Current Waste Management Status and Trends in Russian Federation: Case Study on Industrial Symbiosis

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C. Baskar et al. (eds.), *Handbook of Solid Waste Management*,
https://doi.org/10.1007/978-981-15-7525-9_15-1

Abstract

In the last decade, waste management problems show a continuously growing trend in the Russian Federation. The country generated a total of 7.8 billion tonnes of waste in 2019, which is expected to reach up to 54.9 tonnes per capita in 2024. The extraction of fuel and energy minerals (mainly mining and coal enterprises) constitutes the largest contributor (93.6%) to the total amount of waste generated. To date, disposal on land remains the main method of waste management in the Russian Federation, which is affecting the quality of the environment, public health, and sustainable development. Evidently, the Russian Federation continues to face a serious challenge toward the implementation of its national 2030 targets. Noteworthy, that municipal solid waste (61 million tonnes) only accounted for 0.8% of the total amount of waste generated. Therefore, the development of an efficient national waste management focusing on the industrial sector (including mining enterprises) becomes a pre-requisite toward circular economy (CE).

This chapter provides a general understanding of the CE approach in the Russian Federation. We present a case study of Novokuznetsk industrial district, located in Siberia, Russia, on the development of an eco-industrial park (EIP) as an example of industrial symbiosis. The total amount of accumulated waste (including industrial and municipal) in the Novokuznetsk district is ~258 million tonnes (prior to 2019). This amount includes industrial waste, mainly from coal mining, metallurgical industries, and other polluting industries. This project is expected to produce more than three million tonnes of various types of products annually from industrial waste-recovered materials contributing to a total revenue of 63 million USD. The main objective of this EIP Project is the reduction of resource consumption and environmental impact by providing an industrial symbiosis between different enterprises. The results from this study can be used to guide decision-makers toward the viability of implementing new EIPs projects in other Russian Federation’s industrial district.

Keywords

Waste management · Industrial waste · Industrial symbiosis · Eco-industrial park · Circular economy

Introduction

One of the main trends in the sustainable development of modern society is a change of the economic paradigm. The traditional model of economy based on linear supply chains and often described as “take, make, and dispose,” which includes activities for exploration, processing, and production, as well as waste management, including disposal, has become obsolete. It has been replaced by a circular economy model aimed at creating a closed system of resource consumption in which resources go through this cycle anytime. The idea of creating closed loops with resources is not new. Circularity is a fundamental aspect of industrial ecology (Meadows et al. 1972). However, aspects of current research and action in the circular economy could reveal new perspectives for ensuring the sustainability of industrial systems.

The circular economy concept was developed in the late 1970s (Murray et al. 2017). A prerequisite for the formation of the concept of a circular economy is the description of the economic system as a closed-loop system with limited assimilation capacity, organized according to the principles of ecosystems. The authors in "The potential for substituting manpower for energy. Report to the Commission of the European Communities" (Stahel and Reday 1976) developed a circular economy concept to describe industrial strategies for waste prevention, regional job creation, and resource efficiency and decoupling the dependence of economic growth on resource consumption. In another work, the same author (Stahel 1982) emphasizes the use of a leasing mechanism instead of ownership of goods as the most relevant sustainable business model for a circular economy, allowing industries to profit without externalizing the costs and risks associated with waste management, which subsequently transformed into the way of development of "sharing technologies." The modern understanding of circular economy and its practical application to economic systems and industrial processes has evolved, and through the years, it included various features and contributions from other concepts. Some of the most significant conceptual approaches include "life cycle assessment," "environmental laws," "greening the economy," "ecodesign," "industrial ecology," "biomimicry," "eco-industrial parks," (Gibbs and Deutzba 2007; Chertow and Ehrenfeld 2012; Bilsen et al. 2015) "industrial symbiosis," (Changhao et al. 2015; Chertow 2000, 2007; Smirnova et al. 2018), and others. One tool for limiting waste generation is the concept of extended producer responsibility (Webster and Mitra 2007).

The authors (Geng and Doberstein 2008), focusing on the practice of implementing the concept in China, describe the CE as "the implementation of a closed cycle of material flows throughout the economic system." Webster (2015), in his study, defines a circular economy as an economy that is restorative in nature and aims to ensure that products, components, and materials always have maximum utility and value. Accordingly, Yuan et al. (2008) argue that "the core [of a circular economy] is a circular (closed) flow of materials and the use of raw materials and energy in several cycles." Bocken et al. (2016) characterize the circular economy, defining it as "a strategy for designing and creating a business model in which material flows are used cyclically." This can be achieved through a longer product life cycle ("design for circularity"), repair, reuse, refurbishment, upgrade, and recycling.

The authors Pearce and Turner (1990) attempted to model economics based on material balances and the first and second laws of thermodynamics. In a general, circular economy is a solution that harmonizes economic growth with environmental protection (Lieder and Rashid 2016).

The term "circular economy" has increased significantly in use in policy and business since being advocated in a 2011 joint study by the Ellen MacArthur Foundation (EMF) and McKinsey and Company (Ellen MacArthur Foundation [EMF] 2012). The most famous definition of circular economy has been formulated by the EMF, which describes CE as "an industrial economy that is regenerative on a planned basis" (Ellen MacArthur Foundation [EMF] 2012).

Circular economy is the subject of increased attention in academic research, with a number of reviews on this topic (Andersen 2007; Ghisellini et al. 2016; Lieder and Rashid 2016; Su et al. 2013; Kalmykova et al. 2018; Dorokhina and Kharchenko 2017; Geissdoerfer et al. 2017; Gaustada et al. 2018). Research focuses on closed value and supply chains (Guide and Van Wassenhove 2009; Wells and Seitz 2005; Govindan et al. 2015), circular business models (Bocken et al. 2016), and design for circularity (Bakker et al. 2017). In this context, a number of studies carried out by the Ellen MacArthur Foundation should be mentioned again. The concept of a circular economy, formulated by the EMF, was adopted as the basis for the formation of policies of governments and intergovernmental agencies at the local, regional, national, and international levels.

