A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

The prospects of establishing a waste incineration plant in Nur-Sultan based on the experience of the Baku incinerator

Ayana BIISEITOVA

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Ayana BIISEITOVA

CENTRAL EUROPEAN UNIVERSITY

ABSTRACT OF THESIS submitted by:
Ayana BIISEITOVA
for the degree of Master of Science and entitled:
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The everyday activities are inherently associated with material turnover, and with the resulting burden of managing the waste. Most of the developing countries have developed integrated waste management systems that include recycling, composting, energy recovery, and other mechanisms. Most of the developing countries, in turn, disposes of the waste in landfills, which result in negative environmental and public health impacts. Kazakhstan is no exception. Kazakhstan suffers from a massive amount of accumulated waste in landfills, unsatisfactory waste sorting practices, and an underdeveloped recycling sector. To respond to the waste-related problem, the government of Kazakhstan has decided to establish, six new waste incineration plants by 2025. Incineration is an indispensable part of waste management in the most developed countries, yet it can be considered as a conflicting technology with numerous constraints. Therefore, the prospects of the establishing plant in Kazakhstan have been analyzed based on the experiences of a similar plant in Baku. The comparative analysis has shown that a waste incineration plant will solve the immediate problem of waste accumulation and excessive landfilling. However, technology is the only temporary solution that would pose significant economic and social constraints. It has been shown that incinerators would require considerable investments, and it is not clear who will bear the cost burden. Also, the waste composition in Kazakhstan is not studied carefully, and the efficiency of energy generation may be undermined. Most importantly, there is a definite threat that incineration could compromise the development of other waste management options situated higher on the waste hierarchy. The specified issues are deteriorated by the fact that the government showed no attempts to involve the general public in the discussion stage.

Keywords: waste management, waste-to-energy, waste incineration, sustainability, recycling, Post-Soviet countries.

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1.Introduction

1.1 Background

Everyday human activities are inherently connected to material turnover, the development of civilizations led to an increase in the number of materials we use, and the accumulation of these materials (Brunner and Rechberger 2015). As time has passed and more and more waste got accumulated, it caused immediate concerns for humans. The increase in physical weight and volume of the waste brought the need for sanitation and reducing the waste volume. Later on, with the depletion of primary materials, new ways to recover materials from waste have been developed. WTE or waste incineration are indispensable waste management practices that include controlled combustion of waste to recover energy and reduce the waste volume. Open-air waste burning has always been part of waste disposal practices, however, the first plants started to emerge in Europe in the 18^{th} century. Currently, developed European countries are at the forefront of waste management, with the most efficient and sustainable systems. However, these developments are not present everywhere, most developing/transitioning countries dispose of their wastes in landfills, which are mostly mismanaged or illegal. Waste management in Kazakhstan is no exception.

Currently, the majority of municipal solid waste (MSW) in Kazakhstan is disposed of in landfills, therefore, almost 120 million tonnes of waste has been already accumulated (Baigarin 2020). Considering that majority of landfills in Kazakhstan do not satisfy local and international sanitary standards, the accumulation of waste on landfills turned out to be a great threat to public health and the environment. The portion of waste that can be partially offset by recycling is also negligible (14%) and is developed in a few regions (EGOV: Public services and online information, 2020). To respond to the problem, the government of Kazakhstan has decided to establish WTE projects. Namely, six new waste incineration plants will be launched in different regions of Kazakhstan, according to the Minister of Ecology Magzum Mirzagaliyev by 2025 (Pokidayev 2020). Despite being an effective technology for waste sanitation and volume reduction, waste incineration is quite conflicting technology.

The proponents of incineration pay attention to hygienization and volume reduction potential (Brunner and Rechberger 2015). Considering, that the technology allows for energy recovery and material recovery of metals, some authors believe that WTE agrees with the principles of the circular economy. Finally, waste incineration environmental impacts are usually juxtaposed to landfilling, which is considered to be the worst possible waste disposal option.

Even though incineration allows to slowly move on from landfilling, many negative impacts provoke public opposition. Firstly, air emissions and public health effects are one of the biggest dangers of waste burning. Apart from well-researched and documented environmental and health impacts, there are more subtle considerations of socio-economic and sustainability aspects, that have to be analyzed in different regions. Therefore, it was important to analyze different factors that would affect the implementation of the WTE project in Kazakhstan.

Also, it is important to note that most of the studies on different aspects of incineration have been based on European experience that can hardly be compared to other developing countries. That's why the characteristics and development of European incinerators would not be useful for analysis and comparison with Kazakhstan. Now there are only a few cases that can be used for comparative analysis, only Azerbaijan and Russia have incinerator plants among CIS countries, and they have been built only recently. Considering that the Azerbaijani government has built only one plant in Baku (capital city) in comparison to the ambitious plan to build more than 30 incinerator plants by 2024 (Mereminskaya 2020), it was decided to select the Baku incinerator plant as a case study for comparative analysis. Baku and Nur-Sultan have a comparable population and size, similar waste management and waste generation trends. Moreover, the incinerator plant in Baku was also built-in 2012 to protect the environment from impacts that arise from the massive Balakhani landfill, which produced harmful emissions from constant burning and waste decay. The plant is operated by the state-owned organization JSC "Tamiz Shahar", and the plant itself has been built by the French company Constructions Industrielles de la Méditerranée (CNIM). The plant is a unique facility for the Central Asian region, the plant can combust 500 thousand tonnes of MSW yearly and produce electricity (Asian Development Bank 2020). Even though there is not enough information on the waste incinerator in Nur-Sultan, the analysis of the Baku incinerator will bring valuable insights for establishing WTE in the region.

1.2. Aims and objectives

The main aim of the study was to critically assess and predict the socio and economic constraints that may arise during the implementation of the incineration plant in Nur-Sultan. The main methods of analysis will include the comparative analysis with the case of the Baku Incinerator. To achieve the main aim, it is necessary to address to fulfill the next objectives:

- Conduct a critical analysis of waste management systems in the cities of Baku and Nur-Sultan, identify main actors and parts of the system, inspect other contextual economic and social factors, investigate if these factors are conducive for plant construction and operation
- Assess the performance of each part of waste management and disposal (landfilling, energy recovery, recycling, etc.), identify main obstacles for the development;
- Perform the comparative analysis of waste management systems of Baku and Nur-Sultan, investigate factors that are similar/different in two cities;

- Evaluate the establishment and operation of a waste incineration plant in Baku, assess the social, environmental, and economic aspects to identify the characteristics of the plant operation in the region;
- After the analysis of the plant in Baku, extract the best practices for recommending them for the plant in Nur-Sultan;

1.3. Limitations

The establishment of waste incineration is a massive project that would require many studies that would include environmental, social, economic, political, and other numerous nuances. The space limitations of the current study will only allow for investigating the socioeconomic aspects of establishing an incinerator plant in Nur-Sultan. However, these factors cannot fully predict the plant operation in the future, and additional research on technical aspects like emissions, energy and technology efficiency, public health, the institutional framework has to be conducted.

The waste management systems in both Kazakhstan and Azerbaijan are in a basic stage of development, and both countries lack access to systematic data about waste management indicators in the country. Therefore, it is expected that certain aspects of waste management will not be completely covered in the study. Certain statistical data may not be present for each year and may represent the only approximate picture.

Finally, the study will only focus on waste management practices and waste incineration plans of Nur-Sultan city, however, the government is planning to build 5 more plants in other regions. The conclusions made about the plant in the capital city will not apply to other regions due to differing demographical situations, waste characteristics, infrastructure, and waste management practices.

1.4. Outline

The thesis is divided into several chapters. The main literature is presented in the ***literature review*** part. This chapter presents the major concepts of waste management, mainly focusing on the aspects of the waste hierarchy. Also, the literature on environmental, social, and other aspects of waste incineration has been discussed. Next, the ***methodology*** section introduces detailed information on tools and techniques that have been used for obtaining the necessary information. The main ***discussion*** part presents the comprehensive comparative analysis of waste management of Baku and Nur-Sultan. Firstly, the contextual factors like main stakeholders and waste generation trends are analyzed. Later, the waste management is analyzed according to individual disposal practices. Lastly, the study focuses on waste incineration in Baku and WTE plans in Kazakhstan. Barriers related to sustainability, economic feasibility, and public opinion are investigated and discussed. Finally, the ***recommendations and conclusions*** on the socio-economic sphere are given based upon the constraints identified in the main chapter.

2. Literature Review

2.1 Waste Hierarchy

Waste management is a broad concept that encompasses activities dedicated to managing waste on all stages. The concept not only includes end-of-life management (waste treatment or disposal), but other aspects like waste collection, transportation, and product design principles. However, due to the limited scope of the thesis, the analysis will be focused on two main concepts of sustainable waste management – Waste hierarchy and Integrated Waste Management, that will be used for the analysis of waste management systems of Baku and Nur-Sultan.

The waste hierarchy is the conceptual tool that evaluates and rates waste management techniques according to their sustainability characteristics (Williams 2015).

The waste hierarchy is based upon several principles:

- The prevention principle has emerged as a response to increasing concerns about emissions and the limited effect of technological advancements. It became obvious that technological improvements cannot guarantee zero-emissions without sound integrated waste management that starts at the production process (Hulpke, Miiller-Eisen 1997);
- The precautionary principle advocates for precautionary measures even if there are no established scientific proofs of negative consequences. There are 4 main dimensions: use prevention principle if uncertainty is involved; to enable activity, the proofs must be provided by the proponents; all the possible alternatives must be studied before enabling harmful activity; and, finally, the public must be aware and involved in decision-making (Tickner and Raffensperger 1999, Kriebel et al. 2001).
- Polluter pays or extended producer responsibility necessitates producers take account of end-of-life management of waste, that has been generated by the

consumption of their products. Moreover, WFD2008 establishes that producer role responsibility applies not only to direct manufacturers but also to sellers and importers. WFD2008 states that the principle should be implemented through measures on the consumption phase as well as the product design phase (European Parliament and Council of the European Union 2008).

- Proximity and self-sufficiency principles ensure that the Member States would be self-reliant in waste management activities and treat waste in the closest possible facilities with the best available technologies. The WFD2008 also notes the importance of prioritizing self-sufficiency by limiting waste imports and exports if it may interfere or deteriorate National Waste Management Plans (European Parliament and Council of the European Union 2008).
- Finally, the principle of subsidiarity focuses on the importance of power decentralization and community engagement. WFD2008 allows Communities to establish their measures of waste management, meaning that WFD2008 is only a subsidiary document. However, the whole idea of supra-national policies and national plans defy the principle (Spicker 1991).

Hultman (2012) describes the waste hierarchy model as “normative” since it prescribes EU member-countries to follow certain hierarchical order, yet the model allows for certain adjustments according to local factors of adopting country. Williams (2015) criticizes this aspect of the model noting that only a few countries (Northern European countries, Germany, Austria, Belgium) were able to construct an integrated model, that would take into account all steps of hierarchy/ The other countries, especially east and south European countries that have entered the EU later, treat the hierarchy rather as a “ladder” that would require them to go through all steps of hierarchy.

2.1.1 History of Waste Hierarchy

The very first attempts to regulate waste and waste movements were made by European Union in 1975 when they have enacted the first Waste Framework Directive (1975/442/EEC) that established basic concerns about environmental, health damage, as well as the illegal movement of hazardous and non-hazardous waste. The 1975 Directive was revised several times, but the main document that defines waste strategies of EU Member States is Waste Framework Directive (2008/98/EC) (European Commission n.d.).

The beginning of EU-wide waste policy and has been comprised of three documents: Waste Framework, Waste Shipment Directive, and Hazardous Waste Directive. Even though the aforementioned documents established all the basic concepts, waste treatment principles, and negative impacts of waste on public health and the environment, the waste hierarchy was not mentioned in the document. Moreover. There were no specific environmental standards for common waste treatment operations like incineration and landfilling, that was only resolved by their respective directives at the beginning of the 2000s (European Commission n.d.).

The next biggest development in the establishment of waste policy was the 1989 Community Strategy on Waste Management. First of all, the Strategy established and harmonized the strict environmental standards for emissions for waste treatment and industrial facilitates. The document stressed the importance of standards to address the NIMBY (not in my backyard) effect (Commission of the European Communities 1996). Also, the established principles of self-sufficiency and proximity. However, the most important contribution of the 1989 Strategy is the formal introduction of the first variant of the waste hierarchy. Recovery (that included reuse, recycling, and energy recovery) are no longer considered to be a priority option of waste management. No matter how the waste disposal operation, the waste is a polluting agent for the environment. The prevention is then established as the most desirable option, while disposal has to be avoided as the last resort operation. Finally, the strategy started to emphasize the importance of producer responsibility and take into account waste generation at a design stage (Commission of the European Communities 1996).

For a long-time waste hierarchy remained in the same 3 ladder stage, (first step- prevention, second step – reuse, recycle, energy recovery, third step - disposal). Even the first Waste Framework Directive Proposals (**DIRECTIVE 2006/12/EC**) were put to reuse, recycling, and energy recovery, and were encouraged after prevention and reduction measures. Annex 2 of the same proposal established that secondary material recycling and energy recovery under the same recovery operations list (European Parliament 2006).

2.1.2. Disposal

The bottom of the waste hierarchy is presented by the least desirable option – disposal. Despite pre-conceived notion, disposal not only concerns landfilling and release into the water, but Annex 1 of WFD2008 also includes other disposal operations like storage, incineration on land, and deep injection of waste liquids into pits, wells, and other repositories. Effectively, WFD2008 establishes that disposal includes “any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy” (European Parliament, and Council of the European Union 2008). Disposal is considered to be the least desirable option due to contradiction to the main tenets of sustainability and the deleterious environmental effect. The main environmental consequence associated with landfilling is landfill gas and leachate. Landfill gas forms primarily as a result of the reaction of aerobic (and later anaerobic) decomposition of waste materials, which result in CO2, water, and microbial cells. The landfill gas (on a dry volume basis) mainly consists of methane (40-70%) and carbon dioxide (30-60%) (Robinson 1986).

Leachate, in turn, forms as a result of water leaching through waste mass and mixing with the able element in waste. The main source of the leaching water comes from natural processes like precipitation, runoff, and groundwater, also moisture content and waste liquids form as a result of decomposition partially contribute to leachate.

Leachate and landfill gases create environmental consequences that might pose a noteworthy hazard. Methane and CO2 from landfill gas with numerous by-product gases is the reason behind air pollution, odors, and explosion hazards, leachate pollutes groundwaters (El-Fadel et al. 1997). In addition, avoiding landfilling is particularly important for developing countries since landfilling is usually is the cheapest tool of waste management (Rushbrook, 1983), which creates additional incentives to use landfilling as the main waste treatment option.

