relies heavily on easily-collectible garbage from industrial networks and transportation. When the selective collection and recycling of home waste is intensified, the recycling rate will be able to rise even more. To do this, nevertheless, calls for significant social campaigns to raise the general public's ecological consciousness in addition to governmental and organizational improvements. The Polish recycling and plastics manufacturing sectors will need to invest more in technology and work more closely with R&D facilities.

The most recent data indicates that 259 projects were launched in Poland's garbage sector last year. At the end of 2019, 286 licensed landfills and 1,868 wild dumps were still being counted nationwide.

Waste-to-energy conversion is becoming more and more significant. There are currently nine waste-to-energy facilities running in Bydgoszcz, Bialystok, Konin, Kraków, Pozna, Rzeszów, Szczecin, and other cities. In Gdansk (Gdansk), work has started on a new waste-to-energy facility with a 160,000-ton annual capacity. The towns of Olsztyn and Wroclaw are also planning waste-to-energy plants that will produce heat and electricity, and the town of Rzeszów is even thinking about building a second facility. The decision about Veolia's request to construct a waste-to-energy facility at Łódż has not yet been made. The Warsaw trash incineration plant will be expanded by the South Korean company Posco Engineering & Construction, bringing its annual capacity from 40,000 tons to 305,000 tons (https://waste-management-world.com/...).

Paper, cardboard, glass, metals, plastics, organic garbage, and mixed rubbish are all being collected separately. Based on the amounts produced, 50% of municipal waste in Poland must be recycled starting in 2020. But energy recovery is also considered to be a part of recycling. Municipalities are in charge of execution, or the development of the related rules.

In Poland, over 127 million tons of trash were produced in 2019. There was 332 kilos of volume per person. The mining and extraction industry produces the most garbage, accounting for 55.8% of total waste production, followed by industry (23.8%) and the energy industry (12.3%). 5% of the waste was disposed of elsewhere, albeit it can be presumed that this was hazardous waste. According to CIS statistics, while 49% was recycled, 43% was landfilled (https://waste-management-world.com/...).

Municipal garbage was collected separately 31% of the time in 2019. One third of the four million tons of waste that were collected separately was made up of PPK, glass, and plastic. Biowaste made up 30% of the waste, while packaging, electronic garbage, and worn textiles made up 21%. As of 2018, 58.5% packaging was recycled. Steel packaging, including sheet metal, has a 90% recycled content. It was 83% for PPK packaging, 52% for aluminum packaging, 62% for glass packaging, and slightly more than 30% for wood and textile packaging. In 2018, roughly 30% of plastic packaging was landfilled and 30% was recycled for electricity.

Because of its potential for economic growth and in light of environmental limits, a circular economy has emerged as a strategic objective at the EU level. Stakeholders will be required to behave in a certain way as a result of legal requirements, which will replace their prior reliance on their own goodwill with a legal obligation. Real changes can then be anticipated when this is combined with rising consumer awareness. The biggest influence on the process of change in the Polish recycling industry will come from EU rules.

3.6. Plastic waste management in Turkey

Following China's 1st January 2018, ban on plastic imports, Turkey grew to be a significant global importer of plastic garbage. Before the ban, Turkey only imported 261,864 tonnes of plastic garbage annually; by 2020, that number had risen to 772,831 tonnes. Turkey has imposed import limitations on plastic trash (quotas, a 1% contamination limit, and a ban on mixed plastic waste imports), yet widespread reports of unlawful dumping and burning persist. Turkey is the second-largest producer of plastics in Europe and seventh globally, but the country's current recycling and waste management systems are unable to keep up with the growth of domestic plastic garbage. Approximately 90% of Turkey's municipal solid waste is disposed of in landfills. Mismanagement of plastic trash causes plastic to leak into the Mediterranean Sea, with Turkey accounting for the largest share (16.8%) of the plastic pollution in the seas of Europe. Turkey now has the chance to expand and improve its own domestic waste management infrastructure in order to reduce indiscriminate plastic marine contamination thanks to this most recent import limitation (http://antalya.bel.tr/...).