In this context, definitions of CE have been extensively reviewed by academics and scholars. Leading CEPS scholars (Rizos et al. 2017) have found that there is a wide range of interpretations and definitions of CE that represent the diverse goals and opinions of the various stakeholders concerned. Definitions start by relying entirely on material flows and resources, heading to a massive restructuring of the economic system that extends well beyond waste and resource management. They concluded that "the circular economy is a complex concept and it is unlikely that in the short term there can be an international consensus on its meaning." Homrich et al. (2018) analyzed 327 academic papers and concluded that there is a lack of agreement on the use of various definitions and terms for the CE among academics, policymakers and practitioners examining the patterns, trends, differences, gaps, and convergence of the CE literature. Two different clusters are also shown in the literature analyzed. One cluster focuses on eco-parks and industrial symbiosis, mostly in China. The second class includes supply chains, material closed loops, and business models. Similarly, Kirchherr et al. (2017) reviewed 114 circular economy definitions which were coded on 17 dimensions. In this paper, within addition to acknowledging the conceptual blurriness, the writers have established a unifying and synthesized definition that aims to resolve the differences they have found. It should be noted that the above list of definitions is not exhaustive; however, some commonality of approaches can be established. The idea behind the circular economy is to create a so-called cyclic metabolism that allows materials to maintain their resource status for as long as possible. And effective waste management plays a significant role in this matter (Maalouf and El-Fadel 2020). To conclude, there is no generally agreed definition of the term "circular economy," but various interpretations reflect the general principle of decoupling natural resource extraction and utilization from economic output, with improved resource productivity as a primary outcome. We recognize that we potentially exclude possible meanings by including only one CE definition. Nevertheless, in order to identify the indicators, we need to specify the boundaries of the various CE approaches (Moraga et al. 2019).

In 2008, the People's Republic of China was the first to enact a particular law: "Law of the People's Republic of China on the Development of the Circular Economy" (Lieder and Rashid 2016; CIRAIG 2015). This country contributes to a significant part of CE-related literature (Ghisellini et al. 2016; Homrich et al. 2018). In addition, the shift to a circular economy, which is the official Chinese policy for almost 15 years, requires more clean cycles and thus more final sinks to depollute material cycles (Mavropoulos and Nielsen 2020). In concrete policies, Germany and Japan were also pioneers in the promotion of CE.

Germany integrated the circular economy into national legislation as early as 1996. German Resource Efficiency Programme II, a program for the sustainable use and conservation of natural resources, was later adopted. Japan passed on the Basic Law on the Establishment of a Resource Conservation Society (METI 2004). The European Commission has also adopted circularity as a new economic paradigm for Europe, starting with the launch of its first EU Circular Economy Action Plan in 2015 and its revision in 2020 (European Commission 2020).

In Russia, although many laws and regulations were adopted in the early 1970s for particular waste streams during the Union of Soviet Socialist Republics (USSR) period, the collapse of post-Soviet Russia created a major void in the legal and institutional aspects, leading to a substantial fall in the waste management industry. However, in accordance with the circular economy strategy, the Russian Government has introduced a range of "green" initiatives aimed at controlling and eliminating waste, primarily from large-scale state-owned companies, and adopting best practices in the EU wherever possible. Moreover, a serious reform of municipal solid waste infrastructure, recycling and institutional development is on the way (Fedotkina et al. 2019). This highlights the importance of the waste sector toward the shift to circular economy globally (Maalouf et al. 2020).

The beating heart of human society is the cities. They are the world drivers' economic activity, vibrant centers of innovation, and home to much of the population of the world. Cities are an engine of growth and production but also of consumption. People in cities have a higher average income and higher per capita consumption than their rural counterparts. The economic activity of cities is substantial. They generate approximately 80% of the global GDP. Cities cover just 3% of the total global land area but house more than half of the world's population, consume about 60–80% of energy and available raw materials, and generate about 75% of human-induced greenhouse gas emissions (United Nations 2020). In 2018, 55% of the world's population lived in cities (4.2 billion people). It is expected that by 2050, these percentages will further increase to reach 6.5 billion people (about 70% of the world's population will live in cities) (UNDP 2020). This increase in urbanization enhances expansion of the city limits, an increase in infrastructure development, as well as an increasing need for products and services within cities. This provides both the opportunity and the obligation of cities, regions, and districts to play a leading role in the transition to a sustainable circular economy.

The industrial sector plays the most important role of the Russian economy. The share of industry in the country's gross domestic product (GDP) is approximately 40%. Industrial production employs about 32% of the population. The most developed fields of the Russian industry are the oil and gas sector, ferrous and nonferrous metallurgy, general and transport engineering, and food production. Currently, more than 349,527 industries and enterprises are developing in Russia, generating about 7,690 million tonnes of industrial waste, which constitutes about 99.22% of the total waste generated in the country.

This chapter presents an analysis of the current status and trends in waste management in the Russian Federation. The ultimate purpose of this chapter is to evaluate to what degree the waste management, as a part of the CE, is implemented in Russian Federation and if it can solve the issue of reducing the environmental impact of the industrial sector through the implementation of the network of eco-industrial parks. The functioning of eco-industrial clusters is called industrial symbiosis, currently defined as the collaboration of different business entities that establish a cooperative network to achieve competitive advantages through the physical exchange of materials, energy, water, and/or by-products and services and infrastructures (Baldassarre et al. 2019). For this purpose, the development of the eco-industrial park in Novokuznetsk district is taken as a case study. This district is one of the ten most environmentally neglected industrial districts in Russia and generating the highest amount of industrial waste. A set of indicators were developed to assess the CE performance and develop an action agenda to move itself toward increased circularity. The study highlights some limitations and presents recommendations for future research, as well as policy implications toward guiding decision-makers for future improvement of the CE in the Russian Federation and potential collaboration among the different districts.

Materials and Methods

This chapter used a qualitative method of analysis that was implemented in three steps.

Step 1: A literature review of the principles, effective factors, and challenges associated with the implementation of the CE in the Russian Federation was conducted.

Step 2 was based on Step 1 and offered a conceptual basis for implementing and assessing the development between 2010 and 2019 of the regulation and control of the waste management systems. This step was focused on a review of state legislation and state development strategies and policies focusing on waste reduction priorities.

The main purpose of this step was to assess the current status and trends of waste management in Russia in order to identify the most significant waste stream. We used different sources such as Federal Statistic Service, the state report "On the Condition and Environmental Protection of the Russian Federation in 2019," the electronic database "Consultant" in Russia, and the database "Joint information resource" provided by the ecological industrial policy center (EIPC) for searching, selecting, and analyzing regulatory documents and design documents of the eco-industrial park project in Novokuznetsk as well as published state reports, official public documents, and interviews with consultants in the industrial sector.

