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GHG Emissions Assessment as Part of MSW Green Cluster Design: Case of Large Cities in Russia and Kazakhstan

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***Abstract* – The increasing pressure on the environment and the exhaustion of non-renewable natural resources has led to the emergence of a new type of clusters – green clusters. In green clusters, the purpose of combining entities into a cluster is not only to increase their competitiveness, but also to increase the efficiency of using natural resources and reduce the impact on the environment. Companies of various types of activities get united into green clusters; this article considers green clusters in the field of municipal solid waste (MSW) management. The authors described two green clusters in project in the field of MSW management in two large cities – Yekaterinburg (Russia) and Almaty (Kazakhstan). The main difference between these clusters is the ratio between waste management practices. Further, using the IPCC methodology for calculating greenhouse gas (GHG) emissions, the authors analysed GHG emissions per tonne of MSW in both clusters. The calculations have shown that the green cluster of Yekaterinburg is more stable and efficient – the carbon content of 1 tonne of processed MSW in Yekaterinburg is 22.4 % lower than it is in Almaty (329.5 kg CO_2eq/tonne of MSW in Yekaterinburg and 424.1 kg CO_2eq/tonne of MSW in Almaty). To reduce the MSW green clusters' climatic impact, it is necessary to organize a full-fledged separate collection of different types of waste at the household level; to stimulate waste recycling activities; to reduce the use of non-recyclable packaging, including the implementation of extended producer responsibility; to reduce energy utilization, especially at the waste incineration plants; to stimulate the use of organic waste shredders. The practical examples discussed in this article and the conclusions obtained can be useful to decision makers regarding the design and development of green clusters in the field of MSW management in large cities. The study relies on the research data of the project 'Enhancement of the State Regulation Policy for Intensifying Clusterization of Industrial Regions' supported by the Ministry of Education and Science of the Republic of Kazakhstan.**

***Keywords* – Eco-industrial cluster; extended producer responsibility; GHG emissions; green cluster; MSW management; MSW sorting; recycling; waste management practices**

1. INTRODUCTION

Clusters are an effective form of interaction between various entities in the economy, which today allows to increase both the competitiveness of individual entities included in the cluster and the entire cluster as a whole [1]. Clusters are actively used in the industrial policy of different countries. To date, there is a wide variety of clusters that differ depending on their

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goals and organizations that are part of them. For instance, in Russia there are industrial, logistics, innovation, IT, tourism clusters, and others.

The increasing pressure on the environment and the exhaustion of non-renewable natural resources has led to the new type of clusters emergence – green clusters. This is the case when combining entities into a cluster not only increases their competitiveness, but also increases the efficiency of using natural resources and reduces the impact on the environment.

Paraphrasing the definition of a cluster given by Porter [1], the authors propose the following way of understanding a green cluster: a group of geographically adjacent interconnected companies and related organizations operating in a certain area, characterized by common activities and mutually complementary, which makes it possible to increase their economic efficiency, reduce the cumulative negative impact on the environment and strengthen the competitive advantages of both individual companies, and the cluster as a whole.

Studying international experience showed that clusters are created in various industries. Thus, Mc Cauley *et al.* [2] consider green energy cluster initiative in Central Massachusetts (USA) and the potential of this cluster initiative to contribute to a regional socio-technical transition. Hsu M. S., and Lin F. J. [3] use Porter's Diamond model and a case study to analyse the developing strategy of green energy industry cluster, especially for the solar photoelectric industry in Taiwan. In the paper by Svazas M. *et al.* [4] authors outline the synergy between supply chain performance and the sustainable use of forest resources within biomass cluster. Berg S. H., and Hassink R. [5] consider an emergence of green energy clusters in South Korea based on the case of the wind power cluster in Jeonbuk Province. Authors conclude that the role of the central government is too powerful and the role of regional actors (policy-makers and entrepreneurs) is too weak for the successful emergence of green clusters.

In world practice, green clusters are created in various industries. A number of works are devoted to green clusters in the energy sector (green energy clusters). A number of research studies analyse the formation and functioning of green building clusters. Thus, the work of Sreckovic M. *et al.* [6] is devoted to the effective work of green building cluster in Lower Austria. Papadopoulos I. *et al.* [7] consider the development of sustainable building cluster in Greece. The empirical study shows that the significance of clusters is continuously growing. They can play a fundamental role in the building of green economy and the improvement of innovative and entrepreneurial landscape of a country on the basis of cooperation.