2.1.3. Other Recovery

The next step in the waste hierarchy represents all the processes that are aimed to prepare waste to serve "a useful purpose by replacing other materials which would otherwise have been used to fulfill a particular function", which mainly means includes operations like energy recovery, oil re-refining, and regeneration of acids (European Parliament, and Council of the European Union 2008). The energy recovery systems which are mainly considered under the r "recovery" step, was one of the first attempts to deal with emerging waste problems. Initially, the increase of waste generation and accumulation brought concerns about increasing waste volume and sanitation issues. This way, the first attempts to manage waste started to develop in Europe. Indeed, the first incinerators were developed in response to major cholera outbreaks in Nottingham, England in the 18th century (Umweltbundesamt 2008). However, this kind of plant could rather be considered as a "disposal" method, due to lack of filters, resulting in environmental harm (Bruner and Rechberger 2015).

Based on the energy recovery system, we can identify two general types of WTE systems. Pyrolysis, gasification, and incineration involve waste utilization at a high temperature, which makes them part of thermal energy recovery, while biofuels from the waste are considered to be a biochemical method. Incineration, which is the main focus of the research, is usually considered to be a less sustainable option, due to by-products of combustion, like air-polluting particles (carbon, nitrogen oxides, dioxins, furans) (Khan and Kabir 2020), as well as solid polluters like bottom and fly-ash, that has to either recycled or safely disposed of.

Generally, WTE systems are considered to be economically viable (Kumar and Samadder 2017), the key element of circular economy (Sharma et al. 2020), (Malinauskaite et al. 2017), other authors emphasize the importance of technological advances that considerably decrease the harmful environmental effects (Psomopoulos et al. 2009), (Stehlik 2009), (Brunner and Rechberger 2015). However, it had it be taken into account that waste hierarchy has to be followed integrally, and all steps have to go hand-in-hand.

2.1.4. Reuse and recycling

The next step that is preferred to landfill and energy recovery is recycling and reuse. Indeed, most of the developed countries nowadays have a high level of MSW recycling, for example, countries that have adopted integrated approach towards waste hierarchy like Austria, Netherlands, Germany, and Belgium has a recycling rate of way over 50%, which is in line with waste recycling target set by WFD2008. Even though EU27 (44,9% for 2019) has not achieved the stated goal and may less developed countries be far from achieving 50% goal, from 2018 the targets have been raised to achieve a +5% increase each consecutive 5 years till 2035 (European Environment Agency 2021)

Recycling is an important tool of waste management since it can offset the consequences of one of the most prominent parts of MSW – plastic waste. Plastics, one of the very short-lived waste, also heavily contributes to the expansion of the oil industry and its direct consequences. There are generally four types of recycling based on the final product of recycling:

- Primary – recycling with end-product of similar quality, closed-loop recycling;
- Secondary, downgrading – the plastic recycled with a different or lower quality end-product;
- Chemical/feedstock recycling – the recovering of certain chemicals that can be used in plastic production (Fisher 2004);
- Energy recovery –WTE and composting of biodegradable plastics (Hopewell et al. 2009);

Moreover, it is important to note that the steps within the hierarchy may conflict with each other. Plastics, being an important component of recycling and energy recovery (due to higher calorific value) pose the perverse incentive, and the steps of hierarchy may be altered (Triyono et al. 2018).

Reuse is the next step in the waste hierarchy, and WFD2008 established that waste has to be prepared for being used again without any additional pre-processing measures for the same purposes it has been initially designed to. WFD2008 also necessitates supporting and designing different policy, economic and other encouragement instruments to promote reusing a repair network. Despite the overall benefits of re-using schemes, the re-use option is mostly used for glass and iron in the construction material industry (Ismail, Al-Hashmi 2008). Re-use of plastic packaging could be less feasible due to logistical issues. Currently, consumers are located at a considerable distance from the centralized facilities, therefore re-using packages may be only feasible for smaller businesses (Hopewell et al. 2009).

2.1.5. Prevention

Waste prevention is the highest step of the hierarchy and represents the most desirable outcome for wastes. In comparison with previous steps, waste prevention requires not only end-of-life waste management on a product design stage. According to WFD2008, waste prevention not only refers to generated waste quantity volume but also strives to decrease the hazardous content of the waste and reduce negative environmental consequences (European Parliament and Council of the European Union 2008).

Since waste prevention is at the top of the hierarchy, the WFD2008 establishes responsibility for the Member States to formulate programs that would facilitate waste prevention till 12 December 2013. Furthermore, the WFD2008 establishes that waste prevention measures must take into account the principles of circularity and the idea of decoupling economic development from additional waste generation (and resulting environmental impacts). Considering the link between economic growth and waste generation WFD2008 pays an additional to economic instruments and policy tools for ensuring extended producer responsibility (European Parliament and Council of the European Union 2008).

However, we need to take into account that measuring and evaluating waste prevention is an extremely difficult task, the evaluation options can be either inconsistent, biased, or require many resources for meaningful results. Only highly targeted integrated behavioral studies can provide reliable results (Zorpas and Lasaridi 2013). Even though the evaluation methods are of limited reliability, certain studies have shown that prevention only slightly affects environmental impacts due to the fact other material/energy recovery is more effective to offset environmental impacts. Moreover, most prevention campaigns focused on less harmful materials like glass, plastic, and paper, and do not play a big role considering the overall waste quantity (Gentil et al. 2011), (Salfoher et al. 2008). Another barrier to establishing meaningful waste prevention lies in consumers' behavior, for instance, Cox et al. (2010) see that the main problem in low-involvement in UK households is mainly caused by increasing consumerism, and that recognizing that prevention is the best waste treatment option (in comparison with recycling). Later studies focused on social norms and behavioral motivations have found that most EU citizens involve in waste prevention only because of intrinsic motivations, and policy did not establish measures that might affect individuals without intrinsic motivations (Cecere et al. 2014).

WFD2008 also establishes various measures to promote waste prevention. Proposed measures range from planning and framework solutions, recommendations of a more sustainable design process to measures for end-of-life use or consumption.

2.1.6. The Limitations of Waste Hierarchy

Even though the waste hierarchy is used as a rule of thumb in EU waste policies, and it has been developed for more than 40 years, the hierarchy may pose limitations in the goal of reducing waste generation. The main limitation lies within the most basic concept: the definition of the waste itself. Even 1996 Communication on Community Strategy has identified that there is no clear distinction between waste and goods. The main question is to identify when waste becomes waste. The Strategy also proclaims that waste must be identified regardless of its economic values (Commission of the European Communities 1996). The WFD20008 similarly identifies waste as “any substance or object which the holder discards or intends or is required to discard”. The definition disregards the material value of the waste, and the main stress is placed on discarding (European Parliament, and Council of the European Union 2008).

Hultman et al. (2012) explain that the relationship of industrial society with waste has been characterized by dissociation (McDonough and Braungart 2009). However, lately waste has become a more visible phenomenon, and waste hierarchy is the main instrument that can help start to form the wide view of waste as a resource. Similarly, current trends like the closed-loop, circular economy, or zero waste ideologies promote "waste as a resource perception".

The distorted view of waste as an end-product or discarded material results in the main limitation of the waste hierarchy – inability/weak promotion of waste prevention. The most widely used waste treatment operation in EU countries is recycling. The actual potential of waste prevention is limited. The current waste management in the EU is limited to recycling, incineration, and landfilling, while reuse and prevention are not in the mainstream of the waste management industry. Bartl (2014) believes that waste prevention, if successful, will result in a decrease in consumption and profit for most companies in the industry. Literature review of existing policies has shown that most waste policies focus on waste recycling (Gertsakis and Lewis 2003), landfill diversion, or certain technicalities like waste transportation (Wilkinson 2002), while prevention is omitted from national policies. Kijak and Moy (2004) believe that the waste hierarchy that was mostly directed to the waste management industry is utterly inefficient since the industry is only responsible for end-of-life management, while prevention is just out of the scope of the industry's responsibilities. Extended producer responsibility is the only aspect of the hierarchy that integrates other actors. Deteriorated by the decentralized and mostly unregulated attempts to prevent waste and aforementioned difficulties of measurement shows that the waste hierarchy has certain limitations in promoting prevention.

The waste hierarchy presented in the current form lacks specificity. For instance, there is no apparent distinction between open and closed-loop recycling. Open-loop recycling (similar to secondary recycling) cannot align with the notions of circular economy, and recycled materials will not stay in a circular process, but rather downgrade to the next product with its life cycle, and environmental impact of this change also had to be taken into account (Ekvall 2000). Similarly, increasing recycling rates only represent the overall trend of recycling, both primary and secondary types.

Another conceptual fallacy within the hierarchy is that the waste hierarchy prescribes certain order (implicitly allowing landfilling to be the viable option in certain circumstances) while simultaneously promoting radical principles of zero waste (Van Ewijk and Stegemann 2016). Moreover, the idea of the ladder of preferential waste treatments assumes the idea that countries have to move up the ladder towards the best options. Countries that start to incorporate waste incineration to reduce landfilling will go in line with the order of the waste hierarchy. On the other hand, this attempt will, not contribute towards the most important goal -waste prevention, and the waste hierarchy will fail to prescribe the integrated approach. Therefore, the waste hierarchy is mostly useful for incremental changes, to recommend certain orders towards more sustainable waste management (Van Ewijk and Stegemann 2016).

2.2. Waste Incineration

2.2.1. Waste-to-Energy

The increase in waste generation in the last few centuries has brought concerns about the safe utilization and reduction of waste volume. Therefore, waste-to-energy (WTE) became one of the first solutions to address the immediate need for waste sanitation and volume reduction. Currently, WTE not only helps serves its immediate goals but also can produce additional energy in the form of heat, electricity, or fuels. Based on the energy extraction technology the WTE can be divided into two broad categories: biochemical and thermal routes. Waste decomposition at a high temperature includes pyrolysis, gasification, refuse-derived fuel, and incineration, while aerobic and anaerobic disintegration is in the biochemical route of WTE (Malinauskaite et al. 2017), (Sharma et al, 2020). Ouda et al. (2016) also include the third possible route of the physiochemical process of transesterification (turning waste oils into biofuels through chemical reactions).

Brunner and Rechberger (2015) identify that WTE is an essential part of waste management, and several functions are particularly important. The waste incineration prevents pollution by disintegration if hazardous or potentially contaminated MSW. Unregulated landfills can pose the danger of methane emissions that can be partially offset by incineration (Mustafayev pers. comm.). Another benefit from waste restoration comes from retreating resources from incineration by-products like metals from bottom ash (Brunner and Rechberger 2015), and fly ashes (Kubonova et al. 2013). Finally, produced energy (around 5% of all energy demand) can substitute energy that is produced using fossil fuels.

2.2.2. Waste-to-energy: Pros and Cons

Despite the several functions and certain advantages that WTE systems might bring, there are polar views about the sustainability of WTE systems. Sharma et al. (2020) believe that WTE systems could be considered as a part of the linear economy since the energy recovery and partial resource conservation are in line with the material circularity. However, there are views that WTE is not the most desirable step in the waste hierarchy. Ensuring enough feedstock for already established incinerators may divert waste from recycling facilities and encourage increased waste generation. Indeed. European Commission advises the Member States to gradually phase out the incineration as waste treatment, and only increase incinerator capacity if there is enough waste for the incinerator operation span (European Commission 2017). The main order of the waste hierarchy must be taken into account when integrating WTE into waste management systems. Several NGOs Like GAIA (Global Alliance for Incinerator Alternatives) and Zero Waste Europe promote a zero-waste economy and claim that WTE, namely incineration cannot be considered part of sustainable waste management (GAIA - Global Alliance for Incinerator Alternatives 2017). They emphasize the polluting effect of incineration by-products. Indeed, the burning of MSW may result in emissions that contain toxic sulfur, carbon, nitrogen oxides, dioxins, and particulate matter (Khan and Kabir 2020). However, we need to take into account that the most criticism is usually directed towards incineration and other combustion WTE technologies.

On the other hand, from the energy perspective WTE systems are considered to be the important source of renewable energy. Biomass energy obtained from the organic fraction of the waste is encouraged by the Revised Renewable Energy Directive (2018/2011/EU), where biomass was considered to be part of renewable energy. Currently, the amount of energy that was obtained jointly from waste biomass constitutes more than half of total renewable energy (European Commission 2016). Since the Revised Renewable Energy Directive (2018/2011/EU) the biomass obtained from municipal and industrial waste was also included in the main definition of biomass, the renewable energy currently mostly extracted from biomass (European Commission 2016).

2.2.3. Waste Incineration

One of the most widely used technologies of WTE is waste incineration. According to Cor Coenrady (2020), there are around 2500 WTE facilities worldwide (including the planned plants), and most of them are waste incinerator plants. Currently, one of the largest industries of WTE facilities is located in China and Japan, jointly they account for more than a half of world facilities plants worldwide (430 and 850 plants, respectively). Incineration is “The process of burning solid waste under controlled conditions to reduce its weight and volume, and often to produce energy” (2017). It is important to note that the definition emphasizes waste treatment, while energy recovery is a secondary element since there are plants without energy recovery. The basic technology of waste incineration plants includes generating heat from waste combustion. The generated heat is then used for boiling water. The generated steam can provide energy in two ways: to generate electricity with the help of turbines, while additional captured from the steam is useful for space heating (Knox 2005).

2.2.4. Waste Incineration Technologies

- *Mechanical grate incinerators*

Mechanical grate incinerators are one of the most widely used technologies for incinerators. The main difference in technology is the moving grates that move and tumble waste through various incineration stages. During the combustion process, the air is delivered through the grates to increase the burning and cooling grates. The water-wall technology also implies the supply of the air from the above nozzles (Knox 2005). The biggest disadvantage of this method is that the grating structure does not allow for smaller size waste and/or liquid wastes that might damage the grates (Buekens 2012).

- *Rotary kiln incineration*

Rotary kiln incinerators' primary work principle is based upon the principle of shaft furnaces, where waste is delivered into cylindrical chambers that are constantly rotated, and hence tumbled. Additional air is delivered from the front part of the shell. In comparison with grate incinerators, a rotary kiln allows incineration of waste in any form, including liquid and melting wastes (Buekens 2012). After the combustion in the rotating shell, the generated gas has to move to the post-combustion chamber, since the gas strands could not get mixed within a shell. Even though this technology had been used for thermal integration of waste since the 1960s, there are several disadvantages (Buekens 2012). Firstly, a rotary kiln necessitates a big amount of air introduced into the shell due to offset the effects of sudden temperature changes, as a result, the combustion generates an increased level of flue gases. Therefore, Knox (2005) emphasizes that rotary kiln incinerators need constant maintenance and are generally not feasible.

- *Fluidized Bed Incinerators*

Fluidized Bed Incineration is a comparatively new technology that burns waste on a special metal platform that is filled with hot inert materials like sand, dolomite, or ash. The metal platform is filled with holes that can distribute hair through bed material, and air bubbles that travel create fluidized media, and the pressure creates the so-called "the state of levitation". The air bubbles moving upwards creates the necessary mixing motion that helps the effective burning of wastes. One of the biggest advantages is that the erratic movements of waste (enhanced by air movement) helps the even spread of waste materials, the lighter wastes, and volatile materials move to the upper part of an incinerator. The combustion process proceeds swiftly as soon as the waste is on the bed, and the fluidized bed allows for high heat generation and, hence there are no excessive emissions of flue gas (Buekens 2012), (Knox 2005). Moreover, the technology of fluidized beds is relatively easy, low costs, and the different types of wastes can be utilized there. Also, it is not prone to high-temperature changes, and the operation can be maintained easily. However, the most notable disadvantage of the technology is that the temperature has to be low enough not to melt ashes, which may solidify into one layer with bed material (Buekens 2012). Additionally, the fluidized allow only a limited amount of wastes, so overall incineration capacity is relatively small (Knox 2005).