Step 3 was based on a case study of best available techniques in Novokuznetsk industrial district. The rationale behind the case study was to select a case that is likely to be replicated or extended as it contains the best practices of waste management performed by a specific district toward closing the loops of specific waste streams. Table 1 presents the amount of generated and characteristics of the ten most polluting industrial districts in Russian Federation. Moreover, a successful implementation of the eco-industrial park in Novokuznetsk district will allow to replicate it in other industrial districts with similar characteristics and environmental problems. It should be noted that all these districts do not have any existing eco-industrial park project.

The ten most environmentally neglected industrial districts listed in Table 1 generated about 368 million tonnes of industrial waste in 2019. Novokuznetsk district generated the highest amount of industrial waste (about 203 million tonnes) in comparison to other districts in 2019 and thus contributed to about 55% of the total waste generated from all 10 listed districts.

Results and Discussion

Current Status and Trends of Waste Management in Russia

According to the latest state report "On the Condition and Environmental Protection of the Russian Federation in 2019" published by the Ministry of Natural Resources and Environment, Russian Federation (2020), about 7.8 billion tonnes of waste is generated in the country in 2019, equivalent to 52.8 tonnes per capita per year. Figure 1 shows an overall increasing trend of total waste generated between 2010 and 2019, whereby the total waste generated has increased by twofold during this period from 3.7 to 7.8 billion tonnes. At the beginning of the period under review (till 2012), there was an increase in total waste generated by about 15–16% a year; further till 2015, a relative stability was observed, with minor changes ranging from −4% to 3%; in the period of 2017–2019, waste generation increased by 14% and 7%, respectively.

Moreover, the results show that the degree of waste generation depends substantially on the economic growth (Fig. 2). This result supports the observations of other scholars that the growing standard of living subsequently increases consumption and increases waste generation (Minelgaitė and Liobikienė 2019; Malinauskaite et al. 2017).

Forecasting of waste generated per capita to the year 2024 was carried out using the regression model (presented in Fig. 2) that correlates the GDP per capita with the waste generation, based on GDP per capita forecasting retrieved from the official "Forecast of the socioeconomic development of the Russian to 2024" report.

Table 1 Total waste generated and characteristics of the selected case study in comparison to other regions

District	Population	Main polluting industries	Number of industries and enterprises	Total accumulated waste prior to 2019 (million tonnes)	Total waste generated in 2019 (million tonnes)	Total waste generated per capita in 2019 (million tonnes per capita)	Total industrial waste generated in 2019 (million tonnes)	Total municipal solid waste (tonnes)
Novokuznetsk	549,103	Ferrous metallurgy, machinery construction, and metalworking industry	10,580	974.8	203.2	370	203.008	192,186.1
Norilsk	182,496	Ferrous and nonferrous metallurgy and chemical industry	2,108	522.8	13.0	71	12.936	63,873.6
Magnitogorsk	413,261	Ferrous and nonferrous metallurgy, engineering and machinery construction, metalworking, and metal construction	8,575	428.2	16.7	40	16.555	144,641.4
Cherepovets	314,834	Ferrous metallurgy and chemical industry	11,885	103.5	13.3	42	13.190	110,191.9
Krasnoyarsk	1,094,548	Nonferrous metallurgy, engineering and machinery construction, and wood processing	45,472	91.6	110.6	101	110.217	383,091.8
Nizhiy Tagil	351,565	Ferrous metallurgy, machinery construction, and metalworking industry	6,250	79.9	3.4	10	3.277	123,047.8

Omsk	1,154,507	Petrochemical and oil refining industry, chemical industry, and machinery construction	32,332	76.4	2.2	2	1.796	404,077.5
Chelyabinsk	1,191,994	Ferrous metallurgy, machinery construction, and metalworking industry	47,375	42.4	1.4	1	0.983	417,197.9
Bratsk	226,269	Nonferrous metallurgy, engineering and machinery construction, and wood processing	3,598	9.9	2.2	10	2.121	79,194.15
Lipetsk	508,573	Ferrous and nonferrous metallurgy, machinery construction, and chemical industry	12,799	5.7	3.9	8	3.722	178,000.6
Total	*5,987,150*		*180,974*	*2,335*	*370*	*655*	*368*	*2,095,502.5*

Note that the total waste generated in each region includes industrial waste, municipal solid waste, and other by-products of economic activities and sectors. The total number of industries and enterprises include manufacturing companies, fuel industries, electric power generating industries, food industries, agriculture, forestry, woodworking, pulp and paper industry, mining industries, mining and processing of minerals, and all kinds of SME, among others
Source: Data on the number of enterprises in districts is taken from the database of the International Information Group Interfax for 2019. Available at: https://www.sparkinterfax.ru/ru/statistics/region/32000000000

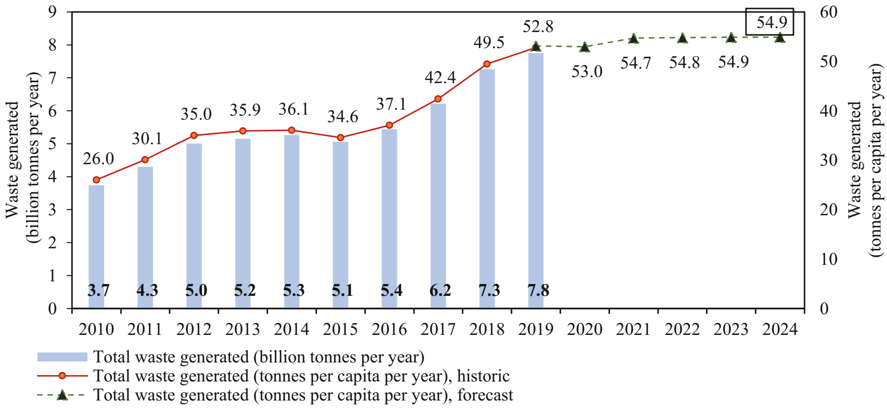

Fig. 1 Historical (2010–2018) waste generated and forecast (2019–2024) amounts of yearly waste generated per capita as predicted by the regression model presented in Fig. 2 (based on GDP per capita forecasting)

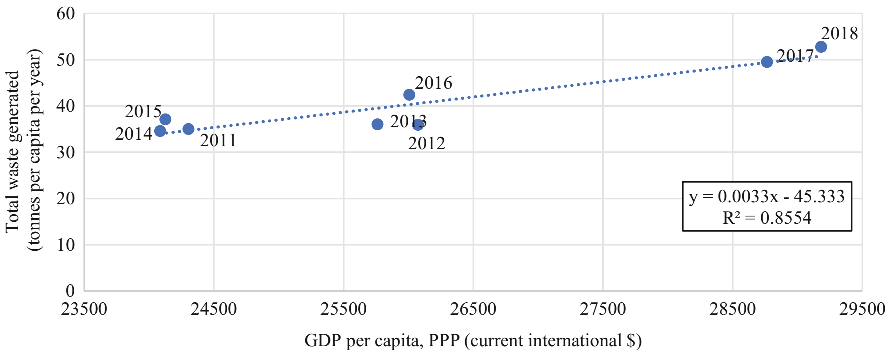

Fig. 2 Annual relationship between waste generation and GDP per capita between 2011 and 2018 (Ministry of Natural Resources and Environment Russian Federation 2020; World Bank's World Development Indicators 2020; Forecast of the socio-economic development of the Russian Federation 2019)

The forecasting results are presented in Fig. 1, which shows that the total waste generation per capita will reach up to 54.9 tonnes in 2024, equivalent to 8.02 billion tonnes per year. It is worth noting that the GDP growth per capita and the total waste generated per capita follow a similar trend.