A large number of articles are devoted to the analysis of green industrial clusters, or, a much more common definition, eco-industrial clusters. Sellitto M. A. *et al.* [8] define how green innovation supports competitive advantage in a cluster of furniture companies located in Southern Brazil. R. R. Heeres *et al.* [9] present data from six eco-industrial parks development projects (three of the projects discussed are located in the Netherlands and three in the US) and highlight the differences in project approach and results on a national level. Tian, J. *et al.* [10], demonstrate economic-environmental performance of 17 Chinese eco-industrial parks, using 10 metrics on resource consuming, economics, and waste emission, and prove that eco-industrial parks have robustly improved in economic and environmental performance.

In many papers, the connection between industrial clusters and industrial ecology in terms of eco-industrial clusters development is analysed. Yoon S., and Nadvi K. [11] integrate the industrial cluster and industrial ecology frameworks and demonstrate that ‘eco-collective efficiency’ is achievable through cluster-based collective action using the case of the Banwol-Sihwa textiles dyeing cluster in South Korea. Roberts, B. H. [12] reveals how industrial ecology has contributed to a more sustainable industrial development in the State of

Queensland, Australia through the creation of the Synergyeco-industrial park. Pauline Deutz and David Gibbs [13] provide an empirical focus on eco-industrial development in the USA to postulate that industrial ecology can be viewed as a distinct cluster concept and to consider the implications of this for both industrial ecology and regional development policies.

The idea of creating green clusters in the field of waste management is connected with the concept of circular economy, which is aimed at solving the problem of natural resources exhaustion associated with their irrational use, accompanied by a large volume of waste generated [14]. One of the main circular economy principle is to avoid waste: waste should fit within a biological or technical materials cycles, and this, together with a prolonged use of goods, will help to reduce non-renewable natural resources consumption and the negative impact on the environment [15]–[17]. To achieve this principle, the circular economy offers a number of business models that can be divided into two groups [14]: the first group includes business models related to the repeated use and prolongation of the service life of goods through repair, restoration, modernization, etc.; the second group includes business models in which the lost properties of goods, as well as waste are processed and become material resources for the production of new goods. The second group include business models associated with reverse supply chain activities and higher degree of cooperation with the actors of the supply chain [18]. Authors believe that they can be effectively implemented in green clusters connected with waste, since they imply geographic proximity and technological complementarity of participating actors [19], [20].

In the field of MSW all stakeholders (population, transport companies, waste processing companies, owners of landfills and incinerators, processing companies) are located on the same territory and are organizationally and technologically interconnected: the waste of some participants (population, waste processing companies) serve as raw material for other participants (owners of landfills, owners of incinerators, processing companies), so they can form a green cluster in the field of MSW.

At the same time, it should be noted that the sphere of MSW management in many countries is an object of active state regulation, therefore decision-makers can choose different options for interaction of actors within the cluster, resulting in a different ratio between waste management practices (landfill disposal, recycling, energy utilization) and a question may arise about the optimal ratio of waste management practices within the green cluster.

Since one of the goals of a green cluster formation is to reduce the environmental impact, the authors propose to use the criterion of minimizing GHG emissions per tonne of waste processed within the green cluster. This criterion seems to be suitable for the evaluation for a number of reasons. Firstly, the threat of climate change is currently one of the most urgent issues. According to the latest IPCC Climate Change report, waste sector accounts for 18 % of anthropogenic emissions of methane, one of the main GHG. Secondly, the specific GHG emissions attributable to each waste management practice correlates with the hierarchy of waste management, according to which the prevention and reuse of waste have priority over incineration and landfill disposal [21]. Each of the waste management practices is a source of GHG emissions, however, landfill disposal and the incineration of waste cause the maximum amount of emissions, which makes the criterion suitable for assessing the environmental friendliness and sustainability of the entire waste management system within the green cluster. The idea of estimating GHG emissions from municipal solid waste management was described in literature (see, e. g., [22] for Depok, Indonesia), it was implemented for choosing appropriate management strategies for the city, not for a MSW green cluster. It should be noted, that there are no studies on Russia and Kazakhstan specific GHG emissions assessment for MSW green clusters. The carbon footprint of different waste management practices for these countries conditions was not also calculated. So, to bridge