- *Multiple Hearth Furnaces*

Multiple Hearth Incinerators consist of several hearths that are vertically attached to chamber walls, the fed waste is then gradually ascending to the lower, hotter hearths with the help of gravity and movement of each hearth. The air is provided from the bottom of the chamber, where it is heated with the ashes. The multiple hearth incinerators are suitable for a vast majority of wastes since waste resides for a long time in a combustion chamber. Therefore, wastes with high moisture content can be easily dried and combusted (Knox 2005). However, due to complex structures and mechanisms, the technology is costly, and capacity is also low. Also, the structure does not allow for swift heating, and it is prone to thermal shocks (Buekens 2012), (Knox 2005).

- Alternative Incineration Technologies

There are many alternative and less-used incineration technologies like liquid injection incineration (Knox 2005), Vortex combustors, Slagging Incineration, Submerged Combustion (Buekens 2012).

2.2.5. Environmental Impact of Incineration

2.2.5.1. Air Emissions

Generally, there are two broad types of emissions that result from the incineration process: waste-specific and process-specific (Riber et al. 2008). Waste-related emissions are based on incineration process outputs, namely flue gas, bottom and fly ashes, and sludge. Process-related emissions concern certain polluting substances that are controlled by air pollution monitoring systems on incineration plants. LCA of environmental impacts of incineration plant emphasizes 8-9 types of emissions, criteria air contaminants (nitrogen, sulfur and carbon oxides, particulate matter and volatile organic compounds), greenhouse gases (carbon dioxide, methane, nitrous oxides, etc.), and acid gases (Assamoi and

Lawryshyn 2012), (Beylot and Villeneuve 2013), (Mendes et al. 2004). According to the harmful substances that are released into during incineration, the literature mainly distinguishes three negative environmental impacts: global warming potential (due to greenhouse gas emissions), acidification potential (nitrogen and sulfur oxides emissions), and Eutrophication effect (effect of emitted NO_x and N_2O) (Assamoi and Lawryshyn 2012). Apart from direct emissions from the incinerator stack, Assamoi and Lawryshyn (2012) also consider that there are additional emissions associated with incineration like emissions related to waste transportation to plant, requirements for additional fuel, and emissions related to ash treatment.

2.2.5.2. Dioxins and Furans

Despite possible negative environmental effects of the aforementioned emissions on global issues like global warming, one of the biggest criticisms of waste incineration is the possible emission of dioxins and furans. Polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and polychlorinated biphenyls (PCBs) are included in dioxin family elements that are usually emitted in a combustion process. There are several explanations for how dioxins are formed during incineration. The dioxin source might already be present in incinerated MSW, and/or the dioxins might form as combustion of chlorinated precursors found in common elements like polyvinyl chloride (Shibamoto et al. 2007), and/or incomplete burning of organic material may also be a precursor for dioxins (McKay 2002).

The biggest danger of dioxins lies within the immediate health risks they may pose for a local population. WHO has identified that dioxins have several negative effects on human health (World Health Organization 2010). Firstly, dioxins are highly carcinogenic, and it has been proven that lengthy exposure to dioxins is associated with a higher incidence of a tumor.

According to the International Agency for Research on Cancer (1997), the most carcinogenic element of dioxin elements is TCDD (Tetrachlorodibenzo-para-dioxin). The 1976 explosion on chemical plants lead to one of the greatest TCDD-related disasters, and numerous studies show that there have been increasing in breast (Bertazzi 2001), blood cancers (long term), and Hodgkin's disease (Warner et al. 2002). PCBs that result from waste incineration is a less dangerous material, yet it has been classified as an element with a limited carcinogenic characteristic. Despite the limited health effect, the biggest disadvantage of dioxins is that the substances do accumulate in animal tissues and can pose danger through local food consumption. The Stockholm Convention on Persistent Organic Pollutants had identified incineration-specific dioxins in Annex 3, which lists pollutants that should be avoided and minimized (Stockholm Convention 2001). The risk assessment of the area between two incinerators in Neerlandqarter, Belgium did not attribute dioxin accumulation to incineration plant operation. However, the highest exposure route was considered to be the consumption of local meat and dairy, which may have significantly affected children (Nouwen et al. 2001).

2.2.5.3. Solid Residues

Incineration is one of the most effective processes of reducing the weight and volume of generated waste, yet the combustion process yields solid residues. Bottom ash is the residue that falls in the main combustion chamber, while fly ash is the particles composed in the aftermath of the main combustion process, that might be captured by filters. Around a quarter of the initial waste, mass turns into ashes (Brunner and Rechberger 2015). Considering the significance of ash residue, they are widely recycled to marketable construction materials like concrete products, road construction (Alkemade et al. 1994), or glass-ceramics (Silva et al. 2019). On the other hand, we need to take into account that bottom, and fly ashes may contain hazardous elements and might get exposed to the environment through mixing with water (Huang et al. 2017). Therefore, numerous studies investigate the leachability of materials made from recycled ash. Indeed, there is some leaching danger, especially in road construction without prior tests and proper drainage systems (Silva et al.2019).

Another solid byproduct that poses a great danger for the public is heavy and toxic metals like lead, arsenic, mercury, and others. Unlike gaseous emissions, metals are not created by the combustion process, the same amount of metals is present in solid residues (Denison and Silbergeld 1988). The situation is exacerbated by the fact that the released particles are a bioavailable form, the particles are small enough to be ingested. Metals are similarly can be leached to water bodies, especially when exposed to additional chlorine from combusted waste. Denison and Silbergeld (1988) also stress the secondary, post-deposit exposure pathways, claiming that metals, similarly to dioxins, can pose great danger to public health through contaminated food, water, soil particles.

2.2.6. Public Perception of Waste Incineration

The aforementioned review of incineration by-products has shown that incineration can produce hazardous components that are of great concern for public health and the environment. Therefore, incineration has always been subject to public scrutiny and opposition. Currently, there are several environmental NGOs that are actively campaigning against the operation of waste incineration plants like The United Kingdom without Incineration Network (UKWIN), Zero Waste Europe, and GAIA. These organizations mostly address more global issues associated with waste incineration (global warming, overcapacity, circular economy).

Not only do global organizations oppose WTE technologies, rather local opposition usually is considered to be an important factor, since the locals can considerably delay or cancel incineration plant construction. The odors, health concerns, and environmental impact are the main reason for local opposition. Lima (2006) identifies three factors that are likely to predict attitudes towards incineration: perceived risk, perceived justice (distribution of various burdens and benefits of incineration), expectations, and trust to local actors. Also, the public may oppose the innovations due to NIMBY (not in my backyard) syndrome. Similar attitudes have been expressed to new environmental technologies, like ocean wave energy (Heras-Saizarbitoria et al. 2013). Locals might even express positive attitudes, but the NIMBY effect still deters them from full acceptance of technology (Achillas et al. 2011). Also, the effect is further exacerbated in countries that have never experienced waste incineration. However, certain authors believe that NIMBY is a simplistic concept that does not uncover, many factors that might cause opposition (Heras-Saizarbitoria et al. 2013). NIMBY may incorporate certain concerns about economic, institutional, and political factors (Warren and McFayden 2010). Finally, one of the most important predictors of social acceptance of incineration is the trust towards information and actions of local administration (Subiza-Pérez et al. 2020), (Huang et al. 2015).

The literature identifies several ways to overcome public opposition: community engagement, trust for local government, improvement of local infrastructure, efficient monitoring systems (for environmental concerns), and communication and flexibility with the local public (Huang et al. 2015).

2.2.7. Waste Incineration and the Waste Hierarchy

One of the biggest concerns that are associated with waste incineration is that incineration may undermine waste treatment operations situated higher in the waste hierarchy.

Firstly, waste incineration can compromise recycling development. It is important to note that morphological waste composition is an important factor of waste incineration. Each material has varying calorific values, which denotes the amount of energy generated from combustion. Plastics, which are usually considered to be recyclable materials, have a higher calorific value in comparison to organic wastes (Triyono et al. 2018). Moreover, higher content of organic waste in mixed MSW will result in higher moisture content of the feed, which will require additional operations for drying. Therefore, there is a belief that there are economic incentives to burn plastic (Knox 2005). Another concern related to recycling and incineration is the diverting attention and financial resources from recycling development to incineration. For instance, currently, Western European countries already have considerable recycling rates (more than 50%), and the political and economic support for incineration may slow down further development in recycling (Wilts et al. 2017).

A similar problem can be also attributable to the conflict between waste incineration and prevention. Incineration may seem to be an easy and effective solution that would immediately offset the problem of waste accumulation. On the other hand, the construction of an incinerator plant is quite costly, and it has to be constantly provided with waste feed to be economically feasible. Essentially, it does mean that waste generation has to remain at the same level, and considerable waste prevention is not possible. The second problem related to waste prevention is the overcapacity of incinerators. If the throughput of the plant exceeds the MSW generation, and there is simply not enough waste to burn, there is a shortage of waste that is usually covered by waste imports (Wilts et al. 2017). For instance, Europe’s incineration capacity is 81,285 million tonnes (2014) (Wilts et al. 2017), and Germany account for approximately a quarter of a whole incinerator capacity, and there is evidence that Germany will experience overcapacity if the recycling rate will increase (Jofra Sora

2013). Overall, it might be concluded that the economic cost of incineration plant construction and operation may come in conflict with recycling and waste prevention.

3. Methodology

This section intends to provide methodological tools that have been used for information gathering and analysis. The main research methodology is based upon several qualitative methods: in-depth comparative system analysis, semi-structured interviews, and policy analysis. The main information is gathered through an extensive review of scientific reports, articles, and statistical databases, yet due to limitations in available data, the information was gathered through semi-structured interviews with experts in the field. Identification and selection of study subjects

3.1. Comparative Analysis

Comparative analysis has a broad range of uses in any domain of science, however, the overall research algorithm is quite similar among all spheres. The comparative analysis mainly refers to analytical research that aims to identify causal correlations or explain certain phenomena based on the analysis of two or more subjects. Essentially, the comparison aspect necessitates at least two subjects that are going to be studied, and the study include may include countries, communities, historic figures, theories, etc. (Pickvance 2001). Apart from different subject units, the analysis subjects may be differentiated based on either space or time. Cross-sectional studies may select countries, nations as the subject of research, while longitudinal, the historical analysis may compare the same subjects over a certain period.

There are two general types of comparative analysis based on the characteristics of research units: “most similar” and “most different” (Przeworski and Teune 1970). The first type of analysis is used for two very similar research units with many common characteristics, except for one variable. The main advantage is of this method is that it helps to reduce the number of uncontrolled independent variables, and the correlation will be likely attributable to the independent variable of analysis. The “most different’ analysis includes researching two polarized subjects that experience the same phenomenon, process, or causal relationships.

3.2. Identification and Selection of Study Subjects

The main subject of research will concern the waste management systems of two capital cities: Baku (Azerbaijan) and Nur-Sultan (Kazakhstan). Considering that both study subjects share many similarities, the main methodology for system analysis is cross-sectional comparative analysis with "most similar" study subjects.

Baku and Nur-Sultan have slight differences in geographical and demographical characteristics. Baku city is generally bigger than the Nur-Sultan area. Similarly, the population is slightly bigger in Baku, too (The State Statistical Committee of the Republic of Azerbaijan 2019). Topographical characteristics with both cities located on flat, steppe-like plains, lowlands. The elevation is low for both of the cities. Finally, the biggest difference is the overall size of the countries, On the other hand, the geographical and demographic characteristics only account for a part of the existing factors.

The most important factor that brings these cities into the "most similar" category is the fact that Baku and Nur-Sultan share the shared Soviet past and the distinct characteristics of the waste management system have been inherited from USSR. After the collapse of the USSR, both countries have faced the problems of waste management. During the Soviet period, there was an established system of collecting secondary raw materials, and therefore, a considerable of waste was collected and recycled. However, after the collapse of the Soviet Union, the former centralized and state-funded system was no longer here, and since then most Post-Soviet countries struggle with waste management issues (Sim et al. 2013). Both Kazakhstan and Azerbaijan have faced the issue of uncontrolled landfilling and waste accumulation, which have negative impacts on the environment and public health (Baigarin

2020). Therefore, both countries were in a dire need of an immediate solution, and the governments of both countries started to show their interest in WTE technologies (Pokidayev 2020). Since, Baku and Nur-Sultan have very similar waste management systems, the only characteristics that differentiate both countries are the incineration plant in Baku, which has been in operation since 2012. Considering that incineration is only planned in Kazakhstan (Pokidayev 2020), the experience of Baku incineration can provide a useful subject for comparative analysis and preliminary predictions.

3.3. In-depth System Analysis

Waste management is a complex system of various tools, techniques, and stakeholders. Therefore, the best tool for the in-depth evaluation would be system analysis.

The system has a very intuitive meaning that is familiar to everyone, yet there are certain doubts about the actual definition. Kadafa et al. (2014) define the notion of a system as a complex of interdependent elements that work together to reach a certain pre-defined goal. The pre-defined definition seems to be universal, yet Ericson (2011) notes that "A system is a holistic unit that is greater than the sum of its parts". The system consists of more subtle components like interrelation, inputs, subsystems (Renger 2015). Usually, system theory and system are thinking are useful for detangling and understanding complex processes of the systems. General System Theory is especially useful since it helps to analyze the system principles across many scientific spheres (Banathy 1992). If we consider system analysis for waste management systems, there are many technical tools. Kadafa et al. (2014) identify two general types of waste management analysis techniques:

- System Engineering Models: Cost-Benefit Analysis, Forecasting Models, Optimization Models, Stimulation Models, and others.

- System Assessment Tools: Life Cycle Analysis, Risk Assessment, Material Flow Analysis, Decision Support Systems, etc.

Despite the various number of available assessment tools, there is not enough theoretical framework for system evaluation. Therefore, for the evaluation of waste management in Baku and Nur-Sultan, I will follow the principles of the newly developed System Evaluation Theory (SET) by Ralph Renger (Renger 2015), which establishes the main principles for system evaluation.

System analysis consists of several steps to be completed. Firstly, the system and its constituent have to be studied, the boundaries have to be defined, During, the first stage, I will conduct a thorough overview of the whole system by defining the main actors, organizations, stakeholders, and their functions. Then, the main processes of the system will be described. The research will not only include the main processes of waste treatment (like waste collection or transportation), but also include the economic and social aspects, and will include the processes like tariff calculation or public participation. Finally, the main inputs and goals of waste management will be studied.

Secondly, the system efficiency will be evaluated. The evaluation will be based upon the identified goals (from the first stage). Additionally, Renger (2015) proposes an evaluation of feedback mechanisms within the system. Feedback mechanisms are the tools within the system that let monitor the processes and overall environment.