Figure 3 presents the amount of waste generated in the Russian Federation by type of economic activities from the different sectors. In 2019, a major part (93.6%) of total waste generated was attributed to the extraction of fuel and energy minerals (mainly coal enterprises), and this is due to the fact that during the extraction and enrichment of the mineral deposits, the largest amount of waste, mainly overburden grounds, are generated. This sector includes mining of coal that contributed to 67% of the total waste generated, mining of metal ores (21.1%), as well as waste

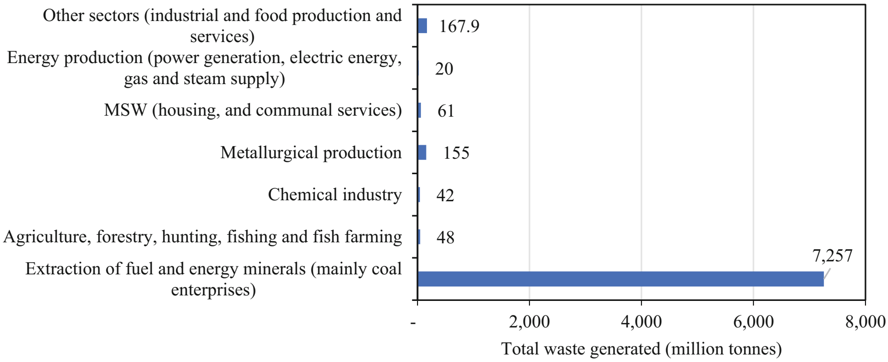

Fig. 3 The amount of waste generated in the Russian Federation distributed by the type of economic activity in 2019, million tonnes (Ministry of Natural Resources and Environment Russian Federation 2020)

generated from mining of other natural resources that contribute to 10.7% of the total waste generated in 2019. The share of the other sectors to the total amount of waste generated was not significant, 2% was attributed to metallurgy production, 0.6% was attributed to the agriculture sector (including forestry, hunting, fishing, and fish farming), 0.5% was attributed to the chemical industry, and 3.2% was attributed to other sectors, including other industries, housing, communal services, and energy production. Municipal solid waste (MSW) contributed to about 0.8% of total amount of waste generated (61 million tonnes) in 2019, or at an average of 1.14 kilogram per capita each day.

In 2019, nonhazardous waste amounted to 7.63 billion tonnes, or 98.45% of all waste generated in Russia. It is important to note that nonhazardous waste constitute the major share of total waste recovered. Wastes are categorized into five hazard classes, according to the attachment to Ministry of Natural Resources of the Russian Federation Order No. of 30 July 2003, “Amendment to the Federal Waste Classification Catalogue.” The total amount of the hazardous industrial wastes generated in 2019 was about 108 million tonnes (1.4% of total waste generated in the Russian Federation). Russian classification of wastes differs from the European classification. The environmental legislations in the Russian Federation require that all types of waste generated during production or industrial activities must be taken into account and reported in the waste statistics. This explains the relatively high amount of total waste reported in comparison to other countries. In reality, the nonhazardous wastes generated during the mining could be utilized as a product during the backfilling or reclamation of quarries and landfills processes. Moreover, the enterprises must pay penalties for the wastes generated or to find the solution for recycling and recovering in order to avoid the penalties.

Table 2 displays the current waste management practices including disposal, recovery, and neutralization in Russian Federation in accordance with Article 1 of the Federal Law of 24.06.1998 No. 89-FZ “On production and consumption waste.”

Table 2 Current waste management practices including disposal, recovery, and neutralization in Russian Federation in 2019

Waste management method	Amount of total waste (million tonnes)	Share of total waste generated (% by weight)
Total waste recovered[a]	3,927	50.7
Total waste neutralized	23.9	0.31
Total waste disposed or landfilled	3,800	49
Total	7,750	

Source: Ministry of Natural Resources and Environment, Russian Federation (2020)
[a]Mainly constitute of overburden material

The total waste generated includes municipal solid waste, industrial waste, and by-products of other economic activities and sectors.

In 2018, 93 new facilities for the recovery and neutralization of waste materials operating with a total capacity of 475.69 thousand tonnes per year were put into operation. This number of enterprises is devoted to the waste recovery, neutralization, and special landfilling (especially for the extremely and high hazardous wastes of the I and II class of hazard) operating facilities and their capacity in the Russian Federation.

The country has a total of 1,000 MSW landfills, 15,000 authorized and 17,000 illegal landfills, and 13,000 illegal waste disposal sites with a total area of four million hectares. This amount is increased by 300,000–400,000 hectares each year. Moreover, 50–70%t of the existing infrastructure is ineffective, and many formal collection systems do not exist in rural villages in Russia.

The amount of the recovered waste in the Russian Federation made up 3.93 billion tonnes in 2019, which is 50.7% of the total amount of waste generated during this year (Table 2). Waste recovery (mainly of overburden) was carried out mainly for the purpose of land reclamation (e.g., quarries and landfills), considered as recycling, which constitutes about 70.2% of the total amount of recovered waste. The types of waste recovered mainly include drilling fluids during oil wells drilling (low-hazard waste), drilling slurry of cuttings associated with base oil extraction (low hazard), base non-granulated blast furnace slag, converter slag, and steelmaking slags.

The total amount of waste neutralized (such as mercury, mercury quartz, luminescent lamps, and other materials that lost their consumer properties) was about 23.9 million tonnes in 2019, which is 0.31% of the total waste generated (Table 2). The largest amount of waste neutralized was attributed to the agriculture sector (19.6%), followed by the extraction of fuel and energy minerals (mainly coal enterprises) sector (18.2%).