this gap, the purpose of this article is to estimate GHG emissions when forming MSW green clusters with different waste management practices combination for Russia and Kazakhstan cities. To do this the authors consider options for creating a green cluster in the field of MSW management for two largest cities of Russia and Kazakhstan. Each cluster is described including information about the interaction of actors within the cluster and the selected methods of waste management. The methodology for estimating GHG emissions for waste management operations is described. GHG emissions are estimated for the projected green clusters in the field of MSW in Yekaterinburg (Russia) and Almaty (Kazakhstan).

2. MATERIAL AND METHODS

2.1. Description of the Current Situation and the Projected Green Cluster in the MSW Sector

2.1.1. Case Study: Russia, Sverdlovsk region, Ekaterinburg

The Sverdlovsk region is one of the leading industrial regions of Russia, its area is 194.3 thousand square kilometres, the population is 4.3 million people, the GRP at the end of 2019 amounted to 27 billion EUR, or 6.3 thousand EUR per person. Yekaterinburg is the capital of the Sverdlovsk Region, one of the 15 million-plus cities in Russia, with a population of 1.53 million people at the beginning of 2020.

The current situation with MSW in the Sverdlovsk region is comparable to the situation in the Russian Federation as a whole: only about 9 % of all MSW is processed; most of the MSW goes to landfills, the capacity of which is close to exhaustion (Table 1).

TABLE 1. CURRENT MSW SITUATION IN THE SVERDLOVSK REGION

Year	2016	2017	2018	2019
MSW produced, thousand tonnes	1285.5	1414.0	1542.0	1513.4
MSW disposed and neutralized by economic entities, thousand tonnes (taking into account past periods)	163.4	155.9	139.9	144.2
Stored, including temporarily stored MSW, thousand tonnes	1124.8	1204.4	1441.3	1505.2

The morphological structure of MSW for the Sverdlovsk region is presented in Table. 2. The potentially recyclable part (paper, cardboard, wood, metals, textiles, glass, rubber, PET) is 45 % of the total volume of MSW.

The target indicators of the MSW management reform for the Sverdlovsk Region are determined in accordance with the Industrial Development Strategy for Processing, Recycling and Disposal of Production and Consumption Waste for the period up to 2030, approved by the Decree of the Government of the Russian Federation No. 86-r dated 25.01.2018; as well as in accordance with the Regional Project 'Integrated System of Solid Municipal Waste Management (Sverdlovsk Region)'. According to target indicators, by 2030 there should be 100 % MSW treatment, 50 % MSW utilization, and only 50 % of all generated MSW will be disposed of at landfills.

The logic of the target indicators is determined by the exhaustion of the existing landfills capacities and the need to reduce the negative impact on the environment, together with careful attitude to non-renewable natural resources, which, in the absence of recycling, fall into landfills as part of waste.

TABLE 2. THE MORPHOLOGICAL STRUCTURE OF MSW FOR THE SVERDLOVSK REGION

MSW type	Specific weight, %
Food waste	17.2
Paper, carton	23.26
Wood	1.35
Ferrous metal	0.85
Non-ferrous metal	1.28
Textiles	3.94
Glass	9.48
Leather, rubber	1.86
Plastic, also:	14.89
– polyethylene terephthalates	3.06
– composite packaging	2.03
– other	9.8
Other MSW	25.89
Total:	**100**

In Russia, at the regional level, MSW management is carried out by regional operators – organizations selected during special procedures. Regional operators receive funds for the MSW treatment from the population at an approved tariff, carry out the transportation, processing, disposal of waste, its placement in landfills, and transfer to incineration plants, in accordance with the territorial waste management scheme specially approved for each region. Depending on the volume of MSW generated, one to several regional operators may be active in a region. In the ownership of some of them there is a dominant presence of unitary or state-owned enterprises, as well as state authorities. As of 2021, there are three regional operators on the territory of the Sverdlovsk region, one of them fully services the territory of Yekaterinburg.

As for municipalities, in Russia they are responsible for a very narrow range of issues related to MSW: organization and maintenance of MSW accumulation sites, environmental education and ecological culture formation.