The final step of analysis will include the holistic assessment of system effectiveness. The overall performance of cities will be evaluated, and conclusions will be given based on the more general principles of sustainability. Finally, the recommendations established on the international incineration industry will be provided.

3.4. Data Collection

Certain aspects of Systems Analysis can be studied with the use of secondary literature and statistical data. Defining the main constituent parts of the waste management system in Baku and Nur-Sultan can be completed using an extensive literature review. On the other hand, social aspects like public opinion are not sufficiently covered in the existing secondary literature. Moreover, the plans regarding the construction of incineration plant in Kazakhstan has been announced recently, and the majority of necessary has not been documented yet. Therefore, the use of primary data like interviews with experts and live conferences was necessary to provide lacking information. Considering that incineration is usually conflicting technology with certain negative impacts (see Environmental Impact of Incineration), interviewing various stakeholders will provide varying viewpoints and experiences related to waste management for both Baku and Nur-Sultan.

3.4.1. Interviews

According to Given (2008, 470), "Interviewing is a conversational practice where knowledge is produced through the interaction between interviewer and interviewee". Interview data is one of the most diverse types of information that allows a researcher to gain more detailed knowledge on researched topics, or engage in theory-building by discovering and analyzing new facts, principles, etc. The necessary opinions on social and economic aspects of waste management and incineration were gathered through 6 interviews with various experts in the field of waste management. Rand et al. (2000) identify 4 types of stakeholders involved in the waste incineration industry: authorities, community, and representatives of the waste and energy sector (Fig. 1).

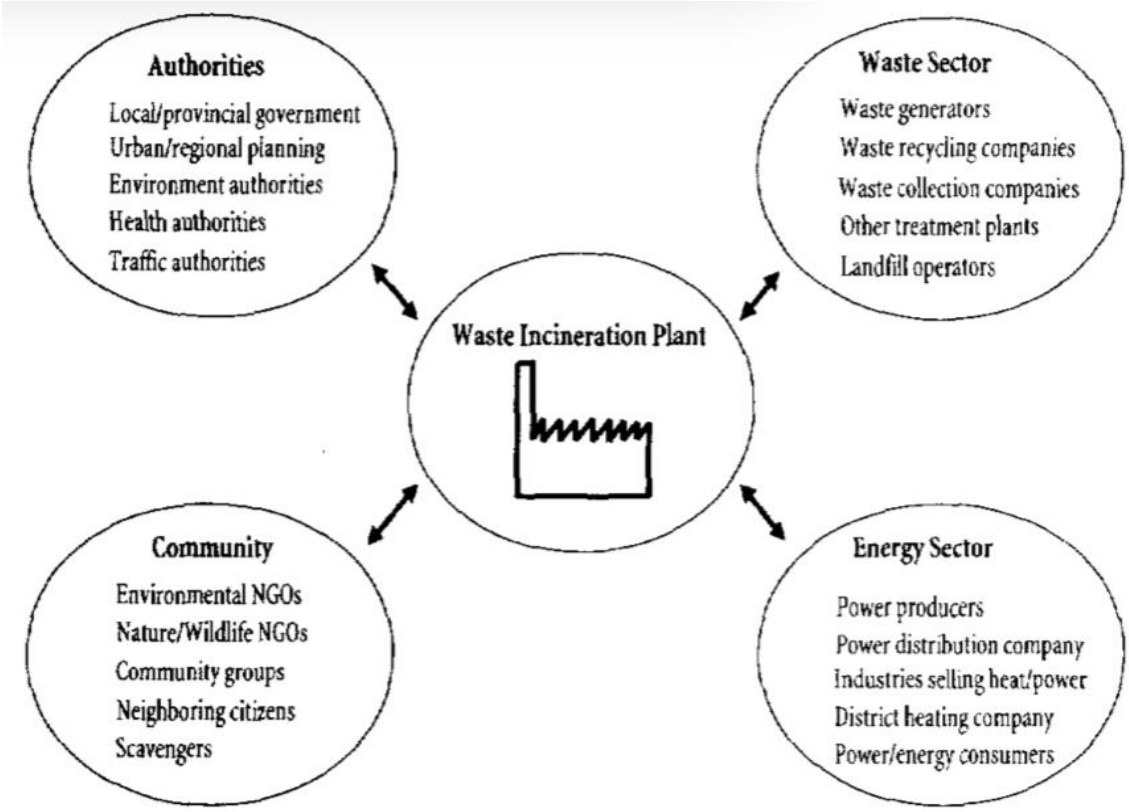

Figure 1. The relevant stakeholders of waste incineration facility. Source: Rand et al. 2000;

In Kazakhstan, the interests of authorities and the energy sector are similar, since the most energy-generating companies are state-owned. Due to lack of transparency and low response levels, the opinions of local authorities have been collected through conferences. The interviewees have been selected from four main groups: representatives of environmental NGOs, industry leaders/experts in recycling, experts in the waste incineration field, and public opinion leaders from Baku and Nur-Sultan. Then interviewees were selected through the "snowball" sampling method. Table 1 represents the details of interviewees and interviews.

Data, collected, from various groups of experts have reinforced more comprehensive study, since the information obtained was not present in any secondary resources, especially for the information related to public opinion.

Table 1. The detailed information on conducted interviews

Interviewee	Country	Occupation
Dr. Islam Mustafayev	Azerbaijan	The member of the National Academy of Sciences of Azerbaijan, chairman of ecological society "Ruzgar", professor;
Kuralay Aliyeva	Kazakhstan	Eco-blogger, eco-activist, the creator of "Stop Incinerator!" [Stop MSZ!] movement;
Javid Gara	Azerbaijan	The founder of Environmental NGO "Ecofront" in Azerbaijan
Medina Hajiyeva	Azerbaijan	The former chief environmental specialist at CNIM Baku incinerator;
Egor Zinger	Kazakhstan	Co-founder of two waste recycling plants in Nur-Sultan and Almaty;
Dr Vasileios Inglezakis	Greece	Chemical Engineer, Reader at the University of Strathclyde, the author of several studies about waste management in Kazakhstan;

Because interviewed experts have been located in different countries and travel restrictions related to the latest COVID-19 pandemics did not allow for in-person meetings, all interviews have been conducted digitally. The conducted interviews have been conducted through the "Zoom" video communication software, which lets video and audio record the interviews. Each interview has lasted approximately one hour and has been conducted in the period of 5th to 25th of June 2021. The majority of interviews were conducted in the Russian language.

The scheme of main questions for the interview has been prepared beforehand and has included various aspects of waste management and incineration, namely economic and legal questions, public opinion on incineration, sustainability aspects, and the relation between recycling and incineration industry. Depending on the expertise area of the respondent certain questions were added or modified. Considering that almost all questions were open-ended, all interview format was semi-structured, and additional follow-up questions were asked, where the new facts or aspects was discovered. The general questions used to lead the interviews can be found in the Appendix section.

After the interviews have been conducted, the recordings have been manually transcribed and recurring concepts were coded. The codes then have been gathered, and relevant themes were identified and analyzed. For example, interviewees often mentioned "landfilling", "recycling", "lack of transparency", "public health and air pollution". Later, the identified topics were classified and analyzed for closing the gaps, that were necessary to perform system analysis.

3.4.2. Live conferences

The conducted interviews have covered a wide range of specialists that provided the necessary information. On the other hand, one of the biggest stakeholders that were not covered during the interviews was the government officials of Kazakhstan, Due to logistical difficulties and difficulties in identifying relevant stakeholders in governmental sectors, interviews with government officials have not been conducted. On the other hand, the information obtained from government officials would be considered fundamental for the research purposes of the thesis. Therefore, the necessary information has been obtained through attending three live conferences that were dedicated to the construction of waste incineration plants in Kazakhstan. Table 2 illustrates detailed information about the date and the topic of the conferences.

Table 2. The detailed information on live conferences

Name	Date	Description
“Recycle or burn” [Pererabatyvat’ nelzya szhigat];	17 May 2021	The conference has been organized by the opposing “Stop Incinerator!” movement. The main topic of the conference was “Public opinion on the project of waste incineration plants in Kazakhstan”. Public figures, scientists, and NGO representatives presented the opinions of various stakeholders. The main issues related to incineration were discussed.
The conference from the Association of Practicing Ecologists of Kazakhstan	18 May 2021	More than 50 eco-activists have discussed the different aspects of waste incineration. The speakers included scientists and engineers, including specialists from France and Russia.
International Congress “Ecojer”, the debate panel “Recycle or Burn”;	3 June 2021	The congress organized debates about waste incinerators in Kazakhstan between Mansur Oshurbayev (Director of Department of public policy and waste management of Ministry of Ecology) and Aiman Seksenova (head of the “Eco Madeniet”). The debate was about the justifiability of waste incineration in Kazakhstan.

4. Comparative Waste Management System Analysis

4.1. Main Stakeholders

MSW management systems in Azerbaijan and Kazakhstan consist of many governmental, non-governmental and, international actors. To conduct system analysis, it is important to limit the boundaries of the system, the identify main stakeholders and their main functions.

4.1.1. The Development of Legal Framework, Waste Management Policies

The regulation of waste management in Kazakhstan and Azerbaijan is quite similar, the main legislative functions in Azerbaijan are made by the ***Ministry of Ecology of Natural Resources*** (later - Ministry of Ecology of Azerbaijan) and ***Ministry of Health***. Both of them form waste management policies to ensure sustainable development and minimize environmental and health impacts. The main waste management policy in Kazakhstan is also defined by the ***Ministry of Energy*** and ***Ministry Ecology, Geology and Natural Resources*** (later – Ministry of Ecology of Kazakhstan). According to the Law of the Republic of Azerbaijan about industrial and household waste (514-IQ) (1998), the main structure responsible for waste management is not only responsible for the formation and implementation policies on waste management but also conducting EIA of enterprises associated with waste treatment, determining national policy on transboundary waste movements and provision of information related to waste. The ***Cabinet of Ministries*** is responsible for adopting resolutions that set general rules for the management of municipal, hazardous wastes, pesticides, and implementation of international agreements (United Nations Economic Commission for Europe 2011).

The main direction of waste management policy in Kazakhstan has been developed by the Ministry of Ecology, later these functions have been transferred to the newly created Ministry of Ecology of Kazakhstan (specifically to the ***Department of State Policy on Waste Management***) in June 2019. ***Environmental Regulation and Control Committee of the Ministry of Ecology*** is the also responsible organ that develops the technical documentation, methodology, and standards for MSW (United Nations Economic Commission for Europe 2019). Also, it was important to note the functions of JSC Zhasyl Damu that was created as a program for the preservation of local ecosystems, and later they started assisting the government in the implementation of environmental policies.

4.1.2. Waste Collection and Transportation in Baku and Nur-Sultan

Waste management in Kazakhstan and Azerbaijan both suffer from numerous problems, and proper collection and transportation have been an issue. In the last few years, both countries have experienced considerable improvements in this regard. However, it had to be noted that most of this improvement only concerns bigger cities.

There are several responsible actors for waste collection, transportation, and treatment. One of the considerable development in Azerbaijan was the creation of state-owned JSC ***Tamiz Shahar*** in 2009 by the presidential decree “On Improvement of Management of Solid Household Waste in Baku city” (Tamiz Shahar n.d.). The company is responsible for waste disposal and recycling (Mustafayev pers.comm.). The collection, transportation, and containers for initial on-site sorting are done with the help of ***Baku municipality*** and privately-owned services. JSC Tamiz Shahar is also an important actor of waste management development since it has assisted in rehabilitating the Balakhani landfill site, which had caused public discontent and negatively affected the environment due to uncontrolled open-air waste burning (Mustafayev pers. comm). The waste collection in Nur-

Sultan is also privately owned, and the companies are selected through the tenders that are organized by local municipalities. ***Clean City NC*** is the main company that performs waste collection and separation in Nur-Sultan. The company owns a base of 66 waste disposal vehicles, that serve all households off Nur-Sultan (Clean City NC n.d.).

After the complex clean-up of the Balakhani landfill and the recreation Balakhani Industrial park, JSC Tamiz Shahar became also responsible for the development of waste recycling facilities (Mustafayev pers. comm.). The waste recycling industry in Kazakhstan is less centralized and mostly consists of privately-owned companies, like Kazakhstan Waste Recycling, Kagazy Recycling, Qazaq Recycling, etc. Therefore, in 2013, the self-regulated organization, ***KazWaste,*** supports waste management and recycling organizations by providing legal and educational services (KazWaste n.d.). However, later the government of Kazakhstan has issued a decree about the creation of a special organization that would develop sustainable waste management. The decree pronounces that ***LLP "Operator ROP"*** is appointed structure the response that would ensure and enact the principles of extended producer (importer) responsibility (Masimov 2015). The "Operator has two main strategic missions – the development of sustainable waste management and educational work with the public to inform them about waste sorting, recycling, and reuse (Operator ROP n.d.). Currently, Operator ROP ensures producer responsibility by the introduction of a contentious "recycling fee", that is to be paid by producers and importers (Zinger pers. comm). Therefore, it can be concluded that the waste collection and treatment in Kazakhstan consists of scattered individual actors and initiatives, while Azerbaijan waste management actors are more organized under the management of JSC Tamiz Shahar.

4.1.3. Environmental NGOs

There are numerous national and international environmental NGOs both in Kazakhstan and Azerbaijan that address the questions of sustainable waste management. For example, ***the Association of Practicing ecologists*** of Kazakhstan constantly performs conferences and studies on issues of waste, like open-air waste burning, centralization of the waste management system, groundwater polluting on landfill sites. Similarly, the aforementioned ***Kazwaste association*** serves as a platform for the development and collaboration between waste management facilities. Local ***NGO Hayat*** in Azerbaijan also creates projects to clean up highly landfilled areas (like in cities Yevlakh and Tovuz) and promotes sustainable waste management practices in schools (Stevens et al. 2007). Similarly, ***Ecological Society "Ruzgar"*** helps organize public movements and supports the government in international projects (Ruzgar n.d.). Finally, there are less publicly organized organizations that aim to improve waste management practices. Ecological activists from Kazakhstan have created a public movement "Stop MSZ" (Stop to Waste Incineration Plant), that opposes the introduction of new waste incinerator plants in Kazakhstan.

4.2. Main Input – Waste Generation and Morphological Composition

It is quite intuitive that the main input into the waste management system is waste itself, and it is important to understand the main trends in waste generation and composition of the waste to predict the efficiency and the necessity to establish the plants. Both countries have experienced a dramatic increase in the MSW generation and alteration of the waste composition in the last few decades after the collapse of the USSR.

In the last two decades, Kazakhstan has experienced a dramatic upsurge in the MSW generation. Such a trend might be attributable to two factors: the socio-economic development and the overall increase in population for over 3 mln people in the last two decades (Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National Statistics 2020). The increase in MSW generation and the accumulation of waste in landfills can also be described by the increase of the population in the gradual increase of population in both countries.