The remaining amount of waste after recovery and neutralization is sent for the disposal and landfilling. The total amount was about 3,800 million tonnes, which constitutes 49% of the total waste generated (Table 2), and it was mainly attributed to the extraction of fuel and energy minerals (mainly coal enterprises and mining of metal ores sector).

In 2019, about 18.2 million tonnes of mixed MSW (30% of total MSW generated in the Russian Federation) was transported to sorting facilities, 8% after sorting are recycled as secondary materials, and 2% are sent to the incinerating plants. The remaining 70% are transported directly to landfills. The amount of MSW collected and transferred to recycling plants in 2019 has been increased by 12% between 2010 and 2019. The main problem for the recycling enterprises is that MSW collected is mostly without any presorting at sources, which reduces the quality and quantity of waste fractions that can be extracted for the further recovery of secondary resources (such as textiles, paper, plastic bottles, and polymer waste), and this ultimately increases the load on landfills. Waste disposal remains the most commonly adopted waste management method in the Russian Federation whereby more than 90% of MSW is sent to landfills.

Background of CE in Russia

The transition to the circular economy principles implies a complete systemic change and development of innovative solutions not only in technological processes but also in the manufacturing organization, institutional structures, and culture of waste management in societies. Under such conditions, timely government support becomes a key one, whether for providing general guarantees to reduce the risks for investors; cofinancing research and development works; reducing debt burden during the creation or acquisition of fixed assets, including the creation of environmental engineering facilities; as well as providing benefits to customers of such equipment, organizing a system of state procurement of the manufactured products with the use of secondary resources.

Starting in 2010, the Russian Federation has been consistently implementing a policy aimed at resolving the accumulated and annually arising environmental issues. This is reflected in the formation of environmental policy papers and legislative and regulatory acts that determine the movement vector aimed at the sustainable development of the Russian Federation.

By order of the Government of the Russian Federation No 84-P of January 25, 2018, a “Strategy for the development of industry for sorting, recycling, and treatment of waste for the period until 2030” (hereinafter referred to as the Strategy) was adopted (Russian Strategy 2018). The Strategy implementation is the most important step in the strategic course development toward the revival of the waste recycling branch in Russia, which will make it possible to implement the principles of resource saving in terms of returning secondary resources to production and back to the economy.

The main Strategy objectives are the formation and prospective development of the domestic recycling, recovery, and neutralization, ensuring the maximum involvement of the industrial and consumption waste into production and the systematic minimization of waste amounts that are not subject to recycling with the use of the “3R” framework. At the same time, the Strategy considers the circular

Table 3 Current status (2019) of sustainable waste management indicators in comparison to the national targets set by the waste management Strategy of the Russian Federation by 2030

	Current status	Targets			
Waste management indicators	2019	2018	2020	2025	2030
The amount of the recycled materials in a total amount of waste (including industrial)	51% (3,927 million tonnes out of 7,750 generated)	60%	65%	75%	86%
The amount of MSW sorted in a total amount of MSW	30% (18.2 million tonnes sorted out of 61 million tonnes generated)	10%	15%	50%	80%
The reduction of waste generation	+6.7% (from 7,266 million tonnes in 2018 to 7,751 million tonnes in 2019)	1.9%	1.8%	1.8%	3.7%
WM industry share in GDP of Russia	–	0.08%	0.09%	0.10%	0.11%
Number of eco-industrial parks	0	4	12	30	70

Source: Russian Strategy (2018)

economy principles, the main of which is resource saving, as a priority development guideline.

Considering the international experience in this field, the Strategy focuses on the maximum reduction of landfill waste disposal through the formation of an integrated management system and encouraging the recovery of industrial waste.

According to the main instructions of the Russian Government (Russian Strategy 2018), the new waste management concept must include the following:

– MSW management based on a closed-cycle economy
– Stimulate production from secondary material resources
– Implement a separate collection of MSW
– Develop eco-industrial parks
– Create a unified state information system for waste accounting

In the process of fulfilling the Strategy's objectives, it is planned to achieve different targets between 2018 and 2030 including core indicators of sustainable waste management as presented in Table 3.

However, for some measures, the target dates have already passed, and for others, the timelines are unachievable. Moreover, based on the 2019 figures of the different waste management indicators presented in detail in section "Current Status and Trends of Waste Management in Russia," we can deduce that the 2018 target was not achieved except for the amount of MSW sorted in total amount of MSW generated that reached up to 30% in 2019 (Table 3).

These target indicators correlate with the target indicators laid down in the National Project “Ecology,” the road map of which was approved on September 24, 2019, by the Presidium of the Presidential Council for Strategic Development and National Projects of the Russian Federation. However, in the middle of 2020, the key indicators of the National Project “Ecology” were revised. Today, the main target in accordance with the National Project “Ecology” is to create a sustainable system for the management of municipal solid waste, ensuring the sorting of waste in the amount of 100% and reducing the volume of disposal in landfills waste by half by 2030, adopted by Presidential Order in July 2020 (National Development Targets 2020).

The Strategy and National Project “Ecology” provide the investment mechanisms for the creation and development of a waste recycling infrastructure, construction of new high-tech waste sorting plants with a share of the secondary resources extraction of 60–70%, waste recovery and neutralization capacities, and infrastructure for the safe collection and neutralization of hazardous waste. In addition, financing will be directed to the modernization of the existing manufacturers in all industries to achieve other target indicators of the Strategy.

The circular economy principle that formed the basis for the development of the above policy papers is a reflection of the principles of the natural systems existence in which one generated waste becomes a resource for another process. It is important to note that the circular economy concept includes not only the (material) waste recycling but also the reuse, repair, and refurbishment of products. Thus, the products should be initially designed in such a way as to correspond to material cycles in which they retain their additional value as long as possible and designed so that raw materials can ultimately return to the biosphere as a safe object. For example, in a circular economy model, the industrial products can be repaired for further use, modernized, restored, or, ultimately, recycled, and industrial processes may be oriented more toward the reuse of products and raw materials and the use of the restoration capabilities of the natural resources, while innovative business models can create new relationships between companies and consumers in product design sphere with planned life cycle.

It is important to note that although the benefits of a circular economy are difficult to question, there is a number of risks that limit its development, including a lack of practice of implementation and investment in the development and production of the “circular economy products”; the level of current prices for resources, which does not encourage the efficient use of the resources and the limited use by consumers and businesses of the potentially more efficient service-oriented business models; problems in obtaining the necessary financing for such projects; and lack of special state support measures for investment projects in the field of waste management. The most important factor that impedes the introduction of the circular economy principles in the Russian Federation is the conflict between environmental and industrial policies, which, in fact, have different aims.

