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ARTICLE

Metabolic Transformations in the Area of Municipal Solid Waste Management in Russian Megalopolises: The City of Moscow Case

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ABSTRACT
Based on secondary data analysis and semi-structured expert interviews (n = 90), the study analyses metabolic transformations in the area of municipal solid waste (MSW) management in Russian megalopolises using the city of Moscow as a case study. The findings suggest that the key node that triggered numerous interdependent processes involved the changes introduced in the legislation on MSW management and the decision to shut down several large MSW landfills without the simultaneous implementation of other landfills. These actions affected the health of the population and contributed to environmental inequality. The authors provide recommendations for the mitigation of risks associated with MSW generation, recycling, and storage in large Russian cities.

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Introduction

According to United Nations (UN) estimates, the volume of municipal solid waste (MSW) is increasing annually, and by 2025 will be five times higher than in 1990 (United Nations Environment Programme, 2015). This issue is exacerbated in megalopolises. Russian megalopolises are no exception here. In the Russian Federation, over 60 million tons of MSW are produced annually, which is approximately 400 kg per person (Zadera, 2022). According to the poll conducted by the leading Russian sociological service, Russian Public Opinion Research Center (VCIOM), Russians considered the following to be the most pressing environmental issues: air pollution (22%), landfill sites (16%), and untimely waste collection and disposal (11%) (Samyi bol'shoi vred, 2021). All of this leads to the deterioration of citizens' health and living standards while also limiting opportunities for the further development of Russian cities. It should be noted that the problems of MSW storage and management are also considered to be one of the most important societal issues provoking the growth of protest activity in Russia in the past few years.

There are many worldwide studies of solid waste management in megalopolises from interdisciplinary perspectives considering the interconnections among economic, social, environmental, and political dimensions. Notable examples are the study of solid waste management and environmental equity in Barcelona (Fragkou et al., 2014); the examination of the conceptual and comprehensive sustainability framework of European cities to support decision-making in waste management (Taelman et al., 2018); and, the study of waste planning and resource management in "metabolic thinking" (Longato et al., 2019), among many. However, in modern Russian science, there is a notable imbalance in favor of the socio-economic and environmental research of waste in cities, such as studies devoted to the analysis of territorial waste management schemes, MSW processing technologies, designing of econometric models, etc. (Bobylev & Zakharov, 2009). Such studies do not facilitate the exploration of the complex interdependent qualitative processes that occur in different systems of waste generation and disposal in Russian megalopolises.

Consequently, to fill this knowledge gap, our research is aimed at analysing the causal relationships in the area of MSW disposal in Russian megalopolises with a focus on the reciprocity and interplay of social, informational, technological, economic, and environmental processes, as well as their metabolic transformations.

We will review these reciprocal relations and interdependent transformations within the scope of socio-ecological metabolism (SEM) (Efremenko et al., 2019; Ermolaeva, 2015). Complex metabolic processes continuously occur in cities and tend to bifurcate sooner or later, creating qualitatively new forms of the reciprocal relations between social life and the environment. The SEM approach is suitable for the research of MSW management as it features the examination of complex metabolic processes between the urban systems, the transition of some processes and substances into others and their interinfluence, as well as the analysis and registration of the invisible consequences of such transitions and transformations for the different groups of stakeholders. In addition, we should consider the constantly increasing value of the information factor that can have a significant impact on the dynamics and modality of the processes of the SEM.

Thus, the goal of this research is to analyse the metabolic transformations in the area of MSW management in Russian megalopolises with a focus on the reciprocal changes in the environmental, social, informational, and technological processes. To analyse the changes, we will use the following parameters: (a) determination of the main SEM "nodes" in the area of MSW management; (b) determination of the causal relationships and metabolic transformations (both positive and negative); (c) determination of the points of metabolic transformations that impose the greatest risks on the citizens' health and wellbeing; (d) provision of recommendations for risk mitigation.

The hypothesis of our research is based on the fact that in Russian cities, dynamic processes in the area of MSW management occur in association with the rapid growth of the volume of both material and informational waste, a shutdown of landfill sites, an increase in the number of unauthorized dumping grounds, construction of waste incineration plants, aggravation and politicization of the environmental protests related to the problems of waste management, and the criminalization of waste management business. These processes served as accelerators for the metabolic transformations occurring in the material, discursive, informational, and technogenic urban environment. Today, we witness how old biochemical and social exchange chains are disintegrating and new ones are shaping under the influence of these processes. At the same time, we can observe and determine the changes in the attitudes and behaviors of the social groups that are sometimes overlooked by the researchers who analyse the socio-political dynamics in modern-day Russia.

Theoretical and Methodological Research Coordinates

"Socio-ecological metabolism" as a term applied to the area of MSW has different connotations in the English language literature depending on the methodological positions and disciplinary boundaries of the researchers.

New conceptual ideas of the urban hybridity by Bruno Latour (1990), Erik Swyngedouw (1996), and others address the physical entities (water, air, etc.) that act as active agents (alongside humans) in the production of spaces. This perspective is very different from the linear models of urban space associated with such concepts

as the “industrial metabolism” (Ayres & Simonis, 1994), “ecological footprints” (Wackernagel et al., 2019), and other functionalist urban space concepts (Ermolaeva, 2015). The notion of urban metabolism is often symmetrical to the notion of metabolism in living organisms since cities are viewed as ecosystems. Cities, like natural organisms, consume resources and produce waste. “Cities transform raw materials, fuel, and water into the urban built environment, human biomass, and waste” (Decker et al., 2000, p. 25).

The SEM concept encapsulates several approaches that transformed into the concept of analysing the life cycle and socio-biotechnological systems (Efremenko et al., 2019), zero-waste approaches (Murray, 2002), the theory of mobility networks and flows (Urry, 2003), and others. The evaluation of a life cycle within the scope of SEM is revised with due regard to the encompassing notion of resource efficiency: the more effective the social community is in using various types of raw natural materials and transforming of energy, distributing the final product, the higher its cultural, technological, and economical capacity. Thus, the greater part waste takes in the transformation chains of production and consumption, the greater is the welfare of the society and the more sustainable is the use of environmental resources. Urry (2003) pays considerable attention to the reverse links featuring non-linear reciprocation. He noted the shift towards the creation of the institutes of reflexive modernization in society, distinguished static communities, and substantiated the changes in the understanding of societies towards networks and flows of dynamic groups that are deprived of precise spatial-temporal parameters. According to the zero-waste approach (Hannon & Zaman, 2018), secondary flows (waste) should be returned into the cycle, while the unrecyclable residue should be burnt and reclaimed in areas distant from residential use. The logistics of secondary materials are covered by non-material flows, such as communication lines and regulating institutions that ensure a certain connection between the different stages of a life cycle and demonstrate the level of development of the waste management culture.