The per-capita waste generation statistics have shown that on average people in Azerbaijan (150-200kg per year) generates less waste than inhabitants of Kazakhstan (250-310 kg per year) in the last few years (Fig. 2 and 3) (The State Statistical Committee of the Republic of Azerbaijan 2018). However, the statistics cannot fully represent the waste generation habits of the capital population, usually, more waste is generated in capitals. For instance, the seasonal analysis of Abylkhani et. al. (2020) has extrapolated that each person in Nur-Sultan threw away 538 kg in 2017. However, later trends have illustrated that waste generation is slowly decreasing in Kazakhstan, which is opposite to the trend for Azerbaijan.

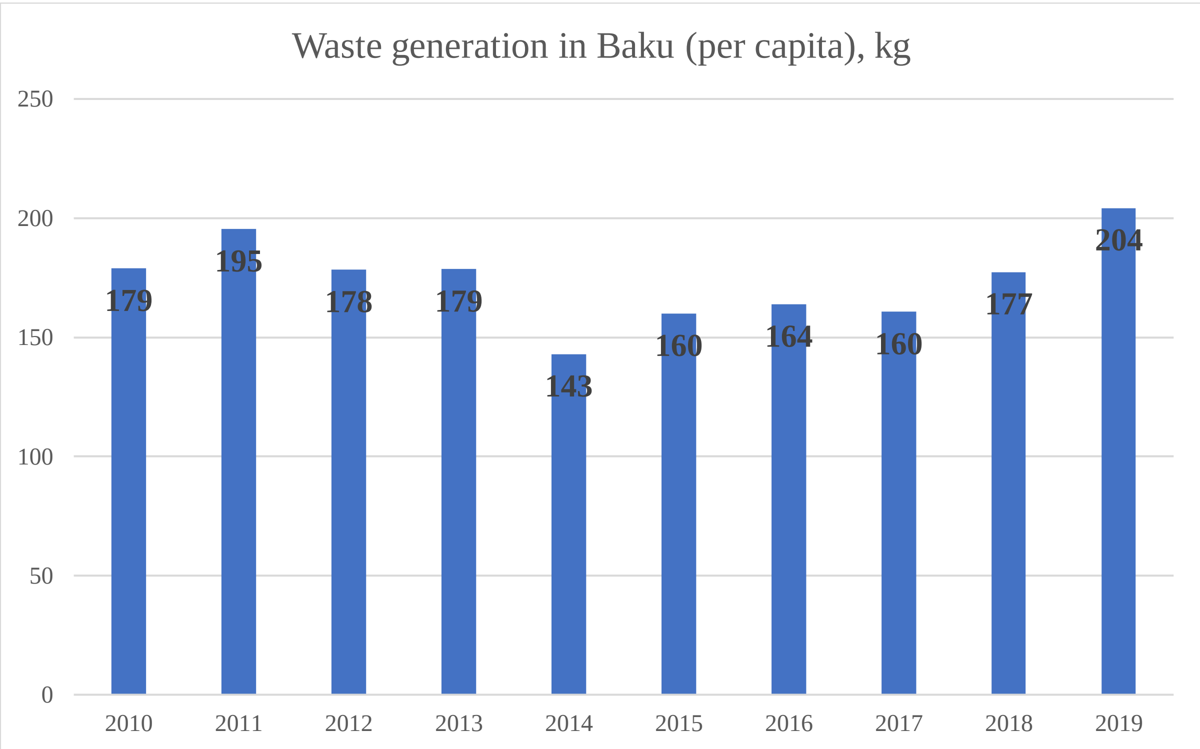

Figure 2. Per capita waste generation in Baku. Source: The State Statistical Committee of the Republic of Azerbaijan 2019;

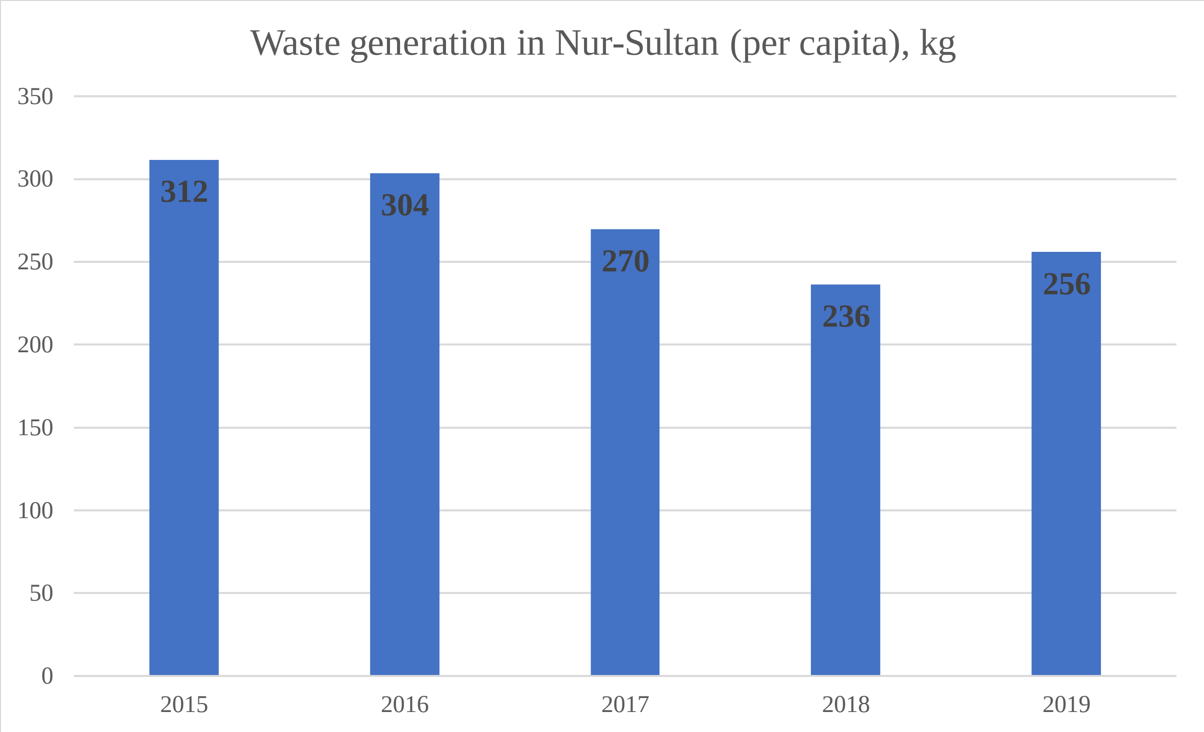

Figure 3. Per capita waste generation in Nur-Sultan. Source: Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National Statistics 2020.

The waste composition in both countries is similar to each other and typical for developing countries. The municipal waste contains a major share of moisture-rich organic waste, plastic, paper, a lesser amount of textile, metals, glass (2-4%), and other miscellaneous wastes, like wood, electronics, and diapers (Abylkhani et. al. 2020). Unfortunately, the statistics on Azerbaijan are quite outdated, yet it can be expected that waste composition has not changed significantly. Both countries have a great recycling potential since recyclable materials (not including organic waste) represent almost 40% in both countries (Fig. 4 and 5). However, this potential cannot be realized completely due to a lack of sorting. According to Zinger (pers. comm.), the morphological composition of waste in Kazakhstan is very “aggressive”, meaning that waste is not undergoing initial sorting, and various types of waste including industrial and hazardous wastes are mixed. Also, the unsorted recyclables that are mixed with moisture-rich organics are almost impossible to sort and further recycling.

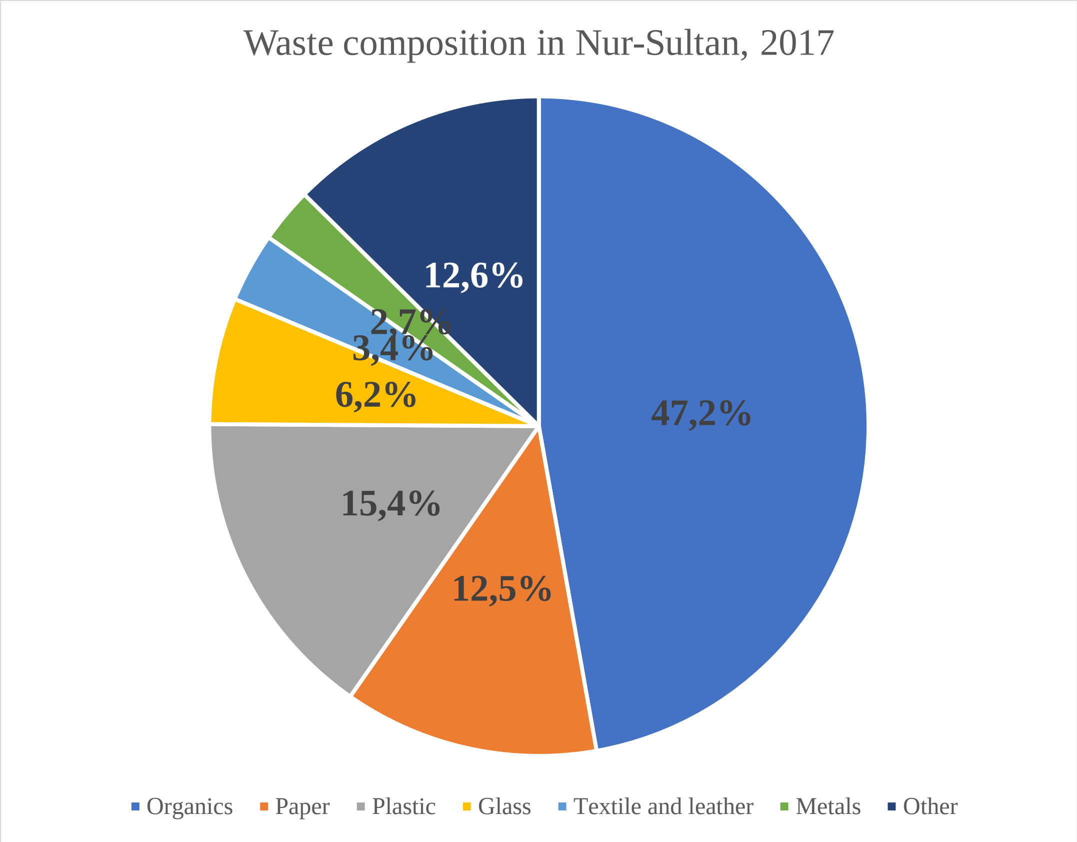

Figure 4. Waste composition in Nur-Sultan (2017). Source: Abylkhani et al. 2020

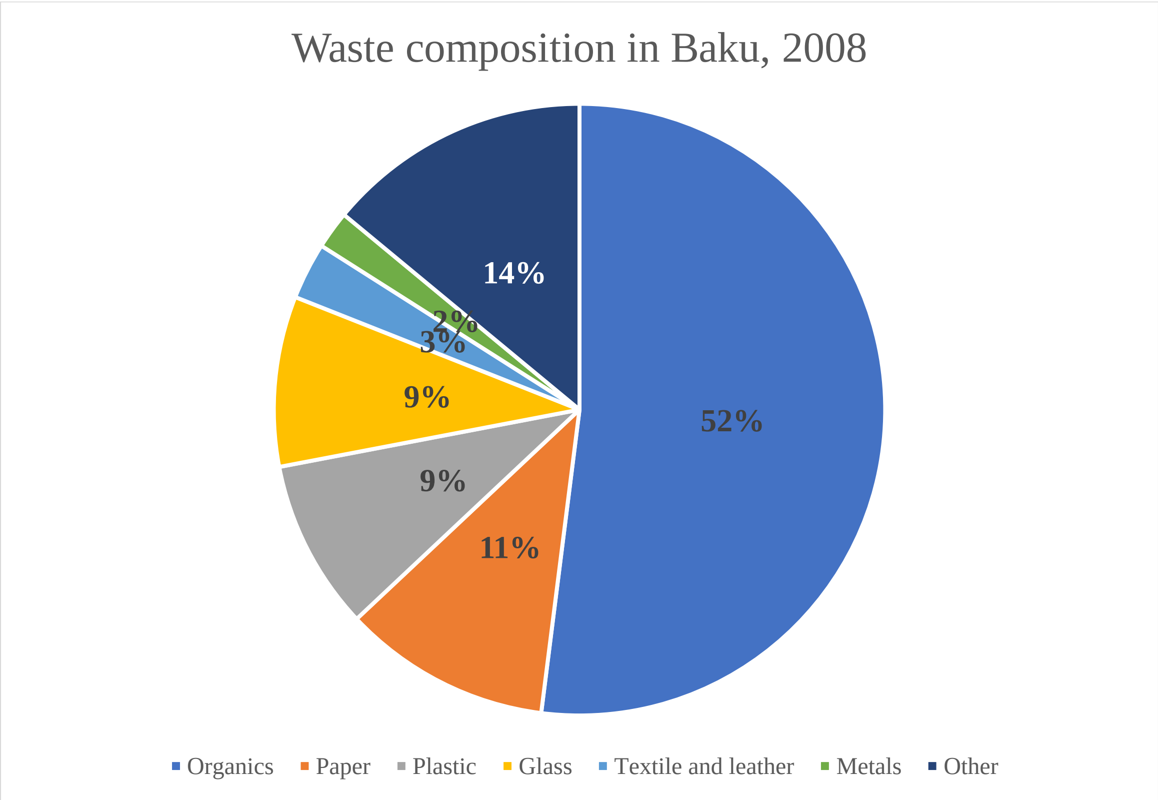

Figure 5. Waste composition in Baku (2008). Source: Hughes 2013;

Finally, it is important to note that all the presented findings were based on a few available studies, and some of them were outdated. There are not enough studies on existing waste generation trends and waste composition. Moreover, the studies that investigate the calorific values of the MSW have to be conducted to build connections between energy and waste sectors.

4.3. Waste Management Systems of Baku and Nur-Sultan

4.3.1. Waste Collection and Transportation

For in-depth analysis of end-of-life waste management, it is important to take into account the situation with waste collection and transportation, since both Kazakhstan and Azerbaijan suffer from illegal dumping and a certain portion of the countries are not covered with satisfactory waste collection services (Mustafaev pers. comm.), (United Nations Economic Commission for Europe 2011). Before the building of incineration plant waste transportation has been considered one of the biggest waste management as well as an environmental concern due to increasing waste generation and inability to timely collect generated waste.