Therefore, one of the main tasks in creating the conditions for implementing the circular economy principles in the Russian Federation is the harmonization of industrial (stimulating) and environmental (conservation) policies, interdepartmental collaboration formation, creation, coordination, and monitoring of the environmental industrial policies implementation. The implementation of the environmental policy paper provisions of the Russian Federation during the next 1–2 years is expected to ensure a mutual coordination of priority projects in the field of industrial development and green production, and to give an opportunity to make additional efforts to introduce the best available techniques (BAT). This will also offer industry additional incentives for sustainable development, from supporting "green bonds" to concluding special agreements and contracts with pilot companies in the most important regions of the Russian Federation.

The Strategy determines that the priority attention of interdepartmental and interregional collaboration should be aimed at creating the conditions necessary to achieve national goals:

- Secondary resources should be enshrined in legislation as a factor in sustainable economic growth and transition to a closed-loop economy; the replacement of newly mined natural resources with secondary ones should become mandatory in the cases where such secondary resources are available and, moreover, accumulated by industry (as so-called technogenic deposits).
- The industrial resource efficiency should be the subject of accounting, an indicator of the enterprise efficiency; the procedure for calculating resource and energy efficiency indicators should be clearly defined.
- Support for the development and implementation of technologies, technical solutions, and equipment offered by domestic companies and aimed at ensuring sustainable economic growth should be of systematic nature.

Among several approaches to implementing the circular economy concept and achieving sustainable green economic growth, the projects for the industrial symbiosis networks development should be highlighted. The industrial symbiosis provides a significant contribution to the circular economy development by facilitating the efficient cooperation of companies through the organization of mutually beneficial relations with the goal of:

- Maximum use of natural raw materials – minimize the amount of waste generated during the industrial process
- Maximum use of secondary material (and energy) resources – their repeated involvement in the economic turnover
- Creation of final production products – the properties of which imply their harmless assimilation by ecological systems
- Reducing the amount of consumption waste, suggesting the possibility of their complete disposal before entering the environment.

The industrial symbiosis center may associate between the industrial and consumption waste management formed outside of its own industrial or consumer process. The mechanism for industrial symbiosis implementing is the exchange of resources between companies. There are three main types of exchanges that may be specified:

– Reuse of secondary resources (exchange of materials specific to a particular production between two or more parties to replace the use of commercial products or primary raw materials)
– Joint use of utilities/infrastructure facilities (sharing and management of resources such as energy, water, electricity, and heat, as well as joint treatment of gas emissions, wastewater)
– Joint services provision (meeting the general needs of companies within the association (technology park, cluster) in relation to auxiliary types of activities, such as ensuring fire safety and utilities, transportation)

The state and government participation and support for the development of industrial symbiosis and legislative initiatives that promote the development of eco-innovative projects in the industrial zones are also of great importance. The financial incentives, economic instruments, and provision of the access to finance help overcome economic barriers and support the measures on eco-innovation planning and implementation. Other initiatives supporting the implementation of circular economy principles in Russian Federation include the ban on the disposal of waste containing useful components (Government Order № 1589, 2017) and the introduction of extended producer responsibility for certain types of goods and packaging (Federal Law №458-FZ, 25.12.2014).

It is important to add that in September 2020, an analytical report about the "Actual situation with waste management for 3rd class hazard waste" made by the Control Department of the Presidential Administration of the Russian Federation was published, following that the President of the Russian Federation signed the Orders (№ 1489, by 16.09.2020). These orders stressed that circular economy, eco-industrial parks, resource efficiency in the industrial sector, and secondary resources turnover are the main accents for Russia toward achieving the sustainable development goals (SDG) 2030 and circular economy principles.

Case Study on Eco-industrial Park in Novokuznetsk District

The development of eco-industrial parks is one of the main goals of the Russian Federation Strategy whereby it is planned that by 2030, 70 eco-industrial parks must be developed within all districts of the country (see Table 3). These parks will be specialized in processing municipal solid waste recycling in addition to industrial waste. The latter constitute a major concern particularly for the ten most polluting districts within the Russian Federation (see Table 1). Novokuznetsk district is located in Kemerovo region in Siberia, Russia, is identified

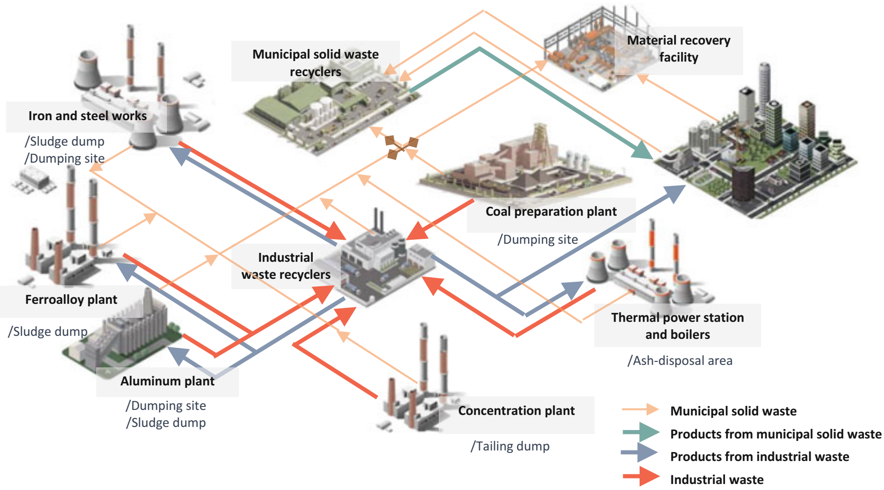

Fig. 4 The organizational structure of the Novokuznetsk Eco-industrial Park showing the exchange of energy generated and recycled waste (source compiled by authors)

as one of the most polluting industrial districts in the country, and is the first to plan for the implantation of an eco-industrial park project within its region as requested under the Federal Project "Clean Air" and the complex plan of action for Novokuznetsk city (adopted by the Government of Russia in December 2018.) The eco-industrial park will consist of several modules including a complex for processing waste of iron ore and coal, a complex for processing metallurgical slags, a complex for processing waste of electronic and electrical equipment, and a complex for processing waste from a coke-chemical production connected by energy flows.

Figure 4 presents the organizational structure of the Novokuznetsk Eco-industrial Park and interaction with external stakeholders as well as the exchange of generated energy and recycled waste from ore dressing and metallurgical production and municipal solid waste generated from Novokuznetsk district.