To explain different processes, metabolic relations, and transformations, we will employ the capabilities of interdisciplinary approaches and private sociological theories.

Out of the numerous approaches to defining SEM (Odum, 1983; Wolman, 1965), we will rely on the approach of Matthew Gandy (2004). He defines SEM as flows that depend directly on external factors, such as energy, materials, and information. Talking about cities in terms of metabolic processes inevitably leads to considering the matter of balance between the social and biophysical in the urban space. Discarding the functionalist perception of this concept, authors regard it dialectically as the interaction of nature and culture in an urban environment. In this sense, this approach conveniently diverts us from the popular SEM tendency to calculate the material flows in the form of the reinterpretation of social relations in cities, such as the division of labor, the configuration of relations of power, and the particular qualities of the alignment of political forces (Martinez-Alier & Walter, 2016). In this work, we will focus on reviewing qualitatively interconnected and interdependent causal relationships and metabolic processes in a city as in an open system in the field of MSW management. We would understand these processes as metabolic transformations—the life cycle of waste

implies further transitions into many substances that produce invisible consequences for the different groups of stakeholders.

Waste disposal requires production capacities and, consequently, additional energy, natural, informational, and social resources. In this regard, we employ the concept of metabolic "nodes" as a network process that overlap and impede; each node of the kind spawns numerous visible and invisible interdependent metabolic transformations that can be viewed as socially and environmentally friendly or harmful, with visible or yet unknown nodes. Later in the study, we would apply this approach to visualize interdependent relationships between and among various nodes that produce either positive or negative effects in the society and environment.

In our opinion, the SEM approach is advantageous for the understanding of causal relationships between subsystems; nevertheless, we will also employ middle-range theories to explain the processes occurring inside them. In particular, we will use the environmental inequality approach (Gonzalez, 2018; Pellow, 2002). We concluded that there is a confrontation between the environmentally unprotected groups of the population, enterprises, and pollution-monitoring structures in the most polluted urban districts. They also determined the positions of such a confrontation.

The notion of a world-system by Wallerstein (2001) is applied to megalopolises, where the inequality in the supply of resources between the center and the periphery becomes a global issue, and is projected on the model of the confrontation between the center and the surrounding territories of cities and megalopolises regarding the provision of equal access to clean residential territories. The infrastructure of built-up cities is hard and slow to change, and such cities are often closely connected with the surrounding territories, which is why the waste streams are taken away from the center and to the surrounding territories if there is no recycling infrastructure, such as sorting stations and well-equipped landfills. Degrading waste, self-ignition of dumping sites, and new incineration plants built within the city boundaries are risk points for the citizens. It raises questions related to the principles of environmental justice, where all citizens, regardless of their race, skin color, national background, and income take equal part in the development of, implementation, and compliance with environmental protection legislation, rules, and policies. The asymmetry in the legislative and politico-economic status of megalopolises, and the territories where MSW emitted by such megalopolises is stored and reclaimed, is an acute problem in the national context of individual countries (in the Russian context, in particular) (Ermolaeva et al., 2019).

Methodology

This research, in the form of an exploratory case study, used a mixed methods approach. The selection of the city of Moscow and its agglomeration as a test bed for the SEM approach is rationalized, first of all, by the bulk of activities undertaken in its territory under the Federal project *Chistaia srana* [Clean Country], a mass recycling campaign, including the building of an incineration plant, etc. Secondly, following the environmental inequality approach, we will reflect on Moscow and its border territories

in the context of a system of flows of substances which are distributed with different degrees of concentration in its territory and in the surrounding environments.

In the first stage, we employed secondary data analysis (public opinion polls, media discourse analysis, federal and regional programs, etc.) to study the existing discourse in the field of education and management of MSW, regional characteristics, as well as determining a pool of experts for interviews. In the second stage, semi-structured expert interviews (n = 90) were conducted with researchers from academia (30) and environmental organizations (30), leaders of environmental and civic initiatives (20), and "garbage" operators (10). Informants were selected based on the snowball sample with the following criteria: wide knowledge of the subject; availability of fundamental knowledge in the field of expertise; the presence of their original ideas and concepts; and, ability to take a clear research position. In the first stage, narrative analysis is performed, to convert the discontinuous, illogical raw material to coherent and ordered text. In the second stage, the meanings were consolidated—the informants' judgments were reduced to short formulations, a set of conclusions. The study was conducted in the spring of 2018.

We would like to state certain limitations associated with the case study approach that could be acknowledged and overcome in future research on the topic. While the desk research highlighted the general state of MSW that is true to all megalopolises in Russia, in the empirical data we analysed SEM based on the city of Moscow and its agglomeration to capture the causal relationship and make SEM conceptualization more precise and region-specific.