The initial collection and transportation of waste is the responsibility of the Baku City Municipality and private companies. They are responsible for on-site sorting and collection of waste from residential blocks to collection points, which are then collected and transported to Balakhani Industrial Park, where waste is either landfilled, sorted, or incinerated. In order to prevent the illegal dumping and ensure that waste will effectively travel to Balakhani Industrial Park (that is located at a distance from the city, on the Baku-Sumgayit road) (Hajiyeva pers. comm.), Baku city has organized two transfer points. After the appointment of JSC "Tamiz Shahar" as the main organization responsible for waste disposal, Baku has experienced certain developments not only in end-of-life waste management activities but also in environmental education promoted through ecological and social events like exhibitions, meetings, tours, and internships for youth (Hajiyeva pers. comm.). Despite the positive aspects of establishing g centralized waste utilization system by “Tamiz Shahar”, the Baku city municipality is responsible for on-site collection. Unfortunately, the municipality failed to organize effective on-site sorting. According to Hajiyeva (pers. comm.), there have not been any on-site sorting attempts till 2018 (6 years after the launch of the waste incinerator) when London-based consultancy company “Mott Macdonald” in collaboration with municipalities tried to organize separate waste collection by installing containers for different waste materials. However, the overall effectiveness of on-site separation is quite low, since only a small part of Baku residents is covered with separate containers. Moreover, there are only two types of containers that would separate recyclables from organic waste (Hajiyeva pers. comm.). Therefore, the presence of state-owned utilization companies helped to drastically improve waste transportation in Baku, yet the municipality should organize a more effective on-site waste sorting system.

The situation with waste transportation in Nur-Sultan is quite similar to Baku’s case. Similarly, privately owned LLP “Clean City NC” is responsible for waste collection transportation. “Clean City NC” LLP is the only company in the capital, specializing in the collection and transportation of MSW from residential blocks. The company possesses waste disposal equipment, (66 garbage trucks and 25 units of specialized machines) of the class "Euro-4". Daily, the company serves all four districts of Nur-Sultan in two shifts (Clean City NC n.d.). Despite the developed coverage of waste collection and transportation, Nur-Sultan suffers from inadequate on-site sorting. The waste in residential blocks is also collected in two differently colored bins. Yellow containers have been installed for the overall collection of recyclables (metal, plastic, glass, paper), while green containers are for general rest waste.

Some of the residential blocks have additional “cage-like” containers that are dedicated solely to plastic waste. However, most of the households fail to sort waste, and both colored containers contain mixed waste (Fig. 6). The main difference is that in Kazakhstan collection and transportation are performed by privately-owned companies that are assigned by the competition organized by municipalities. Overall, it is safe to conclude that situation with waste accumulation and transportation in both cities is quite similar.

Figure 6. The waste bins for general wastes (green) and recyclables (yellow) in Nur-Sultan.

It is important to note that access to centralized and organized transportation is not available throughout all areas in both Azerbaijan and Kazakhstan. For instance, till today 30% of the population in Kazakhstan is not covered with waste collection services (differences apply based on different regions) (United Nations Economic Commission for Europe 2018). Most of the rural areas deal with waste through open-air burning due to the lack of waste management alternatives.

4.3.2. Landfilling

As has been mentioned earlier, landfilling remains one of the least desirable waste disposal options due to air pollution and leachate accumulation. Landfilling is the main disposal option for the waste generated in Nur-Sultan. Similarly, waste from Baku was also accumulated in various landfills before the introduction of the waste incinerator. Moreover, the building of the Baku waste incinerator and the Balakhani Industrial Park is primarily related to acute pollution from the Balakhani landfill and other illegal dumpsites.

There are 4 official landfills that cover all the Baku city (Balakhani, Azizbeyov, Surakhani, and Garadkah). Even though these dumpsites are not used to their full capacity, constant waste burning, and other environmental impacts caused great concern. Due to unsatisfactory waste collection services by city municipalities and private companies, 40% of waste was accumulated in spontaneous dumps throughout the city. For example, in 1995, in the suburbs of Baku and Sumgait (the third biggest city, located near to Azerbaijan), there were 89 illegal solid waste dumps (80 in Baku and the rest in Sumagyit). In 2013, this number increased to 130 dumps (Kahramanova 2013).

Balakhani landfill, which was operating since 1963, was the largest in the Baku region and it presented the biggest concern for locals and the government. Before the rehabilitation, the Balakhani landfill, like many other Azerbaijani landfills, did not follow any international standards and lacked any engineering structures that would prevent negative impacts. The landfill was mostly mismanaged, and there were no satisfactory leveling procedures, despite periodical pressing by bulldozers. Frequent open burning of waste and overall windy of Absheron peninsula led to the smoke pollution in the region and neighboring villages. At the end of 2008-09, a huge incident erupted after a massive fire could not be put out for several weeks, and air emissions have increased significantly (Hajiyeva pers. comm.). The situation has been so urgent and severe that local eco-activists have created documentary movies related to air pollution in the region ("Balakhani smoke" by Islam Mustafayev). Moreover, the landfill presented the problem since it has lacked impermeable layers, that would prevent groundwater contamination. Currently, Balakhani is leveled, fenced and the access to landfills is properly managed.

Even though the Balakhani has been rehabilitated and landfilled waste does not cause health concerns as it used to do, other landfills that collect waste from neighboring Sumgayit and suburb Baku regions, still present the problem due to odors and frequent waste burning, The ministry officials admit that there are complaints about the Sumgait landfill. The inspections showed that the garbage is poorly buried, it often remains on the surface, which causes an unpleasant smell (Zeynalov 2018).

Similar problems with the mismanagement of landfills are present in Kazakhstan, too. Low levels of recycling and the overall mismanagement of landfills that 120 mln tonnes of MSW have been accumulated on landfills according to official numbers (Pokidayev 2020). According to the Association of Practicing Ecologists, out of 3000 dumpsites currently present in Kazakhstan, less than 20% comply with local sanitary norms. Most landfills are overfilled and have reached the end of their recommended operation period. None of the regions has landfills with high-efficiency MSW management (Malikova, "Stop Incinerator!"

conference). Moreover, the landfill with an engineered geo-protection layer is only present in the capital, Nur-Sultan. The majority of landfills are spontaneous and mismanaged, and various wastes (including medical and hazardous wastes) end up together without any prior sorting.

The main landfill in Nur-Sultan is consists of two 12-hectare cells, located at the edge of the city (Alash road, 72). Due to constant waste accumulation, the first cell has been filled up with 3 mln tonnes (which considerably exceeds its initial capacity of 1,8 mln tonnes), and the second cell started its operation in April 2018 with an operational capacity for the next 5 years (United Nations Economic Commission for Europe 2018). The analysis shows that despite rehabilitated or engineered landfills in the capital cities, landfilling is still considered to be the main waste disposal method in Azerbaijan and Kazakhstan.

4.3.3. Sorting and Recycling

Considering that the generated household waste mostly ends up in landfills and there are not enough recycling facilities in both Azerbaijan and Kazakhstan, the overall rates of recycling are quite low for both countries (Fig. 7 and 8). The indicators for Azerbaijan show that despite the building of Balakhani Industrial Park facilities, the overall rate of recycling did not increase significantly, and settled around 25%. However, there is important to note that shown data (Fig. 8) display overall recycling rate including material recycling of MSW, composting, and recycling of industrial and medical waste. The lack of available data on MSW recycling brings difficulties in separating the effect of new Balakhani facilities. The figures for Kazakhstan show a different picture since till 2012, the recycling rates have been really low, not exceeding 5%. However, since 2016, the recycling rate has increased to 1% and more, which may be attributable to the introduction of a law banning the disposal of potentially recyclable materials such as plastic, glass, and paper from 2019 (Sagintayev

2018). Similarly, the actual data on recycling in Kazakhstan may be higher (up to 20%) since some of the recyclables are sold to neighboring Russia, according to the “KazWaste” association (Mustafayeva, “Stop Incinerator!”). Overall, the recycling practices in both countries are still in a very basic stage.

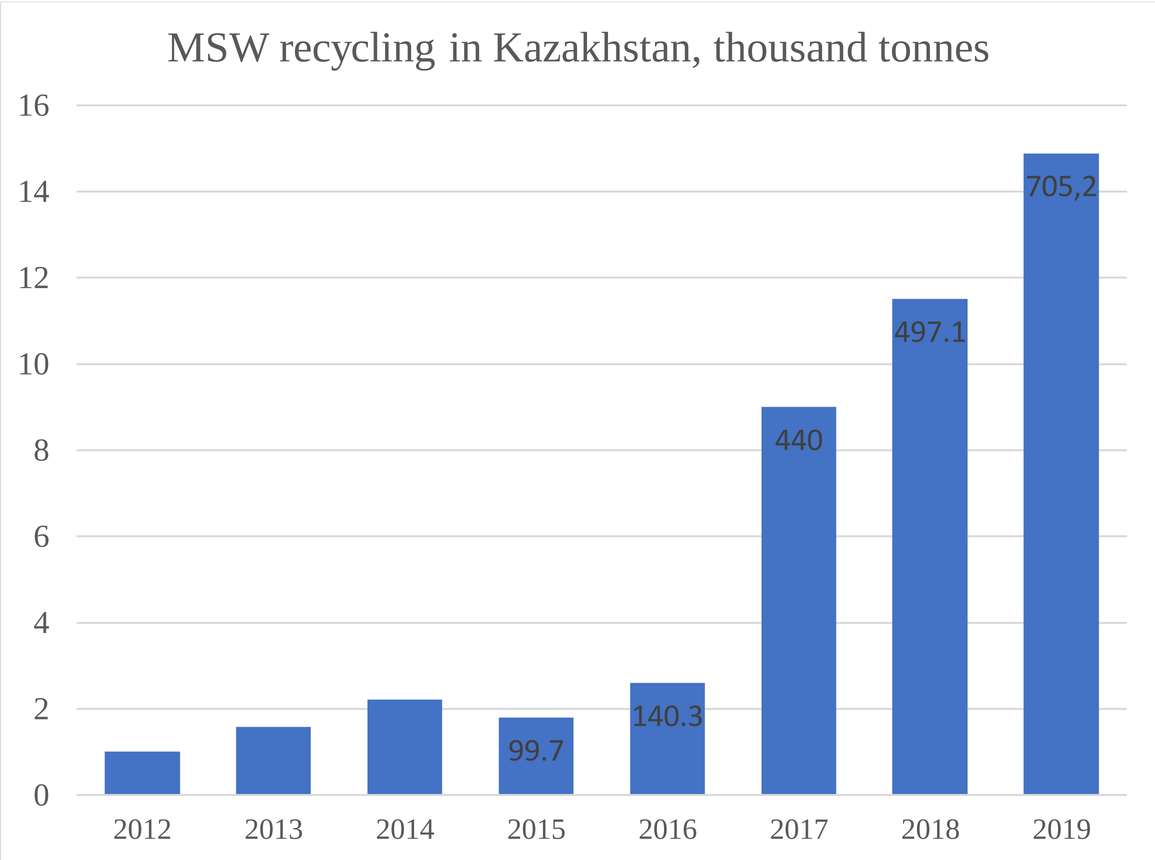

Figure 7. MSW recycling in Kazakhstan. Source: Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National Statistics 2020.

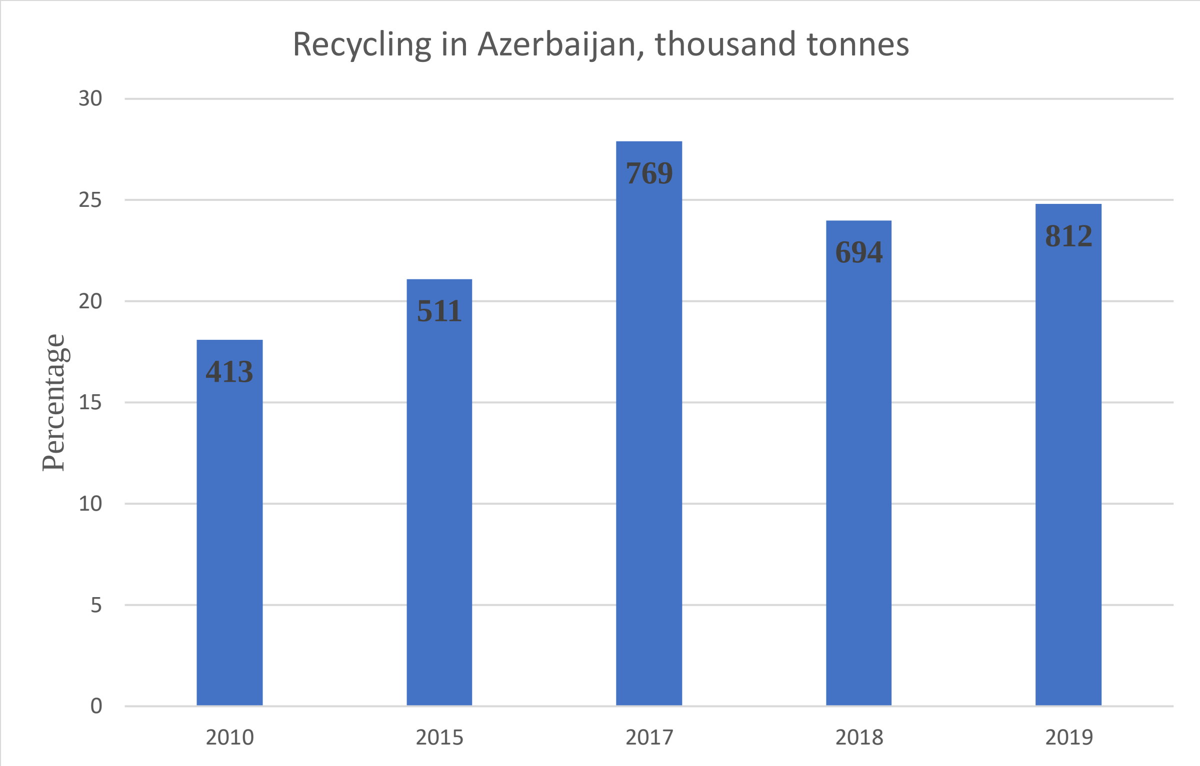

Figure 8. Recycling in Azerbaijan. Source: The State Statistical Committee of the Republic of Azerbaijan 2019;

The sorting and recycling in Baku are mainly done through the two main facilities of Balakhani Industrial Park. After the waste disposal has been redirected to JSC "Tamiz Shahar" under the framework of the 2007 strategy of improvement of MSW management by the president Ilham Aliyev, two main facilities have been built: waste incineration and sorting plants. Waste disposal in Baku mainly consists of three main directions: waste sorting, incineration, or landfilling. Each year, the industrial park receives around 600-700 thousand tonnes of waste, 500 thousand of which is incinerated, 200 thousand tones are sorted (little less than 100 thousand tonnes of it are recycled) (Mustafayev pers. comm.).

The waste that is directed to sorting is first weighed and then sorted into different categories. The sorting on the plant is semi-automatic, therefore bigger wastes are sorted using conveyors and magnets, while others require manual separation. However, not all the waste is getting sorted or incinerated due to the harsh morphological composition of waste and lack of on-site waste separation. The rest of the garbage that is not incinerated or recycled is transported to rehabilitated Balakhani landfill (Mustafayev pers. comm). With the support of the Azerbaijani government and World Bank, the landfill is completely rehabilitated and controlled, leachate and all waste waters are collected and treated for further technical use, while the gas is also trapped and converted into electricity.

The new 2018 National Strategy on the improvement of waste management by the President has announced that the government will build new recycling facilities and infrastructure that will be financed locally and internationally. New improvements will also be introduced to waste transportation and collection. Also, the Strategy pays attention to the improvement of ecological education and supporting NGOs in clean-up events (Hajiyeva pers. comm).