The Ministry of Environment and Urbanization is responsible for waste management on a national scale in Turkey. The role of the Ministry is to make legal arrangements and to supervise all institutions and organizations related to waste management. It is the responsibility of the local governments to collect the waste separately at the source, to ensure that it is separated if it cannot be collected separately, and to transport and dispose of it. Obligations regarding the separate collection of waste and the temporary storage of these wastes are determined by the Communiqué on the Waste Import Center and the Zero Waste Regulation.

Recycling or recycling of waste should be carried out in recycling facilities to be established by local governments and in accordance with the Packaging Waste Control Regulation. Various organizations have been authorized to collect packaging waste from the market within the scope of EMR (Extended Manufacturer Responsibility). In addition, various NGOs are working on raising awareness about waste management, taking initiatives on pollution and improving the waste management system in Turkey.

According to the Turkish Statistical Institute, 98.8% of waste was collected in Turkey in 2018, with the vast majority being disposed of in landfills. Wastes sent to landfills are mixed municipal wastes and plastics are taken to these areas mixed with other wastes. While 67.2% of the collected waste is disposed of in licensed sanitary landfills that meet the technical conditions, 20.2% is disposed of in wild landfills that do not meet the technical conditions and cause harm to the environment. The number of landfills, which was 134 in 2016, increased to 159 in 2018. In 2016, the number of irregular landfills was approximately 800.

4. Methods of against plastic waste: examples

4.1. Reduce disposable plastics

Single-use plastic items are used once or for a short time before being discarded. For example, the average lifetime of plastic bags is 15 minutes. In contrast, the environmental impacts are global and the consequences can be severe. The short life span of single-use plastic products increases the possibility of reaching the seas. The 10 most common (70%) of all marine litter in the EU are single-use plastic items. The EU aims to be a pioneer in the global fight against marine litter and plastic pollution. EU rules aim to reduce the amount and impact of certain plastic products on the environment (Özgür, 2021).

The following actions are recommended for measures to reduce the consumption of single-use plastics (Özgür, 2021):

1. Ensuring that all stakeholders are included in the works to be done for the reduction and correct management of other plastic packaging wastes within the scope of waste management process, with the steps that follow the positive results obtained after the pricing of disposable plastic bags.
2. Taking into account that the correct implementation of bans and finding suitable alternatives will often be costly and present difficulties. In addition, considering the fact that the success of the ban depends on the careful evaluation of the possible effects of the ban on different groups, the measures considered in this context should be given priority in the directives.

3. Establishing incentives to shift the demand for single-use plastic products to alternative products that can be used more than once; imposing a higher tax on single-use plastic products to encourage consumers to choose reusable products.
4. Making joint decisions, in consultation with the waste management sector, for the evaluation/determination of promoted alternatives; establish a national waste management plan that bans/reduces certain single-use plastic products.

Only 29.7% of the plastic waste produced in the EU (25.8 million tonnes) is recycled, this is mainly due to the packaging waste (i.e. main plastic waste fraction). The holistic process for increasing the recycling rates of packaging waste is envisaged. The process involves four key steps: the 1st step – develop of innovative collection systems - smart containers which identify the quantity (using ultrasonic level sensors) and the quality (using a labeling system and RFID card) of packaging deposited into the containers, ensures better separation of plastic waste and reduces the amount of mixed waste generated; the 2nd step focuses on transport - by using a special CAN-Buss device, optimized routes, skipping empty containers route, and eco-driving, all the steps are integrated into a mobile application; by using the modern transport of waste, the transport fees will be reduced and fuel costs will be minimized. The 3rd step refers to sorting – using innovative technologies such as spectrometers the quality of the recovered plastic will increase using better separation solutions for different plastics in treatment plants, including multilayer and multi-material packaging. The 4th and final step involves reprocessing the materials into products such as automotive parts, foam boards for wind turbines, roofing structures, rubbish bags, asphalt, fences, and benches —a closed-loop model will be developed.