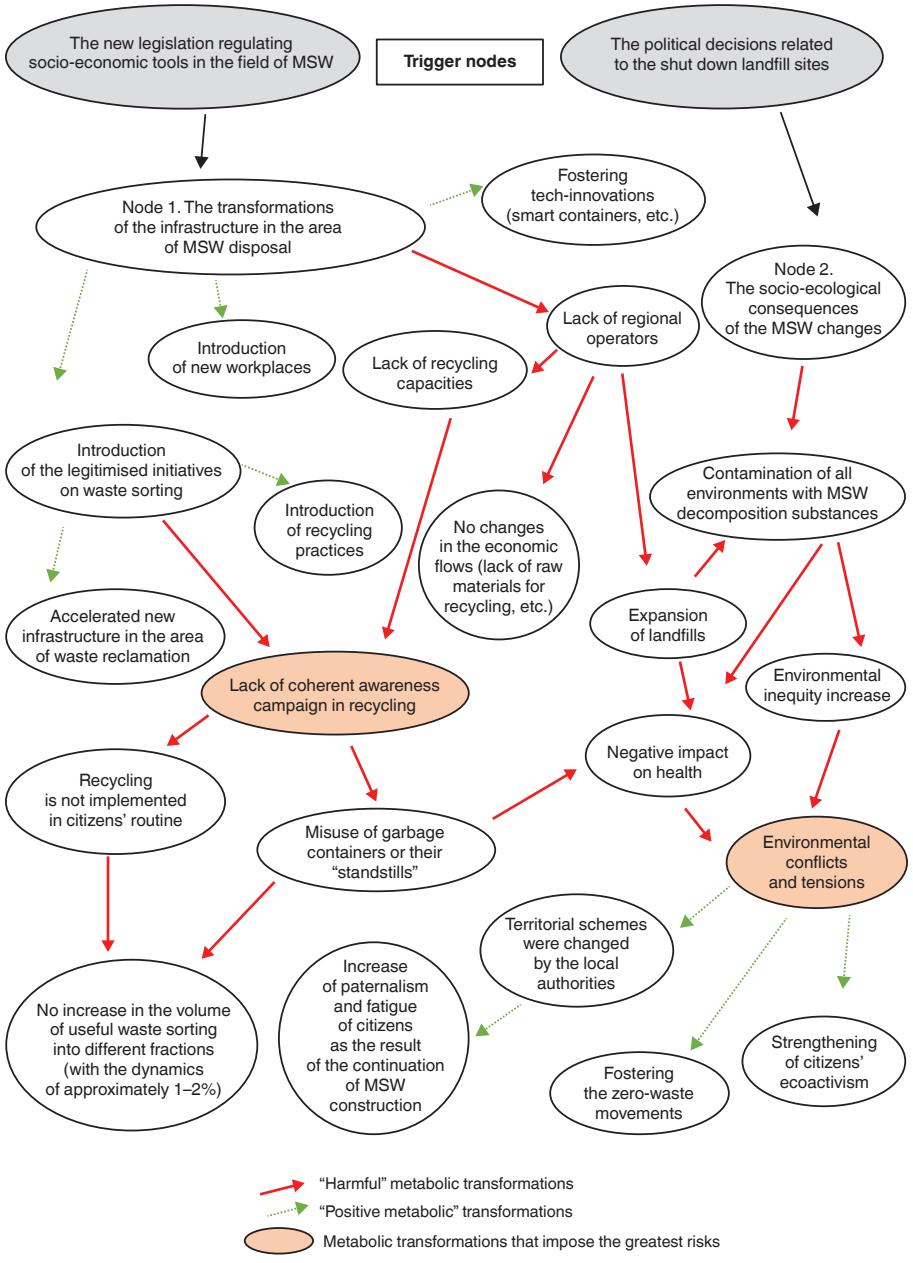
Results

Trigger Node. The New Legislation Regulating Socio-Economic Tools in the Field of MSW Management in Russian Megalopolises and the Political Decisions Related to the Shutdown of Individual Landfill Sites

The issue of managing waste in Russia became especially urgent at the time of the radical reforms of the 1990s and further restructuring of the industrial sector when the elements of the cyclical production and processing of materials, ferrous and non-ferrous metallurgy, and plastics that were available in the Soviet system ceased to exist; only individual initiatives for oil product refining remained, and glass and paper recycling plants became disengaged from direct logistics (Zaytsev, 2012). Discussion and ratification of the procedures and remit of the new institution regulating the collection and reclamation of waste were delayed for two decades. While the infrastructure of the recycling industry was "paused", the citizens' consumption speed, resource extraction, production of goods, citizens' purchasing power, and the variety of goods started to rapidly increase at the beginning of the 2000s, after a sharp decrease in the 1990s. Nevertheless, even during the crisis of the 1990s, megalopolises were growing (Moscow and its urban agglomeration were growing at the fastest pace) at the expense of a migrant influx coming from other regions of Russia and post-Soviet countries. Against this backdrop, the production of municipal waste was rapidly multiplying.

Figure 1

Model of Metabolic Transformations in the Area of Municipal Solid Waste Management: The City of Moscow Case



Note. Source: Authors.

At the legislative level, the regulation of different sectors of waste production and management lost its internal connection, and the metabolic chains of waste management became disjointed, which was an aggravating factor. In other words, the main responsibility for waste collection and disposal was assumed by municipal governments and private waste management companies whose responsibility was to export MSW to landfill sites and waste incineration plants (WIPs). Only a small portion of the enterprises (4%) were responsible for the reclamation and were forced to independently provide themselves with raw materials. Since the beginning of the 1990s, the sector of MSW disposal and storage has become highly criminalized; a considerable proportion of this business was occupied by "unscrupulous" actors, which led to the exponential growth of unauthorized disposal sites around Moscow. A statement made by Russian President Vladimir Putin in November 2016 attests to the dominance of the shadowed waste management business:

> I must admit. As for the Moscow region, I had to address certain issues personally. It was impossible to get things moving, there is criminal activity, and certain businesses flourishing. Citizens were simply unable to solve these issues. Even local authorities were unable to do anything until I personally commanded internal military forces to intervene. (Putin rasskazal, 2016; trans. by P. E., Yu. E., & D. E.)

As a result, 31.1 billion tons of waste were accumulated in Russia, 20% of which came from Moscow and the Moscow region, while the annual increase of MSW amounts to 2.5% (Ermolaeva et al., 2019). The deficit of economic, legislative, and technological tools, as well as a high degree of corruption and the presence of criminal structures, brought Russia to be entrapped in the niche of a "linear" economy.

Stage 1. The new approach to waste management was introduced in 2014 when the new version of the Federal Law No. 89-FZ *Ob otkhodakh proizvodstva i potrebleniia* [On industrial and household waste] (1998) was passed. The amendments included new terminology, and such terms as waste "reclamation", "recycling", "regeneration", or "recuperation" were introduced, which did not affect the development of the infrastructure in this sector but were required for the international standardization of terms (O vnesenii izmenenii, 2014). New principles of waste management were also defined to determine the line of development of this sector (the priority was given to reclamation over waste incineration and landfilling); new regulatory mechanisms were introduced (a ban on the disposal of wastes containing useful components, extended producer responsibility, an institute of regional operators); the powers of the authorities were adjusted (the mission to solve the waste issue was transferred from the municipal level to the regional one); the parameters for calculating and paying environmental charges were defined, as well as the expenditure terms for the environmental charges received in the federal budget. Then, enterprises had to report in and maintain a public record of the extent of waste, which allowed the creation of a base of registered and recorded waste for further processing. However, departments and ministries were still responsible for individual production and consumption sectors, while not being united into a single functional system with a single waste tracking and liability scheme.