In order to achieve the targets related to MSW, it is planned to create a green cluster in the form of an ecotechnopark on the territory of the Sverdlovsk region (Fig. 1).

The park will be aimed at the circulation of MSW, mainly in Yekaterinburg and the agglomeration (about 2 million inhabitants total) with a capacity of 700 thousand tonnes of MSW per year. The area of the technopark will be 80 hectares; it will include a sorting complex, a landfill of MSW and residents of the technopark – small and medium-sized enterprises engaged in waste processing and recycling. In particular, it is planned to carry out recycling of glass (bottle, cullet) with the production of foam glass; recycling of wood waste and large-sized wooden garbage; polymer recycling; tyre recycling; waste paper recycling; electronic waste recycling; extraction of ferrous and non-ferrous metals from waste. Organic waste will be biocomposted and processed into technosol.

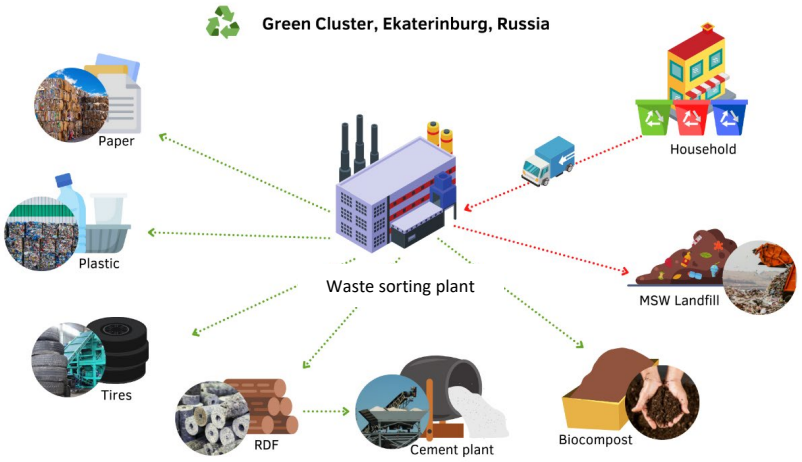


Fig. 1. Green cluster of Yekaterinburg.

Separate collection of waste at the household level will be organized – households will sort useful fractions of MSW (glass, paper, plastic, rubber); non-recyclable waste and organic waste.

It is planned to produce refuse-derived fuel (RDF) from non-recyclable waste and use it as a fuel replacing natural gas for a cement plant located 140 km from Yekaterinburg.

The material balance of one ton of MSW entering the green cluster is presented in Table 3.

TABLE 3. MATERIAL BALANCE OF 1000 KG OF MSW ENTERING THE GREEN CLUSTER OF YEKATERINBURG, RUSSIA

MSW entered the green cluster, kg	**Use of MSW, kg**	
1000	Recycling*	315
	Landfill**	260
	RDF production ***	253
	Compost	172

Note: *in case the installed sorting lines with separate collection can provide 70 % extraction of useful fractions from all potentially recyclable waste (45 % of the volume of MSW), the remaining part of them will be directed to the production of RDF.
**other types of waste shown in Table 2.
***composite packaging and other plastic waste shown in Table 2, as well as the remaining part of sorted MSW.

2.1.2. Case Study: Kazakhstan, Almaty

Almaty is the largest settlement of the Republic of Kazakhstan, a city of national significance (a separate subject of the Republic of Kazakhstan). The area of the territory is 0.7 sq. km.; the population is 1916.8 thousand people, the GRP is about 10 billion EUR, or 5.7 thousand EUR per capita.

The current situation with MSW in Almaty is presented in Table 4.

TABLE 4. CURRENT MSW SITUATION IN ALMATY

Year	2016	2017	2018	2019
MSW generated, thousand tonnes	595.97	629	62837	624.3
Recycle and reuse, thousand tonnes	147.8	155.8	170.1	145.4

The morphological structure of Almaty waste is presented in Table 5.

Over the past few years, Kazakhstan has been performing the MSW management system reform. Thus, since 2016, it is prohibited to bury mercury-containing lamps and appliances, scrap metal, waste oils and liquids, batteries, electronic waste. Since 2019, a ban on the disposal of plastic, waste paper, cardboard and waste paper, and glass has come into force. In the future, it is planned to introduce a ban on the disposal of construction and food waste.