The waste sorting and disposal in Nur-Sultan also resembles the operation of Balakhani Industrial Park, except for the incineration plant. After the waste from two different colored bins is collected, then it proceeds towards the only waste processing plant, that is located near to the man city landfill. Daily, a thousand tonnes of collected MSW is brought to the waste disposal complex. Considering the aforementioned fact that on-site separation does not work in Nur-Sultan (despite the introduction of bins), most of the received MSW is mixed. There are four main areas of the plant: sorting (initial and secondary), production, transportation, and eco wool. The sorting on the plant is not automatic and done manually, so the plant capacity does not exceed 250 thousand tonnes. After, the waste first arrives at the plant it gets the initial sorting manually separates large scale recyclables from the rest of the mixed waste. The small particles are also collected and sent to landfills. According to the former owner of the plant, Egor Zinger (pers. comm.), at this stage, the plant is faced with the problem of separating organic matter from the rest of the waste. Due to the aggressive morphological composition of the waste and the high content of organic matter, the separation cannot be performed effectively. Next, the production department processes PET plastic, films, and other types of plastics. The plant processes and produces secondary products such as pellets, flakes, films (using Austrian technology EREMA), and eco wool. Waste unsuitable for recycling is collected and briquetted into cubes with a density of 1000-1400 kg / m3. Despite the existing recycling opportunities, the current management (KazRecycleService LLP) does not use the full commercial potential of recycled materials, and most of the waste is compressed and exported to Russia for about $ 400 per cubic meter (Zinger pers. comm).

Despite the improvement in the level of recycling in Kazakhstan, the overall recycling rate is low. This fact may be attributable to several issues. Firstly, efficient waste collection and transportation practices in the capital are undermined by the lack of an on-site waste separation system. The quality of secondary materials is significantly deteriorating. Secondly, there is still a shortage of recycling facilities capable of separating and recycling all generated waste. The current plant is only able to process approximately 70% of generated waste. Moreover, the lack of the necessary technologies and inefficient management leads to only primary processing (not realizing full commercial potential) of materials.

4.4. Waste Incineration

4.4.1. Waste Incineration Plant in Baku

The next important part of waste disposal in Baku is the waste incineration plant that is also part of Baku Industrial Park. The incinerator plays an important part in one of the directions of Baku waste management– energy recovery. However, the plant was built to prevent waste accumulation and redirect waste from landfills. Therefore, after the clean-up of the Balakhani landfill, “Tamiz Shahar” under the Ministry of Economy of the Republic of Azerbaijan has built an incinerator in 2012. The plant has been built and operated by the French Company CNIM. The operational capacity (consisting of two lines) of the plant allows it to burn 500 thousand tons of MSW per year. The plant generates electricity only and the capacity is 221.5 million kilowatts/hour. However, the amount of converted energy is negligible for the city’s overall energy consumption (approximately 7-8%). This type of plant is quite unique for the region, and currently, there are no similar plants in the CIS region (except Russia) (Mustafayev pers. comm).

The operation process on the plant is as follows: firstly, after the waste is transported from two main collection points, it is brought and stored in a special bunker. Even though the recyclable materials should have been sorted and processed before getting to the incinerator, usually all sorts of waste end up in the bunker, since there is no direct contact between trucks and bunkers (Hajiyeva pers. comm). Moreover, during the summer months, when the moisture and organic content of waste are higher, the bunker would get constantly flooded with water (Hajiyeva pers. comm). Therefore, there was a constant necessity to remove the accumulated wastewaters from the bunker, At the bunkers waste is lifted with special cranes, and then proceeded for the incineration in the kilns. The temperature in the furnace can reach up to 800 degrees, the burning process boils the water, and steam is converted to electricity. The plant utilizes open-hearth furnaces. Currently, the plant has a possibility of increasing its capacity by adding another line for 250 thousand tons (Hajiyeva pers. comm).

The generated by-products like bottom and fly ashes are collected and transported and buried in neighboring Sumgait hazardous waste landfills. Some metal particles are also recovered from bottom ash. On the other hand, plastics, concrete parts, and glass have also been found in bottom ash due to inefficient sorting. Fly-ash is filtrated through a flue gas treatment system, that controls and monitors air emissions. However, the incinerator lacked the on-site laboratory that would let compare the indicators from the air emission sensors (Hajiyeva pers. comm). Despite certain deficiencies, the plant has been operating under the European Waste Incineration Directive (there is no specific legislation in Azerbaijan) (Hajiyeva pers. comm). Overall, the flue gas treatment system and the isolation and proper disposal of harmful by-products prevent the polluting effect of the incineration plant. However, the lack of on-site sorting, small amounts of generated energy, and burning of potentially recyclable materials undermined the long-term sustainability of this project.

4.4.2. Possible Incineration Practices in Nur-Sultan and Other Regions of Kazakhstan

Currently, there are no operating MSW incineration plants in Kazakhstan. However, due to considerable waste accumulation and decreasing space on the main landfill in Nur-Sultan, the government shows consistent interest in WTE technologies. Initially, the issue of waste management has been mentioned in 2013, when new a concept of the Green Economy has been introduced by the Presidential Decree. This document first warned about the growing amount of waste and ineffective waste management and disposal practices (Office of the President of the Republic of Kazakhstan 2013). Due to the lack of significant developments in the field of waste disposal, Kazakhstan has faith in the problem of waste accumulation and illegal and/or mismanaged landfilling. Therefore, the first mention of the use of Waste-to-Energy (WTE) technologies was made in 2020 by the Minister of Ecology of Kazakhstan Magzum Mirzagaliyev (Pokidayev 2020).

The government is planning to establish the plants in six large regions of Kazakhstan (Aktobe, Atyrau, Almaty, Nur-Sultan, Taraz, and Shymkent) by 2025. Unlike the incineration plant in Baku, the construction and maintenance of the future plants in Kazakhstan will be carried out by private organizations determined at the auction. At the moment, the establishment of incineration plants is at its initial stage. On July 15, 2021, an international auction, that has identified the incineration plant project, was held. The results of auction bidding have identified the winner to be the LLP Waste2Energy from Kazakhstan (JSC KOREM 2021). Even though the plants have yet to be build and the incineration system introduced, it is important to analyze and discuss all the possible constraints of waste incineration in Nur-Sultan.

4.4.3. Constraints

4.4.3.1. Economic support mechanism and its constraints

One of the biggest concerns related to introducing incineration is associated economic costs. The incineration has high costs of installation because of spending on flue gas treatment systems, boilers, generators, turbines, and other equipment. Not only do the waste incineration plants have installation costs, but other costs associated with plant maintenance must be taken into account (labor, operational costs, plant maintenance, chemicals, by-product disposal cost) (Sharma et al. 2020). Therefore, to make the plant building an attractive investment most governments around the world usually provide subsidies or other reimbursement mechanisms. Similarly, the Kazakhstani government has announced that the state will support the plant by purchasing electricity under a certain specified price. Firstly, the Ministry of Ecology has identified the maximum allowed price and the amount of electricity it is willing to purchase. Currently, the maximum allowed price has been set at 191.9 tg/kWh (0.45 USD for 10/08/2021). Next, the auction that would identify the winning investor is held, the investor with the lowest bid and the selling price for the generated electricity is determined. According to the latest auction, the LLP Waste2Energy (the only bidder) has proposed 172.71 tg per kWh, (0.41 USD for 10/08/2021) which signifies a 10% decrease from the maximum price (JSC KOREM 2021). After the identification of the price, the state is obliged to buy electricity and compensate the price for at least the first 15 years of plant operation. However, the electricity is purchased not by the Ministry, but by the Financial Settlement Center of Renewable Energy LLP, created under KEGOC JSC, which was created to support the development of renewable energy in Kazakhstan (Senate of the Parliament of the Republic of Kazakhstan 2020). Even though the price has been already identified, the state is also obliged to index the price following inflation and exchange rate. The aforementioned support scheme may be attractive for potential investors, yet the investing company has to bear high installation and operation costs. Moreover, the electricity generating capacity may be altered due to the specific morphological composition of MSW, which will be discussed later.

4.4.3.2. The Price of Incineration

The installation price is the highest cost of the incinerator, which might considerably increase the price of waste disposal. Considering that the plant establishment in Nur-Sultan is have not started yet, the only information available about the expenses on plant building is 180 billion tenges (more than 423 mln USD) that is planned to be invested into all six projects (Zhuravleva 2021). However, these numbers are preliminary, and there is no information on the actual use of the allocated finances. Therefore, the empirical formula (1) provided by Tehrani and Haghi (2015, 3) might provide the approximate estimation of installation cost:

$$“I = 2.3507 \times C^{0,7753} (1)”$$

"… where I is the investment cost in million dollars and C is the plant capacity (1000 metric tons of waste/year)".

Currently, Nur-Sultan households produce around 1000 tons of MSW daily, which amounts to 350 thousand tons per year. Therefore, the formula predicts the installation price of the installation incineration plant with the capacity of 350 thousand tonnes to be $220.6 million. Hence, the unit price of each tonne of waste will constitute $630. However, we need to take into account the identified installation expenses are only preliminary and many factors might affect the price. For example, the case with the Baku incinerator shows that the capital costs constituted $457.6 million (covered by the governmental JSC "Tamiz Shahar"), which is considerably higher than the $290.9 million predicted by the formula (Asian Development 2020).

Costs associated with plant maintenance also increase the necessary investments. Usually, the operational costs include labor, maintenance, chemicals, disposal of wastewater, and other by-products. Apart from installation expenditures, Tehrani and Haghi (2015, 3) provide a formula for the next formula (2) that estimates the operational costs based on annual capacity:

$$\text{“}A = 0.0744 \times C^{0.8594} \ (2)\text{”}$$

"… where A is the annual operating and maintenance cost in million dollars per year…". Henceforth, the operational cost for the possible plant with the capacity of 350 thousand tonnes will constitute at least $11,43 million per year. Considering that the average operational period of the plant is 20 years, the plant would require around $450 million of investments even without considering other expenses and profits. According to Hajiyeva (pers. comm.), even though the plant was able to resolve the problem of waste accumulation and Balakhani landfill, the government is not planning to increase capacity (there is a possibility to add another chamber for 250 thousand tonnes) or build new incinerator plants. The incineration practice in Baku has shown that the plant could not be considered an economically feasible venture. Similarly, the high investments and the issues related to waste composition may undermine the feasibility of the incineration plant. Moreover, the privately-established plants in Kazakhstan may lack the governmental support provided in Azerbaijan.

4.4.3.3. Waste composition and energy production

The feasibility of the plant is also dependent on environmental factors like waste composition. The amount of generated electricity is the dependent calorific value of the household wastes. The different calorific values of materials define the amount of energy that could be derived from the combustion of waste. As it has been shown earlier, the organics constitute the majority of waste (46.1% to 49.5% according to seasonal differences) (Abylkhani et al 2019). This situation is similar to the majority of developing countries. The high organic content of the waste prevents effective combustion and lowers the overall calorific value of the waste.

The incineration plant in Baku has faced similar problems related to the calorific value of the waste. Even though the operational capacity of the plant in Baku is 231500 MWt/h, the plant electricity production is lower due to miscalculations of waste calorific value (Fig. 9). The initial estimations of 6-9 MJ/kg have in practice turned out to be 4.5-6 MJ/kg. Unfortunately, there are no available data, that would estimate the calorific value of waste in Nur-Sultan, and the waste has to be carefully studied for efficient electricity production for the specified capacity (Asian Development Bank 2020). The winning LLP Waste2Energy has identified that the maximum capacity of the plant in Nur-Sultan will constitute 21.1 MWt (100.8 MWt for all 6 plants). Moreover, we need to take into account that there is only a limited number of studies are available about waste generation and composition in Kazakhstan, the regions apart from Nur-Sultan and Almaty are not studied, hence the plans to launch plants in other regions may not be feasible.

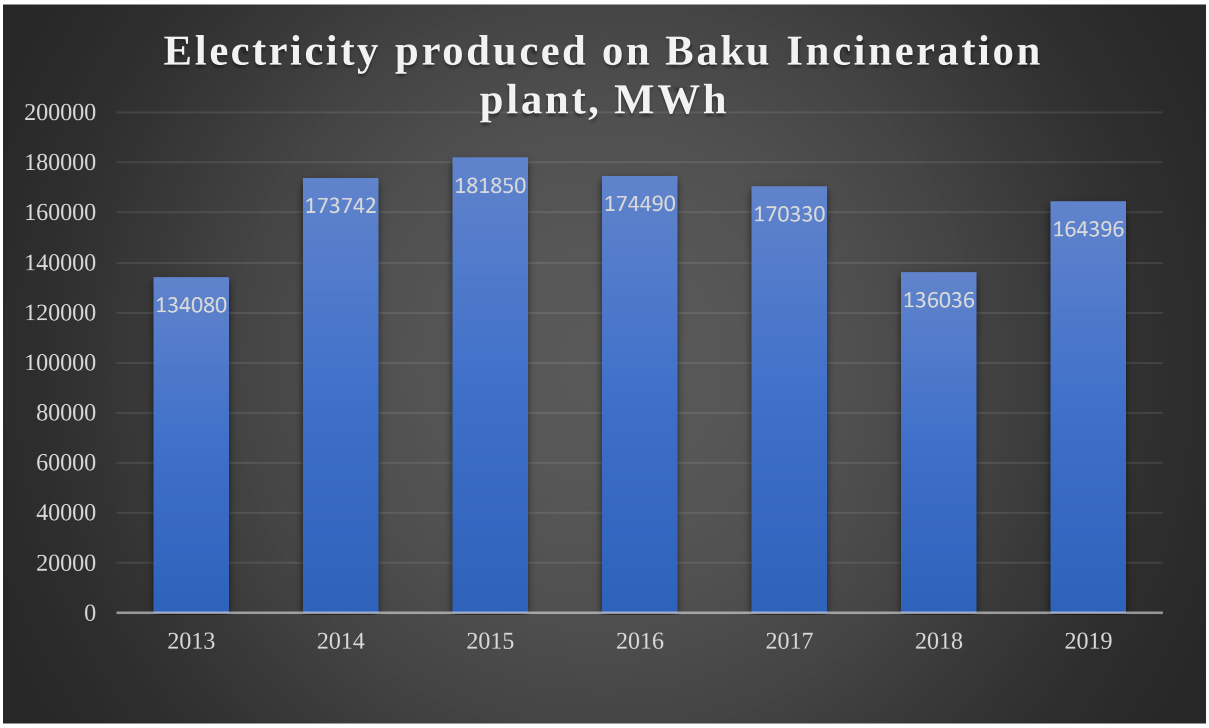

Figure 9. Electricity produced on Baku Incineration Plant. Source: (Asian Development Bank 2020).