Stage 2. This stage is associated with the appearance of regional operators and a whole single tracking system that synchronized different chains of the MSW recycling and reclamation cycle. The regional operators chosen by each region of the Russian Federation to coordinate the process of MSW management were supposed to create a single metabolic cycle. The regional operators have to agree with the political region on domestic waste collection, disposal, and reclamation. Regional operators accumulate all financial flows coming from the population, business, governmental companies, and other domestic waste generators and make agreements on actual waste handling with other market actors or do it on their own, given the opportunity, for the minimum term of 10–15 years (Ermolaeva et al., 2019). The new institute regulates the relationships between all stakeholders in the waste management system in each region by the creation of an infrastructure for waste disposal collection, as well as the development of the necessary sorting capacities. As of the end of 2017–2018, territorial waste management schemes were developed in 85 subjects of the Russian Federation, and regional waste management schemes were developed in 52 subjects (Ermolaeva, 2021).

On January 1, 2018, a new federal law was passed (O vnesenii izmenenii, 2017), according to which Russia began to transition to the new MSW management system. The payment for MSW management is moved from communal expenses to the list of payments for utility services, which increases the cost of MSW disposal and creates an economic resource for the recycling sector. This reorganization of the legislation generates new nodes of metabolic transformations that did not exist before. We suggest reviewing them individually below.

Node 1. The Transformations of the Infrastructure in the Area of MSW Disposal in Russian Megalopolises (see Fig. 1)

Municipal waste constitutes 82%, and its dynamics have not changed (Tulokhonova & Ulanova, 2013). Regarding the observations of the morphological composition of the citizens' waste over 16 years from 1991 to 2013, Tulokhonova and Ulanova's (2013) came to the following conclusions: polymeric materials show the highest increase from 3% to 13.8%, whose amount doubled over a decade; the segment of glass nearly tripled in size (from 4.2% to 11.4%); the share of metal waste dropped significantly (from 8.1% to 2.8%); the segment of organic waste remained at 30% of the total waste generation rate. Although consumption and the amount of waste continue to grow[1], the level of the beneficial use of waste also increased from 40% in 2006 to 60% in 2016 (Ermolaeva et al., 2019). The new infrastructure represented by governmental and private enterprises[2] specializing in waste management began to appear along with new workplaces, forming the seeds of the circular economy. In comparison with

[1] According to the Federal Service for Supervision of Natural Resource, by 2018, 38 billion 73 million tons of industrial and domestic waste have been accumulated in Russia. At the same time, 6 billion 220.6 million tons were generated in 2017 (which is 12.5% more than in 2016). Two billion 53.9 million tons of waste were recycled in 2018. (Riumin, 2019)

[2] Within the scope of the transition to the best technologies available.

the municipal sector where recycling contains only 7–10% of total waste, in industrial waste sectors, the rate of waste reusability is over 60% (Ermolaeva & Rybakova, 2019).

New infrastructural transformations were also associated with the appearance of an initiative on the separate sorting of MSW, as required by legislation. This initiative implies the technological process of waste sorting into small components by hand or using automated conveyors with the collection of the most valuable elements for further recycling. In this regard, the number of material recovery facilities (MRF) in Russia has grown to 60 units since 2010 (Nepomiashchaia, 2018). At the same time, the number of small material recovery businesses employing only manual labor to sort different types of waste increased many times and is not subject to official registration.

Since January 1, 2018, waste sorting was implemented in several Russian regions (the Moscow region, the Republic of Tatarstan, Nizhny Novgorod region, Belgorod region, and others)[3]. Changes were also introduced to the technological amenities of the waste management sector in large Russian cities: online software and applications devoted to waste disposal were developed, as well as systems of waste collection synchronization with municipal authorities and private companies; "smart" containers equipped with the function of alerting the people responsible when the container is full were introduced; navigation control over garbage trucks was implemented (Ermolaeva, 2021). Regional operators and non-profit organizations have organized waste sorting in small and middle-sized towns, such as Vladimir, Izhevsk, Kyshtym, the village of Lisii Nos, Mytishchi, Novokuznetsk, Ozersk, Perm, Saransk, Cheliabinsk, and in most districts of Moscow and Saint Petersburg (approximately 70–80%) (Rukov, 2018).

As one expert commented on this situation:

> Operators are prescribed the task of developing waste sorting in their territories. They try to do this to the best of their personal interests. There are citizens who keep close tabs on the installation of containers in their districts, on the people responsible for that; they check whether everything works the way it should. It gives rise to the public control that makes annual checks of all the issues related to separate waste collection, which allows companies to be more conscientious when it comes to this part of their contract and to develop public collection structures. (The representative of a non-profit organization, personal communication, March 15, 2018; trans. by P. E., Yu. E., & D. E.)

These initiatives triggered the appearance of new waste sorting practices among the population in megacities, yet the major changes will be observed only "after 10–15 years, because people in megacities need time and became more eco-friendly" (The representative of a non-profit organization, personal communication, March 15, 2018; trans. by P. E., Yu. E., & D. E.).

Public polls conducted in Russia showed that by 2019, the dynamics of waste disposal had not changed, and only 7% of the Russian population sorted their waste, the same as in 2012 (Ermolaeva et al., 2019). The respondents stated that they refused to separate their waste due to external factors: 69% pointed at the "absence of the

[3] Most often, recyclable elements (glass, plastic, metal) and non-recyclable waste.

infrastructure for the separate waste collection at the place of residence", 20% of the surveyed people did not know how to separate waste, and 11% alluded to the lack of time (Ermolaeva et al., 2019). A study published by the researchers (Volkova, 2018) showed that the group of people intending to get involved in waste sorting (potential participants) amounted to 19%, along with citizens intending to continue separate waste collection and sorting amounting to 29%. The majority of Russians (68%) have never started sorting waste in recent years (indifferent citizens). Compared to 2014, the number of people participating in waste sorting increased, in a scientists' opinion:

> Operators had to cover 20% of the population in two years, 40% of the population in the following two years, and so on. The population was supposed to become involved in waste sorting. As we can see, only about 10% of the population is currently involved, but the situation is changing, and we hope that in 15–20 years, people will be more involved in these processes, and everything will be great. (The representative of the public administration, personal communication, April 1, 2018; trans. by P. E., Yu. E., & D. E.)

A representative of a non-profit organization observed:

> In 2013, the implementation of government contracts on waste management began, and waste sorting became one of the terms of such contracts. Target values specified in these government contracts are very unimposing. The requirements stipulated in these government contracts for such a megalopolis as Moscow only imply the presence of one waste collection station for every 11,000 citizens. For such an infrastructure, it's a vestige […] Government contracts do not make any provisions for awareness-rising. If we were to put waste sorting containers all across the city, but didn't work with the population and didn't explain how and why they should handle their waste, the situation would not improve. (The representative of a non-profit organization, personal communication, April 5, 2018; trans. by P. E., Yu. E., & D. E.)