These measures have contributed to the development of waste recycling, but so far, the recycling level is low – in 2019, the share of MSW recycled averaged 14.9 % (in 2018 – 11.5 %) [24]. The extended producers and importers' responsibility launched in 2015 contributes to the recycling development.

TABLE 5. THE MORPHOLOGICAL STRUCTURE OF ALMATY WASTE [23]

MSW type	Specific weight, %
Food waste	28.8
Paper and carton	22.0
Plastic	11.1
Glass	6.8
Textiles	–
Rubber	–
Metals	3.1
Wood and garden waste	5.6
Other	22.6
Total	**100**

Tasks in the field of MSW management are defined by the Concept of the Republic of Kazakhstan transition to 'green economy' [25]. The target level of MSW recycling by 2050 should reach 50 %; the share of landfills that meet environmental and sanitary requirements for the MSW disposal should grow to 100 % by 2050.

Local executives are responsible for organizing a rational and environmentally safe system of MSW collection, which provides for separate collection, storage, regular collection, processing, recycling and neutralisation of hazardous components of municipal waste, as well as cleaning the territory of the settlement.

Services for the MSW collection and processing are provided by both state and private enterprises. At the same time, as a consequence of the state's policy of decentralization and privatization, the share of private enterprises in the field of waste collection and transportation services is increasing. In 2016, 90 % of MSW was collected by private enterprises.

The selection of enterprises is carried out by local executive authorities on a competitive basis. In Almaty, since 2000, up to 70 % of the urban area is served by one enterprise (since it invariably wins the tender), while the rest of the city is served by 39 small enterprises.

The formation of green cluster in Almaty (Fig. 2) started in 2018, when a waste sorting plant was constructed in the Alatau district of Almaty with a capacity of 550 thousand tonnes of MSW/year on a land plot of 5 hectares. The plant was built as a part of public-private

partnership agreement concluded between the municipality and private investors for the project 'Introduction of an integrated solid waste management system in Almaty' implementation.

As a result of the activities of the sorting plant, only safe inert and biodegradable materials are sent to the landfill for waste disposal, which will also be possible to recycle in the future. To date, about 50 thousand tonnes of secondary raw materials (or 9 % of the volume of MSW) are extracted from the total volume of waste, of which PET – 31 %, cardboard – 24 %, cellophane – 8 %, glass – 29 %, metal – 7 %. [26].

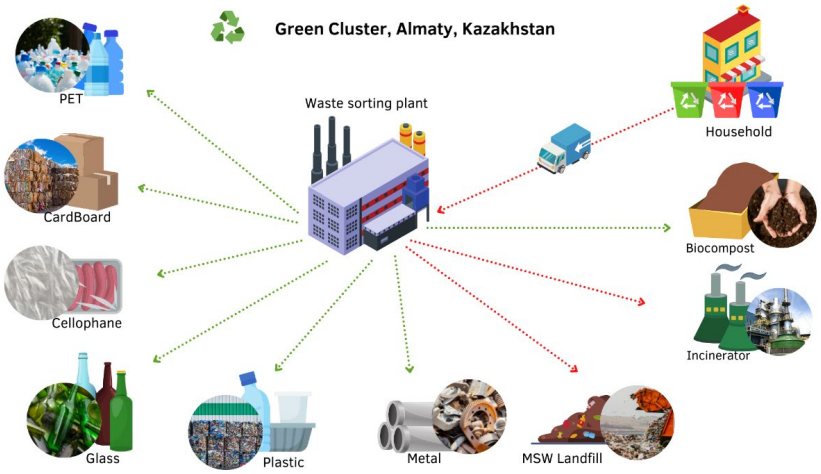


Fig. 2. Green cluster of Almaty.

The extracted useful fractions are transferred to other enterprises for the recycling. In the future, it is planned that the recycling will be carried out on the territory where the sorting plant is located. It is also planned to process organic waste into compost, and to incinerate non-recyclable fractions at the waste incineration plant [27]. According to the project, 720 tons of MSW (263 thousand tons per year) will be delivered to the incineration plant daily, the power plant capacity will be 6.6 MW [28]. The generated electricity will be used both for the green cluster needs and for the city. It is planned that the incineration plant will close the city electricity needs by 0.5 %. Now electricity in Almaty is generated mainly at thermal steam turbine power plants that use solid fuel, which leads to significant GHG emissions.