4.2. Implementation of refilling systems

In addition to the active daily life in our cities, tourism activities, especially in summer, lead to a great increase in the consumption of disposable plastic bottles. In order to prevent environmental pollution from these plastic bottles, it is necessary to provide public drinking water, develop refill networks and expand structures that will allow access to these water sources worldwide. With the expansion of public drinking water sources such as fountains, the need for plastic water bottles for domestic consumption will decrease (Lamba et al., 2021; Özgür, 2021).

1. Developing replenishment networks and expanding nationwide programs/structures centered on access to public drinking water, such as fountains; Establishing, operating and improving water filling stations.
2. Inclusion of actions aimed at reducing plastic waste and garbage in local action plans of municipalities.
3. Sustainable design of the treatment and transmission systems that will ensure the drinking quality of tap water throughout the country and updating the existing systems within this framework.

4. Launching awareness-raising campaigns about the quality of tap water and ensuring the effective use of filling stations. Directing citizens to these points with remarkable internet applications and markings.

4.3. Implementation of policies aiming to reduce microplastics

It is known that the most common microplastics in the natural environment come from treatment plants and are formed through the erosion of unmanageable plastics. Since treatment and waste management systems do not completely prevent the mixing of these microplastics with nature, it is necessary to try to prevent pollution by creating inventories of the products that are the source of these microplastics. Policy measures should also include directives that prohibit or limit products containing microplastic particles. With the prohibitions that may be imposed on the production, sale and import of products containing microparticles, the mixing of microplastics with nature can be reduced to a certain extent (Özgür, 2021).

1. Inventory of products and services that cause microplastic pollution; bringing together all relevant stakeholders and working together to search for alternatives to microparticles.
2. Prohibition of production, sale and import of products containing microplastic particles.
3. Improving the regulations regarding the storage conditions of plastic production raw material particles and their mixing with nature.

5. Conclusions

To ensure environmental safety, an in-depth understanding of each factor is taken into account when making decisions about how to best manage waste. Waste generated in smart cities is a category of municipal waste. Traditional approaches to waste management have failed because they are not reliable or sustainable because they require a lot of input for little or no work output. Because of the increase in population, urbanization, and industrialization, waste generation has increased at an alarming rate, and traditional approaches are unable to collect and analyze data from waste dumps. The incorporation of smart city technology into waste management practices provides a smart way to solve waste issues. The main of plastic waste management is to develop methods to transform plastic waste into a circular economy and bioeconomy. As estimated by 2030 plastic leakage to ecosystems should be 30% reduced, double the global recovery of plastic (collection and recycling), and shift to sustainable inputs for remaining plastic, including recycled content, sustainably sourced bio content, advanced products and reducing unnecessary plastic through a business model, innovation, reduction and substitution. In this study, smart cities are explained, how to manage plastic waste by using smart city components, and methods of dealing with plastic waste are explained.

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References

1. Achmad, K.A., Nugroho, L.E., Djunaedi, A. (2018). *Smart city model: A Literature review.* 10th International Conference on Information Technology and Electrical Engineering, pp. 488-493.
2. Adeniran, A.E., Nubi, A.T., Adelopo, A.O. (2017). Solid waste generation and characterization in the University of Lagos for a sustainable waste management. *Waste Management*, *No. 67*, pp. 3-10.
3. Adıgüzel, M. (2017). *An evaluation model for Turkish cities in the context of smart city* (Unpublished master's thesis). Ankara: Middle East Technical University, Department of City Planning.
4. Albino, V., Berardi, U., Dangelico, R.M. (2015). Smart cities: definitions, dimensions, performance, and initiatives. *Journal of Urban Technology*, *No. 22*, pp. 3-21.
5. *Antalya'da Akıllı Kent Uygulamaları Yaygınlaşıyor (Smart City Application are becoming widespread in Antalya).* Retrieved from http://antalya.bel.tr/haberler/antalyada-akilli-kentuygulamalari-yayginlasiyor, 20.06.2021.
6. Balaban, O. (2019). Smart cities as drivers of a green economy. In: S. Acar, E. Yeldan (Ed.), *Handbook of Green Economics* (pp. 69-92). Elsevier.
7. Baran, M., Kłos, M., Chodorek, M., Marchlewska-Patyk, K. (2022). The resilient smart city model – proposal for Polish cities. *Energies*, *No. 15*, pp. 1818.
8. Barlow, M., Levy-Bencheton, C. (2018). *Smart cities, smart future*. John Wiley & Sons Inc.
9. Bıyık, C. (2019). Smart Cities in Turkey: approaches, advances and applications with greater consideration for future urban transport development. *Energies, No. 12,* pp. 2308.
10. Bolivar, M.P. (2015). Governing the smart city: A review of the literature on smart urban governance. *International Review of Administrative Sciences, No. 82*, pp. 392-408.