4.4.3.4. Waste composition and long-term sustainability

The waste composition and lack of adequate waste sorting may affect the long-term sustainability of the incineration project. As has been mentioned earlier, the calorific value of waste constituents is a predictor of the amount of generated waste. For instance, recyclables like plastic have a high heating value, which might be even 40 MJ/kg, while the organics (around 7 MJ/kg) and unrecycled waste reduce the overall calorific value (Figure 10). According to World Bank recommendations, the state has to have “A mature and well-functioning waste management system has been in place for several years” (Rand, Haukohl and Marxen 2000, 2) to introduce incineration systems. According to Hajiyeva (pers. comm.), due to ineffective sorting certain, materials like glass and heavy industrial waste were found in the bottom-ash of the incinerator in Baku. Considering that Kazakhstan and Azerbaijan do not have an established system of on-site waste separation, and sorting plants is not completely effective in separating waste, there are dangers that potential recyclable plastic will end up in the incinerators. According to the list of materials not subject to energy recovery, only industrial, hazardous, and metal wastes are not allowed in the incinerator. Recyclables, like plastics, textiles, glass, rubber, and paper are not mentioned, potentially allowing the incineration of these materials. Even though the energy from waste is considered to be renewable, the process eliminates materials that might be used more sustainably according to the waste hierarchy.

No	Non Recycled MSW Components	Mass Fraction (%)	Physical Properties (%) – dry based			Moisture (%)		Calorific Value (MJ/kg)		
			VM	FC	ash	inherent moisture	total moisture	dry-based	air-dried	as received
1	Leaf litter	34.67	73.17	17.87	8.96	12.32	40.67	19.62	17.20	11.64
2	Food waste	23.33	84.24	15.11	0.64	8.51	65.00	18.00	16.47	6.30
3	Vegetable waste	14.33	77.09	13.68	9.22	11.46	88.25	18.25	16.16	2.14
4	Fruit waste	11.00	73.38	14.59	12.03	9.92	83.53	18.38	16.56	3.03
5	Non Recycled Plastic	16.67	99.30	0.04	0.66	0.39	1.68	45.80	45.62	45.03
6	Mixed organic MSW	83.33	76.97	15.94	7.08	10.79	61.32	18.77	16.74	7.26
7	Non Recycled MSW	100.00	80.69	13.29	6.01	9.06	51.38	23.27	21.17	11.31
8	Indonesian coal [a)]	–	47.13	46.40	6.47	16.31	34.40	27.14	23.24	17.46
9	Sub-bituminous coal	–						19.33-22.1 (dry basis)		

Figure 10. The calorific value of different waste materials. Source: (Triyono et al. 2018)

Secondly, the energy derived from incineration is not renewable and sustainable since the production process is dependent upon fossils. Considering that the price for the incineration energy is several times higher than the existing energy tariffs, 172.71 tg per kWh based on the auction and 15,46 tg/kWh of the actual tariff. In order, to offset the difference in the prices the incinerator energy will be mixed with fossils (Pokidayev 2020). Therefore, incinerator energy does not promote renewable energy due to reliance on fossil fuels.

4.4.3.5. Public Opinion

Another aspect of incineration that might undermine its successful implementation is public opinion. Due to discussed negative environmental impacts and high costs, the technology is often considered socially conflicting. Moreover, the trust towards the incinerator is undermined by the lack of governmental transparency and public involvement.

This situation applies to the establishment of plants in both Baku and Nur-Sultan. According to experts (Hajiyeva, Mustafayev, Gara pers. comm.), the incinerator plant in Baku has been built in response to the catastrophic situation with the Balakhani landfill, yet there was not any major public awareness about the plant. On the other hand, there was no significant opposition, except few environmental experts, too. There were only several sporadic complaints about the emissions from the Balakhani village locals, and further, these complaints were resolved by the Ministry of Ecology (Hajiyeva pers. comm.).

The opposition to the incineration plants in Kazakhstan, in turn, is more mobilized and organized. Kuralay Aliyeva and other eco-activists have organized the movement “Stop Incinerator!” (“Stop MSZ!”) that actively opposes the building of incinerators in Kazakhstan. The activists have organized interviews, conferences, and informational companies. Also, the petition to ban the implementation of the incineration project has been published on otinish.kz (the official petition website in Kazakhstan). The movement has identified several conflicting issues related to incineration:

- Environmental and public health impact. The activists pay attention to the emissions of dioxins and their effect on public health (especially for childcare).
- Lack of qualified workers and violation of environmental standards. The incineration technology is completely new, and it would require more funds for equipment replacement.

- The contradiction to SDGs and waste hierarchy. According to Aliyeva (pers. comm.), the technology will undermine the following SDGs: 3rd (good healthcare), 12th (responsible consumption), 13th (fight against climate change), and 17th (lack of governmental transparency).
- The lack of governmental transparency and public engagement. The establishment of technology has been implemented immediately without considering public opinion, which is further exacerbated by the distrust of the government.
- The cost of the project and the sources of investments into the plant. It has been shown that incineration would require massive investments, and there is a possibility that the burden will be placed on the population. Indeed, the activists note that the organization "Operator ROP", which is responsible for the implementation of extended producer responsibility in Kazakhstan is ready to co-invest the plant. The organization is mainly financed by the "utilization fee" that is paid by the imported car owners or ordinary consumers (since the fee is already included in the price of goods and services) (Aliyeva pers. comm.). Considering that the capacity is 21.1 MWt, on average plants operate 8000 hours per year and the difference in tariffs constitute 157.25 tg per kW/h (172.71 – 15.46 tg per kWh), the investments to ensure profitability and offset the difference in tariffs has to constitute more than $62 million.

The concerns expressed by the activists agree with the overall theory of public perception towards incineration by Lima (2006). They have realized the *potential risk* for the environment and public health, a *burden* that may eventually lay towards the whole population, and, most importantly, distrust of local actors due to missing public involvement. The movement has identified that the government did not provide open access to all information, they did not engage the general public in discussions and decision-making and did not coordinate all legislative acts, including European Directives (Aliyeva pers. comm.). These facts grossly violate the public participation principles declared in the newly amended Environmental Code:

> “Public participation in decision-making on issues affecting the interests of environmental protection and sustainable development of the Republic of Kazakhstan is ensured from an early stage when all opportunities are open to considering various options and when effective public participation can be ensured.” (Environmental Code of the Republic of Kazakhstan 2021, article 5 paragraph 9).

The NIMBY effect from a local population cannot be assessed for now because there is no information about the actual location of the future plants. Moreover, the government did not organize any public hearings to inform the population about the technology and possible risks and benefits.

5. Conclusions and Recommendations

5.1. Conclusion

The waste management systems in Baku and Nur-Sultan are quite similar to each other. Azerbaijan and Kazakhstan have similar waste disposal practices, main actors of waste management, and waste generation trends (MSW with a high organics and moisture content, increase in the consumption of plastics, increase in per capita waste generation). Both cities have satisfactory waste collection and transportation systems, and basic infrastructure for waste sorting. The waste disposal mechanisms are also comparable, most of the waste ends up in form of briquettes in landfills (Nur-Sultan and Baku before incinerator establishment), some part of it goes through the washing and sorting process. The sorting plants in both cities allow for some material recycling (no more than 20%), yet these indicators are difficult to assess due to inefficient monitoring systems in both countries.

The systematic barriers to the development of waste management are also alike. Firstly, the on-site waste sorting in both cities is, and there are not enough public educational campaigns dedicated to organizing waste sorting. The aggressive waste composition of waste in both countries further deteriorates the waste sorting on existing plants.

The analysis of the cost of the plant in incinerator, capacity, and waste morphological composition in Baku and Nur-Sultan shows that the incinerator may not be considered a feasible facility, it would require considerable governmental subsidies. The government of Azerbaijan has resolved the problem with waste accumulation, yet they do not plan to expand the incinerator network. Experts believe that the reason behind this lies in the economic feasibility of the project. In turn, the plant in Nur-Sultan will be built with investments of the owner company, yet the final price of the plant will be placed on consumers through the increase of communal tariffs.

The experience of Azerbaijan and the early stages in Kazakhstan has shown that plant establishment lacks governmental transparency and public engagement. Environmentally and socially conflicting technologies, like incineration, should be considered and announced at the concept stage. Both cases have shown that the information about the plants has been announced quite late, and in Kazakhstan, public hearings are the responsibility of already identified plant owners. On the other hand, the environmental activists of Kazakhstan have mobilized the movement, that opposes the building of the plant in Kazakhstan.

The analysis of the plant in Baku has shown that incineration is the only temporary decision that was immediately necessary for resolving the waste accumulation on the Balakhani landfill. The plant uses European Incineration and Emissions Directives, and there were no major complaints regarding environmental or public health threats. On the other hand, the Waste Framework Directive and the principles of the Waste hierarchy are not observed since there were numerous cases when recyclables, industrial, and other bulky wastes were sent directly for incineration. Therefore, it can be concluded lack of sorting may lead to uncontrolled burning of all waste constituents, compromising the recycling industry.

5.2. Recommendations

5.2.1. The recommendations on capacities and number of the future plants

One of the biggest problems of designing an incinerator is researching and deciding on its proper capacity. The plant has to both be economically feasible, offsetting costs and gaining some profits, and at the same time, high capacity should not undermine the better waste management options (recycling and prevention). Moreover, the capacity analysis is complicated since, during the operation of the plant, new trends in recycling in waste management may arise, that may decrease or alter the incinerator feed. Currently, there are only a few studies directed to the assessment of waste generation and composition in Nur-

Sultan, and it is difficult to predict the calorific value of the waste. The experiences of the Baku incineration plant have shown that the calorific value differed, and the maximum amount of generated electricity did not exceed 82% of built-in capacity. Therefore, before launching the plant, the plant owner has to carefully study the morphological composition and the moisture content of the waste throughout the year. A similar waste weighing and analyzing system have to be built in the plant itself.

Secondly, the capacity has to be adjusted according to the recyclable fraction of the MSW. If the waste transportation company collects around 400 thousand tonnes, then the waste incinerator capacity should not exceed 230 thousand tonnes (57-58% of waste, which will exclude the recyclable fractions of polymers, paper, glass, metals, and hazardous wastes).

Finally, the government should revise the number of planned plants. The current analysis has only concerned the plant in the capital city Nur-Sultan, with enough population, proper waste collection practices, and a waste sorting plant. The waste management practices in other regions are less studied, and there are no guarantees that such costly and sophisticated facilities could be operated there. Recommendations set the 50 thousand tonnes of annual capacity as the floor for the feasibility of incineration plants. Considering that the information on the waste composition and waste generation in regions other than Almaty and Nur-Sultan is not available, the possibility to launch them is highly questionable.

5.2.2. Integrated waste management

To ensure the further development of waste management in Kazakhstan, and move to higher steps of the waste hierarchy, it is important to develop other aspects of waste disposal and generation. The Baku Incinerator operates within the Balakhani Industrial Park that has a gathered sorting plant, recycling organizations, landfill, and incinerator. Therefore, new projects addressing recycling, composting, and waste prevention must be introduced.

First and foremost, authorities must organize control after the waste streams, which would allow for a better understanding of the waste situation in Kazakhstan. The next step would include the development of educational programs for the general public, that would tackle one of the biggest issues – on-site waste separation and prevention. Apart from community engagement, the government and companies must be encouraged to establish better infrastructure. Namely, the waste collection companies should gradually add more garbage containers for different materials. Another important factor would be to improve sorting and modernize the only waste sorting plant in Nur-Sultan. Considering that the current plant is non-automatic, and it only processes a quarter of incoming waste, there is a threat that the incinerator would work with unprepared waste.

Finally, the government should ensure the financial sustainability of the plant and the overall waste management system by adjusting the fees. According to Zinger (pers. comm.), the waste disposal fees are disproportionally allocated to waste collection companies, and environmental activists from Nur-Sultan have also expressed concerns that the incinerator will also increase energy tariffs. Therefore, the government should conduct and openly publish the feasibility study of the plant.

5.2.3. Recommendations on Public Engagement

The analysis of waste incineration plants has shown that the plans to build an incinerator in Kazakhstan have induced public opposition that has not been present in Baku. Therefore, the government should pay additional attention to building the dialog with the local public and organized movement.

Firstly, the government should conduct a large-scale study that would identify the social, environmental, health, and environmental impacts of the incinerator. This study has to be published on open (preferably digital) resources, the disseminated materials have to be written according to the values and knowledge level involved population. Later, several public hearings have to be organized, the organizers must ensure that the information is comprehensive, yet understandable. These discussions must include all layers of the population, and all opinions have to be given equal consideration. According to National Research Council (2000, 244-245), there should be guarantees that the communications in the meeting should be "timely, substantive, and honest". In order to include the differing opinions, there might be a necessity to conduct additional independent studies or present the findings of independent groups. The opinions of opposing movements and activists must be also given consideration and presented to the general public.

Finally, public engagement is not a singular activity, and must not end as soon as the plant will start its operation. There must be participatory programs, periodical surveys, and/or advisory groups that would help to continuously monitor and communicate the public opinions to the authorities (National Research Council 2000).

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Personal Communication

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Hajiyeva, Madina. Formal online interview. The former chief environmental specialist at CNIM Baku incinerator. 29 June 2021.

Mustafayev, Islam. The member of the National Academy of Sciences of Azerbaijan, chairman of ecological society “Ruzgar”, professor. Formal online interview. 3 June 2021.

Zinger, Egor. Co-founder of two waste recycling plants in Nur-Sultan and Almaty. Formal online interview. 19 June 2021.

Appendix

Possible research questions/ questions to be asked from respondents:

- Did the Ministry of environmental take into account the environmental and other issues related to waste incineration (like environmental consequences, social consequences, demographic factors, long-term sustainability, overcapacity addressed? how this is going to be reflected in policy or other documents?)
- What technology is Azerbaijan is using for incinerators? Which technology is planned to be used in Kazakhstan, any recycling attempts from by-products? (obtained through Ministry of Ecology of Kazakhstan and Temiz Shahar (the company operating the plant in Baku))
- What is the public perception of incinerators both in Azerbaijan and Kazakhstan? If there were any studies about public perception on Azerbaijan and Kazakhstan? IS there was any opposition to launch the plant in Azerbaijan and how did they resolve it? IF they monitor public opinion and how in Azerbaijan?
- What was the initial aim of launching an incinerator (Kazakhstan and Azerbaijan)? Did it reach the specified aims? How has the overall waste management changed/developed thanks to the incinerator? What about recycling? Is there was development in Recycling, and did the overcapacity issue got addressed?
- Incorporation of WTE technologies into policy documents? Did Azerbaijan use any country as an inspiration? How overall waste management policy changed? What perspective of long-term waste management strategy? If any European documents, directives were used as a basis, is it possible to follow EU directives for CS countries?
- Can we consider the experience of Azerbaijan as successful (for eco-groups of Azerbaijan)? Is there are specific factors that should be taken into account when constructing a waste management strategy and incorporating WTE technologies into it? What are future perspectives? If Azerbaijan is planning to expand the number of incinerators? Is incineration is going to be a part of a long-term waste management strategy?
- IS waste incineration sustainable? Is there a place for waste incineration technology in a sustainable and integrated waste management system?
- Should developing countries follow the European experience of launching incinerators and then gradually increase recycling, or the incineration step could/should be completely omitted in countries that struggle with waste accumulation and want to build sustainable waste management systems?