The material balance of one tonne of MSW entering the green cluster in Almaty is presented in Table 6.

TABLE 6. MATERIAL BALANCE OF 1.000 KG OF MSW ENTERING THE GREEN CLUSTER OF ALMATY, KAZAKHSTAN

MSW entering the green cluster, kg	**Use of MSW, kg**	
1 000	Recycling*	90
	Landfill disposal	359
	Compost	288
	Incineration	263

Note: *according to the data, the installed sorting lines, in the absence of separate collection, can provide 9 % extraction of useful waste fractions. The remaining part of the waste will be sent to the landfill, composting and incineration.

2.2. Emission Estimation Method

Since nowadays there is practically no activity related to the incineration of MSW at incineration plants, composting, and incineration of RDF fuel in cement kilns in Russia and Kazakhstan, to calculate GHG emissions for waste management practices within the green cluster (except for the disposal of MSW at controlled landfills), authors used Level 1 method based on national energy statistics; default GHG from the refined 2006 IPCC Guidelines, and comparable emission factors of other countries.

The GHG emission factors for the disposal of MSW at controlled landfills were taken from the data of the national GHG emission inventories for Russia and Kazakhstan.

Eq. (1) was used to determine GHG emissions for operations such as landfill disposal, composting, incineration, incineration of RDF in cement kilns:

$$E_{waste} = m \cdot EF, \quad (1)$$

where

E_{waste} GHG emission related to a specific waste treatment operation, kg CO_2eq;
m Mass of MSW processed in one way or another, kg;
EF GHG emission factor depending on the waste treatment operation, kg CO_2eq/kg MSW.

Eq. (2) was used to determine GHG emissions during waste transportation:

$$E_{trans} = d \cdot m \cdot EF_{trans}, \quad (2)$$

where

E_{trans} GHG emission, related to waste transportation, kgCO_2eq;
m Mass of transported MSW, kg;
d Distance to which the waste is transported, km;
EF_{trans} GHG emission factor associated with waste transportation, kg CO_2eq/kg MSW/km.

Calculations of GHG emissions in the article are made in the equivalent of carbon dioxide (CO_2eq); the conversion of greenhouse gases other than CO_2 into CO_2eq was carried out using approved IPCC conversion coefficients.

GHG emissions EF and EF_{trans} are presented in Table 7.

TABLE 7. EMISSION FACTOR EF AND F_{TRANS}

MSW management operation	Emission factor	Unit of measurement	Source
Organized incineration of MSW	1.396	kg CO_2eq/kg MSW	[29]
Controlled landfill disposal	1.046	kg CO_2eq/kg MSW	[30]
	0.677	kg CO_2eq/kg MSW	[31]
Biological treatment (composting)	0.172	kg CO_2eq/kg MSW	[29]
RDF incineration in cement kilns	1.1	kg CO_2eq/kg MSW	[32]
Transportation	$0.06 \cdot 10^{-3}$	kg CO_2eq/kg MSW/km	[33]

It should also be noted that the article provides calculations of only direct GHG emissions, i.e. emissions directly related to operations carried out with waste. Indirect emissions associated with the consumption of energy resources to ensure the management of MSW were not considered.

In addition, the article did not consider the GHG emissions associated with waste recycling within the green cluster. On the one hand, recycling activities involve energy consumption and, consequently, indirect GHG emissions. On the other hand, the use of MSW as secondary material resources for the production of goods prevents the involvement of non-renewable resources in economic turnover, the production of goods from them and the associated GHG emissions. Therefore, in this article it will be assumed that net GHG emissions related to waste recycling are zero.

A number of waste management operations, such as the use of RDF as fuel for a cement plant in the Sverdlovsk region and the use of MSW for electricity generation in Almaty entails the substitution of fossil fuels and, consequently, reduces GHG emissions associated with their combustion. This fact was taken into account by the authors in the calculations under the following assumptions.

Using RDF as a fuel for a cement plant allows to reduce the amount of natural gas that is currently used at the plant. The emission of GHG during the firing of 1 m^3 of natural gas is 1.8 kg of CO_2eq. In terms of calorific value, 1 kg of RDF replaces 0.55 m^3 of natural gas. Thus, burning 1 kg of RDF will prevent the release of 1 kg of CO_2eq associated with the firing of natural gas.