11. Cesconetto, J., Augusto Silva, L., Bortoluzzi, F., Navarro-Cáceres, M., Zeferino, C.A., Leithardt, V.R.Q. (2020). PRIPRO—Privacy profiles: user profiling management for smart environments. *Electronics, No. 9*, p. 1519.
12. Çetin, M., Çiftçi, Ç. (2019). Investigation of the smart city concept with examples from the world and our country. Literature Review. *National Journal of Environmental Sciences Research, No. 2,* pp. 134-143.
13. Dąbrowska, J., Sobota, M., Swiąder, M., Borowski, P., Moryl, A., Stodolak, R., Kucharczak, E., Zięba, Z., Kazak, J.K. (2021). Marine waste - sources, fate, risks, challenges and research needs. *MDPI, IJERPH, Vol. 18, Iss. 2,* p. 433, doi: 10.3390/ijerph18020433.
14. Dener, M. (2018). Smart cities companies in Turkey. *The Eurasia Proceedings of Educational & Social Sciences (EPESS), No. 9,* pp. 344-348.
15. EPA (2020). *Best practices for solid waste management: A guide for decision makers in developing countrie*s.
16. EPRO (the European Association of Plastics Recycling and Recovery Organisations). *Plastics – the Facts 2018 An analysis of European plastics production, demand and waste data,* https://plasticseurope.org/wp-content/uploads/2021/10/2018-Plastics-the-facts.pdf, 18.06.2022.
17. Esmaeilian, B., Wang, B., Lewis, K., Duarte, F., Ratti, C., Behdad, S. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. *Waste Management, No. 81,* pp. 177-195.
18. Faraca, G., Astrup, T. (2019). Plastic wastes from recycling centers: Characterization and evaluation of plastic recyclability. *Waste Management, No. 95*, pp. 388-398.
19. Fatimah, Y.A., Murniningsih, R., Setiawan, A., Aman, M. (2019). *A smart sustainable approach for waste management in post natural disaster phase*. IOP Conf. Series: Materials Science and Engineering, 674, 012042.
20. Fayomi, G.U., Mini, S.E., Fayomi, O.S.I., Mbonu, C.C., Udoye, N.E. (2021). *Sustainable smart city and its promising urban value: An overview*. IOP Conf. Series: Earth and Environmental Science, 655, 012040.
21. Fayomi, G.U., Mini, S.E., Chisom, C.M., Fayomi, O.S.I., Udoye, N.E., Agboola, O., Omole, D.O. (2021). *Smart waste management for smart city: Impact on industrialization*. IOP Conf. Series: Earth and Environmental Science, 655, 012040.
22. Gade, P., Dipak, S., Aithal, P.S. (2021). Smart city waste management through ICT and IoT driven solution. *International Journal of Applied Engineering and Management Letters, No. 5,* pp. 51-65.
23. Glouche, Y., Sinha, A., Couderc, P. (2015). A smart waste management with self-describing complex objects. *International Journal On Advances in Intelligent Systems, No. 8*, pp. 1-16.