Statistically, even after the waste is sorted, 80–90% of it goes to landfills. The State Register of Waste Disposal Sites documented 849 landfills, disposal sites, dumps, and different types of storage facilities, 170 of which are designated MSW landfills (Pasport natsionalnogo proekta, n.d.). All of this, in turn, puts a strain on the environment through spontaneous combustion of landfills, air and groundwater pollution, etc. Among all Russian regions, the Moscow region remains the most loaded with municipal waste, and became the point with high-level protest activity among the citizens (Skipor, 2020). The environmental inequality between the center and the periphery in terms of waste disposal offers new criteria for social stratification and redefines the established social distance and roles of Russian megalopolises and neighboring territories (for example, Iadrovo and Malinki landfills), which we will discuss in detail below (see Node 2). The reciprocal relations and mutual influence of natural, social, and technological components of waste management that impact

the safety of the population require study. This is vividly illustrated by the case of the emergency landing of *Ural'skie avialinii* [Ural Airlines] plane in Moscow region caused by a bird strike originating from an unauthorized landfill nearby that attracted the birds (Passazhirskii A-321, 2019).

The national project *Ekologiia* [Ecology] includes nine federal projects (e.g., *Chistaia strana* [Clean Country], *Chistyi vozdukh* [Clean Air], etc.). The work is undertaken in five areas: waste, water, air, biodiversity, technology. The federal projects are aimed at the reclamation of the most dangerous objects of accumulated environmental damage: the elimination of unauthorized dumps within the boundaries of cities. It is assumed that following the results of the projects, the demographic situation in the country and the quality of life of the population will significantly improve. The deadline for the implementation of the national project is December 31, 2024 (Pasport natsionalnogo proekta, n.d.). According to these projects, by 2025, five WIPs should be built (four of them in Moscow region, and one in the Republic of Tatarstan). It is intended that 1–2% of the MSW generated in large Russian urban zones will be delivered there.

For example, in the city of Moscow, in contrast to other regions, several regional operators perform within the city, removing waste from each administrative district. Collection is mixed and separate. In general, Moscow is overloaded with waste, and its citizens do not recycle carefully enough.

According to *Rossiiskii ekologicheskii operator* [Russian Environmental Operator], by the end of 2022, ten waste treatment complexes will operate in the Moscow region, two of which will be a part of the EcoLine group. The company, in turn, exports 42% of the waste from Moscow and 17% from the Moscow region for processing. The waste sorting complex *Vostok* (currently the largest in Europe) is recycling 1.2 million tons per year for 8% of the mixed waste and more than 35% of the separately collected waste. At the beginning of 2022, the most technologically advanced *Neva* complex in Russia, with a capacity of 500,000 tons per year, started operating. Moscow already has an impressive processing infrastructure for waste at the processing stage, but it is not properly loaded with raw materials. Currently, in Moscow there are five waste transfer facilities, four waste sorting complexes, two PET recycling complexes, a complex for the processing of electrical waste, and 134 stationary recycling points. There are more than 2,000 machines for receiving cans, and 2,300 containers for separate waste collection. At the last stage of the life cycle of waste generation, four WIPs operate dealing with 770,000 tons per year; fractions that cannot be processed at the moment are burned here. An increase in the depth of processing is possible if a larger percentage of the population is involved in separate collection. A reduction in the production of non-recyclable fractions can be achieved through direct work with the population and the introduction of economically positive incentives (Chernyshev, 2022).

WIPs do not require preliminary waste sorting, which is why, according to the program, they were considered to be an alternative to landfills and an opportunity to prevent further accumulation of waste in the vicinity of residential areas. However, the construction of WIPs did not discontinue the increase in the number of landfills. This is how one of the experts commented on the given situation:

> Currently, it is suggested that four waste incineration plants will be built in Moscow region to handle the waste generated in Moscow. Even though it does not fit into the public policy. It is a high risk for the environment [...] Will we believe that recycling is something impossible for us, that our citizens will be unable to sort their waste? Then, with time, we will have more environmental disaster areas in Moscow region. If we manage to turn this situation to support the processing facilities and establish the infrastructure for the collection of recyclable materials, we will be able to transition to good recycling rates and lesser environmental pollution. (The representative of a non-profit organization, personal communication, April 23, 2018; trans. by P. E., Yu. E., & D. E.)

New generation technologies allow the minimization of the negative influence of WIPs on the environment but leave behind up to 0.99% of hazardous emissions in the form of ash, which leads to economic losses and social clashes (Zaytsev, 2012). A separate issue concerns the implementation of the thermal methods of waste decomposition resulting in the production of fuel or chemical raw materials (for example, pyrolysis) that allow plants to function autonomously and give away a small part of the residue for public heating, but cannot compete with the sector of recycling in terms of supplying secondary raw materials.

Thus, despite the priorities stipulated in the legislation, the main waste disposal schemes remain to be landfills and WIPs, while waste sorting is developing slowly (from 5% to 7%) and the recycling sector is progressing even slower—does not exceed 10% by 2018, according to different sources (Ermolaeva, 2021). All of this continues to aggravate the imbalance in support of the linear economy because the main sector of waste sorting and recycling is not progressing. The compilation of territorial schemes under the project “Clean Country” is a significant advance in the issue of standardization of the process, where the main positive force is the coordination of stakeholders, as it allowed the collection of a list of pain points of regions that were previously unknown. However, the principles of the project themselves are not resource efficient in comparison with the zero-waste policy, as confirmed by an expert survey and content analysis of the project. Nevertheless, there was a need to reconsider the power of local solutions on the ground, which can be implemented in Russian conditions. If priorities in the field of creation and infrastructure are redistributed recycling, there is a necessity to pay more attention to the principles of scrupulous waste collection, as well as the creation of complex metabolic systems of ecological and industrial parks. The reform was not fully implemented due to a number of internal shortcomings: some regional operators were not environmentally responsible; the separate collection infrastructure was not convenient for citizens in some regions; tariffs for the population and extended producer responsibility schemes were not developed, including a project to tax companies for packaging; the waste recycling targets laid down in the Industrial Development Strategy turned out to be inconsistent with the content and implementation of the waste management hierarchy; and there was excessive bureaucratization, as a result of which the already implemented recycling schemes with the help of small waste collection companies in small towns could not compete with the newly arrived regional operator.