The use of MSW for electricity generation allows to reduce the consumption of thermal coal at the CHPP power plant in Almaty. The calorific value of MSW, according to calculations for Almaty, is 9 MJ/kg of MSW. The calorific value of the thermal coal used at the Almaty power plant is 18.9 MJ/kg of coal [28]. The GHG emission from burning 1 kg of thermal coal at a power plant is 1.8 kg of CO_2eq [32]. Thus, the burning of 1 kg of MSW replaces the burning of 0.48 kg of thermal coal and will prevent the release of 0.9 kg of CO_2eq.

3. RESULTS AND DISCUSSION

Based on the different MSW practices combination within the green clusters of Yekaterinburg and Almaty (Table 4 and Table 6), it is possible to calculate GHG emissions during the processing of one tonne of MSW. The results of the calculations are shown in Table 8.

The calculations show that GHG emissions caused as a result of handling 1 tonne of MSW in the green cluster of Yekaterinburg are 22.4 % lower than it is in Almaty: 329.5 kgCO_2eq/tonne of MSW in Yekaterinburg versus 424.1 kgCO_2eq/tonne of MSW in Almaty. This is due to a number of factors. Firstly, in Yekaterinburg, thanks to a full-fledged separate collection, 315 kg of MSW from each tonne will be recycled, while in Almaty the introduction of a separate collection is not planned and the level of recycling is quite low – it is planned to recycle only 90 kg of a tonne of MSW. Accordingly, most of the MSW in Almaty, compared to Yekaterinburg, will go to the MSW landfill with a high emission factor. Energy waste disposal at the incineration plant also contributes to GHG emissions in Almaty. Due to the lack of separate collection, in order not to create a large load on the MSW landfill, it is planned to build a fairly large incineration plant in Almaty, where it is planned to dispose of 720 kg of MSW per day. Any energy utilization of MSW does not comply with the circular economy principles and cannot be fully attributed to 'green' technologies. However, authors suppose that RDF production within the green cluster of Yekaterinburg is more preferable, than incineration, since it does not require a constant flow of non-recyclable waste for payback. It can be said that incineration plants will slow down the development of MSW separate collection and recycling in the territories where they are built.

Results of the calculations are graphically presented in Fig. 3.

The analysis GHG emissions structure from MSW processing within the green clusters of the two cities (Fig. 3) allows to note the predominance of emissions from landfill disposal for both clusters (83 % in Yekaterinburg and 58 % in Almaty). The solution to this problem can be an emphasis on separate collection at the household level. It allows to increase the share of renewable secondary material resources to 50 % of all MSW; in the absence of a separate collection only about 10 % of secondary material resources can be extracted.

TABLE 8. GHG EMISSIONS PER ONE TON OF MSW FOR A GREEN CLUSTER IN YEKATERINBURG, RUSSIA, AND IN ALMATY, KAZAKHSTAN

MSW management operation within green cluster	**MSW, kg**	**Emission factor, kg CO_2eq/kg MSW (kg CO_2eq/kg MSW/km)**	**Total GHG emissions, kgCO_2eq**	**GHG emission reduction, kgCO_2eq**	**Net GHG emissions, kgCO_2eq**
1	2	3	4	5	4–5
Yekaterinburg, Russia					
Recycling	315	n/a	n/a	n/a	n/a
MSW landfill	260	1.046	272.0	0	272.0
RDF incineration in cement kilns	253	1.1	278.3	253	25.3
Composting	172	0.172	29.6	0	29.6
Transfer to the landfill and composting, 20 km	432	$0.06 \cdot 10^{-3}$	0.5	0	0.5
Transfer to cement plant, 140 km	253	$0.06 \cdot 10^{-3}$	2.1	0	2.1
Total			**582.5**	**253**	**329.5**
Almaty, Kazakhstan					
Recycling	90	n/a	n/a	n/a	n/a
MSW landfill	359	0.677	243.0	0	243.0
Composting	288	0.172	49.5	0	49.5
Incineration	263	1.396	367.1	236.7	130.4
Transfer to the landfill, composting and inceneration, 20 km	910	$0.06 \cdot 10^{-3}$	1.1	0	1.1
Total			**660.8**	**236.7**	**424.1**

A significant contribution to GHG emissions is made by the energy utilization of MSW at the Almaty incineration plant (31.1 %). Perhaps it is worth considering another, less

capital-intensive, method of currently non-recyclable MSW processing. Especially in the perspective of the extended producers' responsibility successful implementation, within which the turnover of non-recyclable packaging will be reduced [34].