The eco-industrial park project consists of creating technological interaction between the production facilities through the resources exchange (interchange) and waste-recovered materials. The main benefits of the eco-industrial park are the reduction of the resources consumption and decrease in the environmental impact by organizing exchange links between the industrial symbiosis participants, obtaining economic benefits from such cooperation, and sustainable development of the districts. In addition, the creation of these complexes will lead to the generation of new job opportunities of different skill levels, energy savings, and reduction of environmental impacts. It also induces the generation of heating and electric power and production of a wide range of chemical, construction, metallurgical, and other types of products.

Novokuznetsk district's economy is based for more than 80 years on the primary coal and ore processing, which pollute the urban environment with toxic gases and industrial waste. This district has all characteristics for creating and testing the model of implementing an innovative eco-industrial park (hereinafter referred to as eco-industrial park), including:

- The presence of pollution-prone production – ore dressing and metallurgical ones (metallurgical complex JSC "EVRAZ ZSMK," OJSC JSC "EVRAZRuda"), aluminum plant OJSC "RUSAL Novokuznetsk," ferroalloy plant OJSC "Kuznetsk ferroalloys," four coal preparation plants (three heat treatment plants), three heat and power plants (three heat-generating plants), and heat power engineering facilities (three central heating and power plants and many coal boiler stations)
- A significant raw material base of accumulated technogenic resources (waste)
- Operating waste recycling enterprises engaged in the processing of accumulated waste
- Commercial organizations engaged in the field of waste recycling are merged into Kuzbass Waste Recycling Association.
- A complex of administrative support measures at the regional and local levels has been developed.
- Waste recycling is one of the key positions in the Strategy for socioeconomic development of Novokuznetsk district by 2035.
- The presence in the district territory of the developed industrial and transport infrastructure
- High crowding with the metallurgical enterprises – potential consumers of the technogenic resources and products based on them
- The engineering base development, which will ensure the production of equipment for the waste recycling industry
- The existence of a scholarly tradition as a center for generating innovations in the field of waste recycling (Smirnova et al. 2019)

The increased concentrations of pollutants such as dust, benzopyrene, and other carcinogenic polycyclic aromatic hydrocarbons (PAHs), as well as industrial waste, pose adverse health impacts on Novokuznetsk residents and surrounding. The industrial wastewater generated as by-product from coke processes is disposed into "pitch lake" and ultimately evaporates back into the atmospheric air, causing enormous damage to the environment and health of Novokuznetsk residents.

The total amount of waste accumulated prior to 2019 was about 257.5 million tonnes, which consists of various waste having been accumulated in industrial waste and sludge storage areas in the district territory (Table 4).

Table 4 The amount of accumulated waste by 2019 from different industries in Novokuznetsk district

Type of industrial waste	Source of waste generation	Industrial waste storage area (hectares)	Total amount of accumulated waste prior to 2019 (million tonnes)
Finely divided slag of iron ore beneficiation	Tailing dump №1 of Abagur sintering plant	100	90
Slag of steelmaking	Dumps of the Novokuznetsk Metallurgical Complex (NKMK OJSC)	176	20
Finely divided blast furnace sludge	Dumps of the Novokuznetsk Metallurgical Complex (NKMK OJSC)	20	1
Finely divided waste of metallurgical production	Slag storage of JSC "EVRAZ ZSMK"	300	140
Liquid waste of coke production	Dump of coke and by-product process	10	0.5
Ash and slag waste	Dumps of thermal power station and boilers	50	1
Finely divided waste of coal beneficiation	Tailing dump of JSC TSOF "Abashevskaya"	15	5
Total		*683*	*257.5*

Source: Smirnova et al. (2019)

Circular Economy Benefits

At present, the construction of the eco-industrial park in the Russian Federation is at the introductory stage. The amendments to the Federal Legislation Act 488-FZ (about the industrial policy) have been prepared by the ministry of industry and trade and are undergoing approval by the government, and the following findings can be attributed to the planned results of its implementation in the industrial district of Novokuznetsk. The implementation of eco-industrial park project in Novokuznetsk district will allow the processing (for recycling) of more than five million tonnes of waste annually into various types of products (such as iron ore concentrate, pyritic concentrate, garnet concentrate, construction sands, fuel briquettes, coal concentrate, metal slag scrap, reclamation feedstock, zinc concentrate, crushed stone, ferrous metals, nonferrous metals, precious metals, plastic, sleeper impregnation oil, briquettes binders, heating oil, technical carbon, sorbents). The eco-industrial park products are in demand by the enterprises of the district and beyond.

The estimated economic and environmental benefits when using these cooperation principles within the framework of the eco-industrial park are 1.5–2.0 times higher in comparison with the situation when every enterprise works as an autonomous producer due to the following most significant combined effects:

- A high degree of the potential use of raw material and fuel in obtaining the final product
- A significant reduction in the costs of using the external energy sources and certain types of raw materials
- High added value due to the implementation of deep recycling of the raw materials
- High environmental performance of production due to the elimination of intermediate stages, a significant reduction in emissions of solid and gaseous substances, and recycling the secondary resources

In this context, the implementation of eco-industrial parks in the industrial districts of the Russian Federation might enhance the economic development through the development of complex recycling processes of the natural raw materials and technogenic wastes.

Table 5 displays the estimated economic benefits from the development of innovative technologies within the framework of implementing the experimental innovative eco-industrial park project in Novokuznetsk district. The estimated total amount of industrial waste recovered materials is about three million tonnes contributing to a total revenue of about 63 USD million from selling products produced from waste-recovered materials. It is worth noting that the price of material produced has varied between 3 and 625 USD per tonne, depending on the type of industrial waste recovered material and the type of the technological process whereby the higher the level and the more advanced the technology, the higher the price. Moreover, the price can be affected by the market demand to the total amount of material produced from recovered industrial waste.

Involving technogenic waste in the recycling will allow liquidating the objects of their placement as the sources of atmospheric air pollution and will reduce the extraction volumes of the natural resources, replacing them with technogenic resources, while the social tension in the region will be reduced, which is caused by the negative environmental situation.

Thus, the practical implementation of the circular economy principles in a particular region will lead to positive results in both environmental and industrial policies. Moreover, the solutions obtained may be used not only in the Russian Federation but also abroad.