As one academic interviewee stated:

> We need a waste incineration plant. Waste sorting lines are only suitable for the "fresh stuff," the waste that has just been collected and is being taken to a sorting station at once. The thing is, if waste spends half a year lying in a landfill while the seasons change, it is no longer suitable for sorting. This is why we need a waste incineration plant to simply get rid of the solid domestic waste landfill. Though this is not a solution for the newly generated waste. (The representative of academia, personal communication, May 13, 2018; trans. by P. E., Yu. E., & D. E.)

Although currently there are 14,000 companies with a license for waste disposal, only about 200 enterprises specialize in waste reclamation and the acquisition of secondary raw materials. The necessity of implementing waste sorting to 100% for the replenishment of the raw materials base is a major challenge. The amendments to the legislation did not trigger any internal changes in the economic flows in 2014–2019, including the stagnant demand for the final product (derivative products), lack of raw materials for recycling (inability to ensure a stable supply is a result of not having an effective system of waste collection and the lack of sorting capacities), and others.

Compared to 2010, the cost of environmental protection almost doubled in 2015 and continues to grow, while the beneficial use of waste remains at an unjustifiably low level. While the financial flows are directed at the remediation of the landfills and construction of WIPs, the imbalance in the distribution of waste flows will also persist. Investments into the main capital intended for the protection of the environment from the harmful effects of the waste comprised 8.423 billion rubles in 2016 according to the Russian Federal State Statistics Service, which is 33% less compared to 2015 (Krasnoshchekov & Olgarenko, 2019). The major portion of these investments is still used for the construction and remediation of MSW landfills.

In the course of establishing a single system and registry of the regional waste management schemes, internal communication mismatches surfaced in the constituent elements of the consumption and recycling node, such as the lack of recycling capacities, and lack of regional operators in several regions and the expansion of landfills, etc. This leads to a further environmental imbalance that begets new socio-ecological conflicts (Node 3). Stagnant demand for the final product (derivative products) continues.

Despite the escalating environmental issues, the last link in the metabolic chain (recycling) has slowly become bigger, and over the past ten years, the overall percentage of recycling of different elements of waste increased by 3–5%. The recycled paper market is the leader of the Russian reclamation sector with 2.9 million tons of secondary raw materials employed with a recovery efficiency of 27%. In 2017, 11% of the recycled pulp collected in Russia was shipped for export. The recovery efficiency of plastic and rubber-containing waste is significantly lower (10–15%), which is associated with the fact that the biggest part of such waste is generated by the population (Volkova, 2018).

By 2024, the Ministry of Industry and Trade of the Russian Federation in cooperation with the Ministry of Natural Resources and the Environment is supposed to launch a new MSW management system employing some kind of a public-private partnership where the government can cover up to 30% of the expenses on the establishment of the sector, which is meant to connect the metabolic chains of the technological infrastructure and businesses (Volkova, 2018).

Node 2. Socio-Environmental Consequences of the Changes in the Area of MSW Disposal in Russian Megalopolises (see Fig. 1)

Russian dumping sites release 1.5 million tons of methane and 21.5 million tons of CO_2 into the atmosphere every year (Ferapontov, 2018). The environmental load is indicated in Table 1.

Table 1

Environmental Waste Impact

Impact on soil and water	Residues resulting from the incineration of household waste classified as hazardous. Infiltrates and ash from incinerated wastes of the following elements, which in excess can be harmful to the environment and humans: mercury, lead, arsenic, cadmium, chromium, some heavy metals, asbestos, radioactive elements including medicines (Ob utverzhdenii sanitarnykh pravil, 2021)
Impact on atmosphere	Waste incineration is one source of dioxins and furans, the most toxic of all persistent organic pollutants (POPs), and include polychlorinated dibenzo-p-dioxins and dibenzofurans (dioxins and furans or PCDD/DF), but are not limited to them. In emissions MSW also contains other dioxin-like compounds, for example, polychlorinated naphthalene. Dioxins and furans are defined in the Stockholm Convention on persistent organic pollutants as unintentional POPs. Also, depending on the quality and degree of purification in waste, solid particles can form from sulfur dioxide. Landfills without special equipment and uncontrolled landfills may generate excess landfill gases—methane, carbon dioxide, nitrogen oxides, polychlorinated biphenyls (PCBs) (Stockholm Convention, n.d.)
Costs of operating landfills and incinerators that are close to residential areas	Smell, visual impact, parasites (insects, rats), heavy transport traffic, noise (Eldesbaev et al., 2015)
Social aspects	Related conflicts with unfair distribution. Environment and competition for land (between different social classes and households)
Land use	Land use sites designated for landfills and other waste treatment, as well as waste disposal sites, are unsuitable for agriculture, construction and recreation
Possible long-term effects	Loss of biodiversity and ecosystem services (regulating services, cultural, supply services, and in cases of dishonest operation of landfills emergency situations are possible—fires due to possible spontaneous combustion of landfills) (Bobylev & Zakharov, 2009)

Municipal waste can contain significant amounts of toxic chemicals. According to the literature, the average concentrations of heavy metals (zinc, manganese, copper, chromium, lead, mercury, etc.) in MSW have increased by 1.6–3 times over the past four decades (Cherniaeva, 2013). In the 80–90s of the last century, it was found that compost made from household waste significantly exceeds the content in soils in terms of the presence of a number of toxic elements (the content of lead, zinc, copper, molybdenum, silver and ten times greater—mercury) (Shcherbo, 2002). Currently, more than 100 substances defined as hazardous are used in everyday life. First of all, heavy metals are emitted (cadmium and nickel contained in batteries, consumer electronics, plastics, paints; lead—in paint, electrical wiring, batteries; mercury—in fluorescent lamps, etc.), various types of pesticides, as well as substances contained in cleaning products, varnishes, etc. The combustion of polymers, the content of which in MSW reaches 40%, leads to the formation of highly hazardous toxicants, specifically polychlorinated biphenyls, dioxins, benzofurans, cadmium and zinc (Onishchenko, 2003). The consequences of the impact of waste on the human body are set out in Table 2.