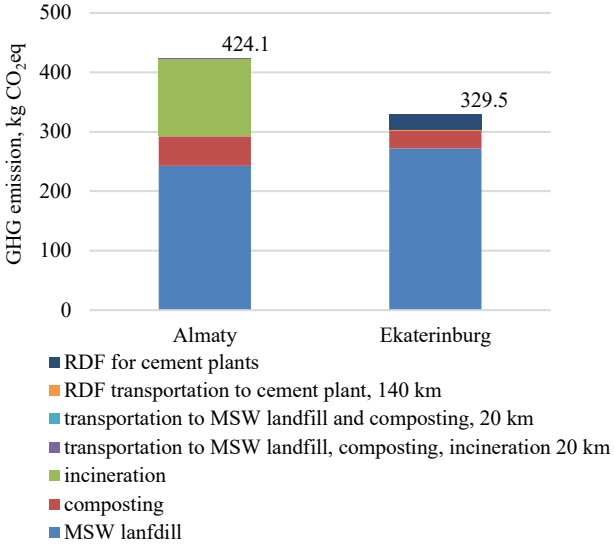


Fig. 3. GHG emissions during 1 tonne of MSW treatment within the green cluster in Almaty and Yekaterinburg.

GHG emissions from composting of organic waste should also be noted. Within the framework of the projected green clusters of the two cities, they account for 9 % of GHG emissions in Yekaterinburg and 12 % of all GHG emissions in Almaty. If the share of organic matter in the structure of MSW cannot be reduced, attention should be paid to such technologies for handling organic waste as waste shredders. In the USA, 55 % of homes are equipped with such devices, in New Zealand –37 %, in China –20 %, in the UK –7 % [35]. In the future, organic substances in wastewater can be used to generate electricity at water treatment plants (for example, the Kuryanovsky sewage plants in Moscow).

4. CONCLUSION

The authors considered two green clusters in project in the field of MSW management in two large cities – Yekaterinburg (Russia) and Almaty (Kazakhstan). The main difference between the two green clusters is the ratio between waste management practices. In Yekaterinburg, a three-stream separate collection is planned (organic waste, recyclable, non-recyclable waste) with subsequent sorting and selection of useful fractions at a waste sorting plant, the 'tails' will be sent to the production of RDF for incineration at a cement plant and to MSW landfill. In Almaty a two-stream separate collection with the extraction of organic waste will be carried out. It is planned that only a small part (9 % of all MSW) will be sorted at the waste sorting plant for further recycling. In order to avoid an excessive load on the landfill, Almaty plans to build a sufficiently large incineration plant for the energy utilization of 720 tonnes of MSW per day (263 thousand tonnes per year).

Further, using the GHG minimizing criterion per ton of processed waste within the green cluster, the authors analysed GHG emissions per ton of MSW in both clusters. As a result, it

can be stated that according to this criterion, the green cluster of Yekaterinburg is more stable and efficient – the carbon content of 1 tonne of processed MSW in Yekaterinburg is 22.4 % lower than in Almaty (329.5 kg CO_2eq/tonne of MSW in Yekaterinburg and 424.1 kg CO_2eq/tonne of MSW in Almaty).

Based on the considered practical cases, the authors propose the following recommendations to reduce the climatic impact of green clusters in the field of MSW: organization of full-fledged separate waste collection at the household level; reduction of non-recyclable packaging usage, including with the help of the extended producer responsibility implementation; reduction of energy utilization, especially at the incineration plants, because their construction requires large investments and a constant flow of non-recyclable waste to ensure operation, and also has a negative impact on the environment and public health; stimulating the use of waste shredders for processing organic waste, possibly at the expense of the state.

Practical examples discussed in this article and the conclusions obtained can be useful to decision makers regarding the design and development of green clusters in the field of MSW management in large cities.

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