Due to the industrial symbiosis organization of the waste recycling enterprises with the companies in which waste is generated, new waste recycling enterprises may be created, the capacities of the existing enterprises may be increased, and new types of products based on waste may be produced for the use as technogenic resources of the city industrial enterprises, primarily for metallurgical enterprises. The partial natural resources replacement by technogenic ones will contribute not

Table 5 Estimated economic benefits from the development of innovative technologies in the experimental innovative eco-industrial park "Novokuznetsk" at its first stage of implementation

Technology name/process	Type of waste-processing facility	Type of generated products	Estimated quantities (million tonnes)	Price of products/ recovered materials (USD/tonne)	Total revenue (million USD)
Waste recycling and iron ore and coal dressing	Factories for iron ore and coal dressing	Iron ore concentrate	0.02	44	0.66
		Pyritic concentrate	0.01	81	0.73
		Garnet concentrate	0.03	108	3.23
		Construction sands	0.07	7	0.46
		Fuel briquette	0.11	23	2.36
		Coal concentrate	0.02	70	1.05
Recycling fine powder fractions of metallurgical slag	Slag dumps of metallurgical complexes	Iron ore concentrate	0.20	44	8.53
		Metal scrap	0.18	65	11.70
		Technical soil for remediation	0.23	3	0.56
		Construction sands	0.66	7	4.54
Recycling metallurgical productions sludge	Metallurgical productions JSC "EVRAZ ZSMK"	Iron ore concentrate	0.10	44	4.38
		Zinc concentrate	0.01	108	1.34
		Reclamation feedstock	0.08	3	0.19
Complex of recycling sludge collector waste JSC "EVRAZ ZSMK"	Sludge collector of metallurgical complexes JSC "EVRAZ ZSMK"	Iron ore concentrate	0.24	44	10.50
		Crushed stone	0.42	8	3.41
		Construction sands	0.24	7	1.65
		Reclamation feedstock	0.12	3	0.30
Recycling of electronic and electrical equipment waste	Population and industrial enterprises of Novokuznetsk city	Ferrous metals	0.00	150	0.45
		Nonferrous metals	0.00	250	0.75
		Precious metals	0.00	625	0.19
		Plastic	0.00	125	0.56

(continued)

Table 5 (continued)

Technology name/process	Type of waste-processing facility	Type of generated products	Estimated quantities (million tonnes)	Price of products/ recovered materials (USD/tonne)	Total revenue (million USD)
Recycling ashes of the central heating and power plant and boiler stations	Ash and dust disposal plants of the central heating and power plant and boiler stations	Sleeper impregnation oil	0.03	106	3.19
		Briquettes binders	0.01	10	0.08
Recycling ashes of the central heating and power plant and boiler stations	Ash and dust disposal plants of the central heating and power plant and boiler stations	Ferrous and nonferrous metals concentrates	0.03	44	1.09
		Construction materials	0.15	7	1.00
Total			2.93	21.5	62.9

Source: Smirnova et al. (2019)

only to saving natural resources, reducing the energy consumption of the technological processes and the amount of the buried waste, but also solving a set of environmental problems.

At its core, an eco-industrial symbiosis will be organized by analogy with the natural one – mutually beneficial cooperation of the waste recycling enterprises, operating industrial enterprises, consumers of the waste-based products, equipment manufacturers, scientific and engineering companies, educational institutions and public organizations, service companies, and testing laboratories, the activities of which will be aimed at ensuring the creation and development of new environmentally friendly branches of the economy, gradual reduction of the consumed natural resources, and amount of and the emission's amount into the environment.

Conclusion

The analysis of waste management generation in Russia Federation for the past decade showed a continuously growing trend from 2010 to 2020. In recent years, minor changes have been achieved in the waste management system whereby disposal on land remains the main (49%) method of waste management in the Russian Federation despite the small increase in the share of waste recovered and neutralized (51% of total waste generated in 2019). In 2019, the country generated a total of 7.8 billion tonnes of waste, at an average of 52.8 tonnes per capita each year, which is expected to reach up to 54.9 tonnes per capita in 2024. The extraction of fuel and energy minerals (mainly mining and coal enterprises) constitutes the largest contributor (93.6%) to the total amount of waste generated. It is worst noting that the municipal solid waste (MSW) contributed to about 0.8% of total amount of waste generated (61 million tonnes) in 2019, or at an average of 1.14 kilogram per capita each day.

From the above analysis, it is clear that the main goals of the Russian Federation "Strategy for the development of industry for sorting, recycling, and treatment of waste for the period until 2030" were not met in 2018, and 2030 target is not on track. This shows the importance of studies on the project approach to the creation of eco-industrial parks aimed at decreasing waste flows to landfills and increasing the recycle and reuse of secondary materials/resources. In this context, the development of an efficient national waste management focusing on the industrial sector (including mining enterprises) becomes a prerequisite toward circular economy (CE).

Industrial symbiosis (IS), implemented in the form of eco-industrial parks, is a cooperative strategy to competitive advantage through which a cooperative network to share resources, energy, water, and/or by-products is generated by different industries. Eco-industrial parks play an important role in the circular economy, which is known as the most resource-efficient and energy-efficient form of economy. Despite many recent initiatives in the political, legal, and institutional frameworks of the Russian Federation toward encouraging the industrial symbiosis through the development of 70 eco-industrial parks by 2030, the introduction of best available techniques (BAT), and the organization of separate waste collection systems, many of these effective tools toward a circular economy are currently not widely adopted. At present, the construction of the eco-industrial park in the Russian Federation is at its first stage of planning and development.

Subsequently, the aim of this chapter is to facilitate potential research and practice aimed at developing new IS clusters and amplifying eco-industrial parks in the Russian Federation's industrial district. The findings presented in this chapter are attributed to the famous example of the innovative eco-industrial park project of Novokuznetsk industrial district (at its first phase of development). The project implementation reduces air pollution in Novokuznetsk district by eliminating areal sources of pollution with dust, benzopyrene, and other carcinogenic polycyclic aromatic hydrocarbons, mainly due to avoiding the extraction of natural raw materials, which are substituted with the technogenic material or products from the industrial enterprises. Moreover, it is estimated that about three million tonnes of waste-recovered materials (mainly metallurgical slags which are recovered from industrial landfills) will be processed into different kinds of products. Therefore, the total economic benefit or revenue from implementing this project is estimated about 62 million USD. It is worth noting that the price of material produced has varied between 3 and 625 USD per tonne, depending on the market demand, the type of industrial waste-recovered material, and the type of the technological process whereby the higher the level and the more advanced the technology, the higher the price.

The findings of the study are of practical interest to the public authorities, current and future partners in eco-industrial parks, waste management professionals, environmental scientists, and economics scholars.

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