Table 2

The Burden of Waste on the Body, Inherent in Working Landfills and Living Close to Unequipped Landfills and Incinerators

1. Central nervous system	The main target organ is the brain, especially the harmful effects rendered by lead, beryllium, arsenic, antimony, polychlorinated biphenyls (PCBs)
2. Digestive and urinary systems	The main target organs are the liver and kidneys. The impact is caused by lead, cadmium, antimony, dioxins and furans, bromine-containing fire retardants, vinyl chloride (from PVC), PCB
3. Reproductive and endocrine systems	Main target organs are the reproductive glands, but none of the effects are most harmful. Impacts are rendered by lead, brominated flame retardants, dioxins and furans, and types of microplastics containing xenoestrogens
4. Circulatory system	Especially harmful effects, impacted by lead and mercury
5. Skeleton	Especially harmful effect, impacted by cadmium
6. Respiratory system	Target organ: lungs. Increased releases of methane, oxygen, carbon dioxide, in excess, can cause human suffocation
7. Total toxin load	It can be expressed as a moderate or strong systemic load on the body. A toxic load can provoke cancer, provoke both reduced immunity and autoimmune diseases, skin diseases, general weakness, oxide stress, premature aging, weakness and depression

The problem of environmental security is especially pressing for the territories neighboring megalopolises that have become the destination of waste export for large cities (statistically, 15,000 tons of waste are being exported daily from Moscow to the neighbouring regions) (Ferapontov, 2018). In the end, the disposal

of Moscow's waste outside the city limits resulted in conflicts as it did not solve the original problem (to establish a waste recycling and disposal system within the framework of the Ecology and Clean Country projects). One supporter of the current arrangements for waste disposal asserted:

> They [WIPs] are absolutely safe. What is the safety criterion for waste incineration plants? Only one thing, the temperature inside waste combustion chambers must be maintained at 1200 degrees. In this case, everything burns to carbon dioxide, water, and hydrogen chloride in the worst case (if it's organochloride). (The representative of academia, personal communication, April 16, 2018; trans. by P. E., Yu. E., & D. E.)

The media played a great part in the dynamics of waste-related conflicts and strengthened the support of civil interests. Citizens living in the vicinity of the intended waste disposal facilities decisively promoted and combined different forms of activism (picketing approved by the authorities, demonstrations, hunger strikes), digital activism (petitions and pollution-tracking mobile platforms). Wide media coverage supplemented with photo and video reports made it possible to attract numerous participants, namely, 4,000 citizens and activists. The tone of the publications related to waste in the Russian media changed drastically after the traditional annual *Priamaia liniia s Vladimirom Putinym* [Direct Line with Vladimir Putin] in 2017, which featured the question of a resident of Balashikha, Moscow region, where the Kuchino landfill is located holding over 50 years of accumulated waste. In the context of the Russian political and media reality, it meant that the federal authorities did not find it advantageous to ignore this problem and were ready to discuss it with the public. It was most likely that regional middle-ranking officials would be held responsible for the aggravation of the environmental situation there. However, the Russian president's immediate decision to shut down the Kuchino landfill in response to the question led to a chain of systematic consequences because the load on other landfills surrounding Moscow increased sharply, which resulted in a series of protests across the Moscow region. The decision to shut down the Kuchino landfill and the introduction of changes into the legislative base forced the SEM associated with the generation, reclamation, and storage of MSW around Moscow to transition from the regular mode to the emergency mode that can potentially lead to a crisis.

> Currently, waste-related issues are stemming from the fact that the population is motivated; they collected signatures and conducted surveys proving that the people are ready, while the authorities aren't. It's not enough to install separate waste collection containers to solve the issue, it's necessary to establish an infrastructure. The first line of battery recycling was founded by a private business, not the government. A 10–15% increase in the utility rates is justified here. (The representative of industry, personal communication, April 17, 2018; trans. by P. E., Yu. E., & D. E.)

According to the Presidential Council for Human Rights of the Russian Federation, at the beginning of 2019, protests associated with waste-related issues took place in 30 regions of Russia. The most hotspots appeared in different communities of Moscow region, Volokolamsk's Iadrovo, Voskresensk, Odintsovo, Kolomna, Krasnoarmeisk, Serpukhov, Klin, Balashikha, and Dmitrov, where protests were registered. The authorities of Tver region refused to accept the waste coming from Moscow since it was considered to be an issue of the "environmental safety of the region"; the same happened in Kolomna in December 2018. A waste-related conflict directly linked to Moscow even took place a thousand kilometers away from the Russian capital, in Arkhangelsk region, near Shies railway station, where the construction of a landfill was launched to store Moscow's MSW. Importantly, these protests were characterized by the absence of an outspoken leader, unification of participants on a non-ideological basis with a focus on a specific environmental issue, and their network structure. Representatives of the environmental non-governmental organizations had been founded long before the aggravation of the "waste crisis" and did not focus exclusively on this issue, but undoubtedly, contributed to the protest activity and, on several occasions, helped to define the specific demands of the protesters. One of the main demands frequently articulated by the participants of the protests is that waste should have an owner and must be processed in the territory where it was generated (Putin rasskazal, 2016).

The situation associated with the expansion of landfills received widespread publicity, motivated the population to establish new movements, "StopVybros" and "Dushegubka.rf", and rendered active the non-government groups that have been participating in the organization of waste sorting for a long time (Ermolaeva & Rybakova, 2019). In November 2017, Alexander Kogan, Minister of Ecology of the Moscow region, announced that the authorities were changing the "territorial scheme" because of the local protests.

These conflicts gave rise to numerous direct and indirect processes that had an impact on the environmental, social, and political landscape of Russian cities. In 2018–2019, the protest activity associated with the issues of landfills and waste processing plants was comparable in scale to the political protests and even exceeded them in relative terms. Thus, 7,000 people took part in the largest "waste" protest in Volokolamsk, while the total population of the town amounts to 19,000 people; on August 10, 2019, the largest protest associated with the non-admission of independent candidates to the elections in Moscow took place, attracting from 20,000 to 60,000 people according to different estimates, while the total population of the Russian capital amounts to 12.69 million people (Ermolaeva et al., 2021).

On the one hand, waste-related conflicts united various social groups (environmentalists, the academic community, residents, young people, etc.) into a single powerful movement resisting the decisions of the federal and regional elites. Regional movements supporting waste sorting have been the most active new projects ("Eco taxi", "Sobirator", etc) and appear to ensure the local support of eco-friendly companies specializing in MSW sorting and recycling.

> Professional growth inevitably led to the strengthening of the personal civic stance. The more you realize the damage done by waste incineration, the more certain you are about being right, and the easier it is to persuade others on the necessity of waste sorting and the development of the waste recycling sector. (The representative of a non-profit organization, personal communication, March 25, 2018; trans. by P. E., Yu. E., & D. E.)