24. Khatoun, R., Zeadally, S. (2016). Smart cities: concepts, architectures, research opportunities. *Communications of the ACM, No. 59*, pp. 46-57.
25. Koelmans, A.A., Besseling, E., Foekema, E., Kooi, M., Mintenig, S., Ossendorp, B.C., Redondo-Hasselerharm, P.E., Verschoor, A., van Wezel, A.P., Scheffer, M. (2017). Risks of plastic debris: Unravelling fact, opinion, perception and belief. *Environmental Science & Technology, No. 51*, pp. 11513-11519.
26. Köseoğlu, Ö., Demirci, Y. (2018). Smart cities and employing innovative technologies for tackling urban policy issues. *International Journal of Political Studies, No. 4,* pp. 40-57.
27. Lamba, P.,·Kaur, D.P.,·Raj, S.,·Sorout, J. (2021). Recycling/reuse of plastic waste as construction material for sustainable development: a review. *Environmental Science and Pollution Research, No. 2,* pp. 78-92.
28. Liu, Q., Ullah, H., Wan, W., Peng, Z., Hou, L., Rizvi, S.S., Ali Haidery, S., Qu, T., Muzahid, A.A.M. (2020). Categorization of green spaces for a sustainable environment and smart city architecture by utilizing big data. *Electronics, No. 9*, p. 1028.
29. Lombardi, P.L., Giordano, S., Farouh, H., Yousef, W. (2012). Modelling the smart city performance. innovation: *The European Journal of Social Science Research, No. 25*, pp. 137-149.
30. Mahajan, R., Quazi, T.Z. (2017). Review paper on plastic waste management for smart city. *International Journal of Scientific & Engineering Research, No. 8,* pp. 194-198.
31. *Mikroplastik.* Retrieved from https://mikroplastik.org/mikroplastik-nedir/, Mikroplastik Nedir?, 15.05.2022.
32. Mokale, P. (2019). Smart waste management under smart city mission – Its implementation and ground realities. *International Journal of Innovative Technology and Exploring Engineering, No. 8,* pp. 3095-3102.
33. Örselli, E., Akbay, C. (2019). Technology and transformation in urban life: smart cities. *Journal of International Management Academy, No. 2,* pp. 228-241.
34. Özgür, G. (2021). Türkiye'de Plastik Atık Sorunu ve Politika Önerileri. WWF. Retrieved from https://www.wwf.org.tr/11580/Turkiyede-Plastik-Atik-Sorunu-ve-Politika-Onerileri, 7.12.2021.
35. *Plastic wastes and its management. Published on line at bioenergy consult.com.* Retrieved from https://www.bioenergyconsult.com/plastic-wastes-management, 9.05.2022.
36. Ritchie, H., Roser, M. *Plastic Pollution. Published online at Our World In Data.org.* Retrieved from https://ourworldindata.org/plastic- pollution, 6.08.2020.
37. Singh, P., Trivedi, L. (2020) Plastic waste management. *GIS Science Journal, No. 7*, pp. 25-31.
38. Singh, D., Jara, A.J. (2022). Transforming future cities: Smart city. *Electronics, No. 11*, pp. 1534.
39. Soydan, O., Benliay, A. (2020). Evaluation of the smart city applications in terms of users: the case of Turkey. *European Journal of Science and Technology, No. 20,* pp. 381-391.

40. Surapaneni, P., Symala, M., Maguluri, L.P. (2018). Solid waste management in smart cities using IoT. *International Journal of Pure and Applied Mathematics, No. 118*, pp. 635-640.
41. UNEP. Retrieved from https://www.unep.org/news-and-stories/press-release/mounting-problem-worlds-cities-produce-10-billion-tonnes-waste-each, 12.02.2015
42. *Waste Management Recycling, by WEKA Industrie Medien*. Retrieved from https://waste-management-world.com/artikel/recycling-poland-is-slowly-catching-up/, 10.04.2021, 9.11.2021.