The central headquarters of the strongest NPOs promoting a zero-waste policy were established, for example, *Tsentr resursosberezheniia* [Resource Saving Center], *Otpor* [Rebuff], *Razdel'nyi sbor* [Separate Collection], *Musora.Bol'she.Net* [Garbage.No.More], *Dvizhenie EKA* [EKA Movement] and others (Ermolaeva, 2019). Network structuring allows public organizations and action groups to enhance each other's potential while facilitating the organization of joint events. Considering the spread of the data transparency policy (online platforms tracking dumping sites where anyone can enter data associated with improper disposal of waste and mark the spots of unauthorized dumping sites), it becomes easier for municipal establishments, companies, and citizens to solidarize locally: local solutions are becoming more transparent and legitimate.

> Most large enterprises are introducing technologies that can reduce the negative impact on the environment. This includes *Tatneft* and *Taneko* as examples. When through the introduction of new technologies, we get the effect of more rational use of water, we get the effect in the form of a decrease in emissions into the air. Also, work has been established in the republic to monitor the state of the environment. (The representative of a non-profit organization, personal communication, May 01, 2018; trans. by P. E., Yu. E., & D. E.)

On the other hand, the preponderance of political, economic, and social capitals in the hands of the resource groups provoked a certain apathy among the originators of civic initiatives, which could cause their erosion and the strengthening of the paternalistic position. Despite the protests, the construction of WIPs continued. The informational policy of governmental and numerous non-governmental media promoted the initiation of a regular and systematic discussion between the representatives of the government and civic activists.

The problem of combating landfills in Russia is similar to those in the United States, Latin America, and India, and touches on issues of environmental justice. In a number of urban areas where there is not a sufficient level of waste processing, both landfills and incinerators are the main means of disposal, moreover, they are located on the outskirts of city districts (on the periphery). In such areas, a greater number of diseases that are related to the environmental situation are recorded, living standards are falling, social tension is growing, and, ultimately, people have less access to ecosystem services, which provokes an exacerbation of environmental inequality. In combination with the environmental burden, inequality is exacerbated (Pellow, 2002).

Conclusions and Discussion

The health and living standards of Russians are being directly influenced by a variety of interdependent processes. Heightened processes of globalization and urbanization and the expansion of consumerist values have led to a rapid increase in the amount of waste with a consequent growth of unauthorized dumping sites, the construction of waste incineration plants, and the aggravation and politicization of the environmental protests associated with waste disposal.

Most of the current studies on MSW in Russia are conducted via specific disciplines—Sociology, Environmental Studies, Economics, and Political Science which limit the exploration and discussion of MSW as a holistic phenomenon with interconnected processes that occur in different systems and dimensions. Our key objective that allows our research to stand out from other respective works is to show this interconnectedness in MSW beyond the disciplinary boundaries. Thus, we made the first attempt to research the processes of waste disposal in Russian megalopolises through the case study of the city of Moscow from the perspective of the concept of SEM, according to which the life of waste discarded into the environment by humans leads to further metabolic transformations. Following the tradition established by M. Gandy (2004), we focused on the comprehension of qualitative interconnected and interdependent processes and causal relationships in the area of MSW management in Russian megalopolises. When reflecting on the nature of environmental conflicts triggered by the export of waste from the capital of Russia to its neighbouring territories, we extensively employed the approach of environmental inequality.

We concluded that the SEM node that triggered numerous interdependent processes involved the changes introduced in the legislation on MSW management and the decision to shut down several large MSW landfills without the simultaneous implementation of other landfills or WIPs. As a consequence, the new infrastructure represented by governmental and private waste processing enterprises began to appear, forming the makings of the circular economy and new workplaces. New infrastructural transformations were also associated with the appearance of a legally secured initiative on waste sorting that accelerated the development of the infrastructure in the area of waste reclamation. It gave rise to the formation of new practices among the citizens of Russia and augmented their environmental awareness. Nevertheless, infrastructural shortcomings and the lack of a large-scale systematic information campaign in the area of waste sorting prevent these practices from becoming routine and, on the contrary, cause a lot of trouble by triggering a series of negative metabolic processes (for example, the misuse of garbage containers or their “standstills”, etc.) while there was no significant increase in the volume of useful waste sorting into different fractions (with the dynamics of approximately 1–2%).

The socio-ecological consequences of the changes in the area of waste management in Russian megalopolises were represented by such processes as the systematic contamination of all environments with MSW decomposition substances,

resulting in them directly affecting the health of the population and contributing to environmental inequality among different groups of citizens (those who live near MSW storage sites and those who reside in relatively safe districts), which aggravates social conflicts and tension. This is exemplified by the protests that took place in the towns of Moscow Oblast where the waste from Moscow is exported. The aforementioned environmental conflicts and protests and the public concern with the construction of WIPs led to radical changes in the SEM of the Russian capital, its urban agglomeration, and some large Russian cities, and became the major risk-genic issues for the urban space. Even though in 2017–2019, the synergy of waste-related conflicts and protests associated with purely political reasons was avoided, this dangerous prospect persists in the future as the systematic problems of MSW generation, recycling, and storage have not been resolved.

We believe that the proposed analysis confirms the original hypothesis. Paradoxically, the metabolic transformations in the area of MSW management, that were largely disseminated by the political elite in the media as environmentally significant in the area of MSW, brought little temporary change into the SEM of the city (for example, the appearance of a new waste sorting infrastructure did not have any significant impact on the number of people sorting MSW) while the environmental conflicts and tension had much more substantial and irreversible effects on the SEM of cities.

Undoubtedly, the general problem of modern-day Russia that cannot be solved when applied exclusively to the environmental challenges is the sustainable interaction of different levels of the political and administrative hierarchy and the public. At the same time, based on the expert interviews, it is possible to articulate recommendations for the mitigation of risks associated with MSW generation, recycling, and storage in large Russian cities:

A. Establishment of federal standards concerning the industrial specifics of individual cities that ensure the priority of the development of a recycling infrastructure to create self-contained metabolic chains in the area of MSW management.
B. Development of economic tools for the support of “green” enterprises and increase of the penalties for the major contaminators; introduction of economic incentives for the population, such as lower communal charges for sorted waste or differentiation of tariffs according to the types of waste, etc.
C. Establishment of a convenient waste sorting infrastructure with responsible regional operators.

The opportunities to address the shortage of raw materials in the metabolic chain of waste reclamation are found in the development of sorting capacities and the stimulation of MSW sorting (both commercial and domestic). Businesses, citizens, and the government should have mutual obligations, whose development and acceptance should be realized based on the extensive and inclusive participation of the stakeholders. The metabolism and waste management scheme should be established starting at the regional level while taking into consideration the common federal principles, including the focus on a resource-efficient metabolism.

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