To the issues of waste treatment as a promising source of thermal energy and improvement waste management system

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Abstract. The paper discusses the organization and implementation of waste management activities based on territorial waste management schemes. The territorial waste management schemes of Vologda Oblast, Yaroslavl Oblast, and Arkhangelsk Oblast (Russia) were analyzed and compared. The sources of municipal solid waste formation, their composition, and hazard class were considered. The authors propose a new approach for comprising the territorial waste management schemes. The obtained results can be used when adjusting territorial schemes, establishing differential standards for the accumulation of solid municipal waste.

1 Introduction

World experience shows that the most accessible and one of the most economically viable renewable energy sources is municipal solid waste (MSW), incinerated at thermal power plants (TPPs). Municipal solid waste is a fuel comparable in calorific value to peat and some brands of brown coal. It is formed where heat and electrical energy is most in demand, i.e. in large cities, and has a guaranteed predictable renewal.

The operation of solid waste TPPs does not depend on natural conditions (unlike, for example, solar or wind power plants) and geographic location (as compared with geothermal and tidal power plants). In addition to energy generation, TPPs solve an important social problem - recycling of household waste generated by human life activity.

In the Russian Federation, MSW will be used as secondary energy resources after the adoption of legislative documents aimed at a significant reduction of landfill disposal, at least for large cities, and increasing the interest of energy companies in the development of renewable energy sources.

The issues of waste management have been relevant for several decades [1-4]. In 2018, the Russian national project "Ecology" was approved, the key goal of which is the effective management of production and consumption waste. Amendments are being made to federal laws, government decrees, regional regulations, which are aimed at improving the management tools for the waste management sector [5-7]. With the adoption of amendments to the basic law governing waste management (No. 89-FZ "On production and consumption waste"), all constituent entities of the Russian Federation are obliged to develop and approve

territorial waste (including MSW) management schemes (TWMS) [8, 9].

This work is aimed at the formation of conceptual approaches to the development (updating) of the Russian territorial waste management schemes based on the differentiation of waste generation facilities and waste accumulation rates.

2 Materials and methods

In 2016 in the Vologda Oblast (Russia), a territorial waste management scheme was developed and approved based on the provisions of federal and regional regulations [8-12]. However, a detailed analysis of its sections (sources of waste generation, amount of waste, morphological composition of waste, norms of waste accumulation) shows that the territorial scheme does not include innovative scenarios for the development of waste processing industry. Moreover, it doesn't include the initial data for planning the industry development or these data are incomplete. For a more objective assessment of the territorial waste management scheme of the Vologda Oblast, the authors analyzed the territorial waste management schemes of the Yaroslavl Oblast and Arkhangelsk Oblast [13, 14]. These regions were selected as objects for comparison due to several reasons. Firstly, these regions border with the Vologda Oblast. Secondly, the climatic conditions of the Arkhangelsk Oblast are similar to that of the Vologda Oblast. As a rule, climatic factors have a significant impact on the morphological composition of waste generated by the population. Thirdly, the population size of the Vologda and Yaroslavl regions differs by 6%, and the population density by 4 times. The density and nature of the population's distribution affect the decision-making on strategic planning of waste management

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Table 1. Characteristics of the studied regions (as of 2018).

Characteristics	Vologda Oblast	Yaroslavl Oblast	Arkhangelsk Oblast
Total population, ths. people	1183.85	1265.7	1111.0
Urban population, ths. people	862.9	1039.3	869.9
Rural population, ths. people	323.9	232.6	242.1
Region area, ths. km ²	36.2	144.5	589.9
Population density, person/km ²	8.22	34.99	2.7
Amount of waste, t/year, total MSW	15 951 453 493 509	3 152 967 649 492	75 047 613 521 662
Amount of MSW, kg/year·person	416.8	513.1	461.4

Table 2. Sources of municipal solid waste formation.

No.	Sources of municipal solid waste formation	Vologda Oblast	Yaroslavl Oblast
1	Apartment residential buildings	783 374 people	1 002 052 people
2	Detached houses (a group of small houses)	404 311 people	263 632 people
3	Offices, administrative buildings, institutions	58 471 employees	931 274 m ²
4	Consumer service enterprise	106 570 m ²	32 556 m ² (including: barber shops, beauty salons, baths, saunas 5 585 items)
5	Retail facilities	1 228 361 items	1 699 185 m ²
6	General educational institution, higher educational institutions, institutions of additional and professional education	187 131 students	279 562 students
7	Preschool education institution	75 606 students	64 979 students
8	Public catering enterprise	106 570 items	52 212 items
9	Hotels, other temporary accommodation	13 160 items	51 322 items (including dorms)
10	Cemeteries	11 717 764 m ²	1 229 695 items (crematoria and funeral organizations 5 675 m ²)
11	Parks	5 745 745 m ²	exhibition halls, museums, zoos, botanical gardens 5 961 661 m ²
12	Sports facilities	9 721 items	
13	Horticultural, gardening or dacha partnership	83 676 allotments	64 195 members
14	Cultural facilities	125 476 items	clubs, concert halls, theatres, circuses, stadiums, camp sites, rest houses-196 958 items
15	Transport infrastructure enterprises	91 624 m ² .	25080 parking spaces; train stations, airports – 69 665 passengers
16	Social protection facilities for short and long stay	3 304 and 1 187 items	
17	Enterprises of other industries		43 725 m ²

activities. The characteristics of the objects of study according to data from [10,13,14] are presented in Table 1.

Territorial waste management schemes contain information about the sources of waste generation on the territory of the subject. Data on the sources of waste generation are necessary to determine, first of all, the morphological composition of waste. The number of

sources of solid municipal waste generation on the territory of the constituent entities is presented in Table 2. The territorial scheme of Arkhangelsk Oblast does not contain these data.

The presented data shows that the territorial schemes do not take into account the following sources of MSW formation: orphanages, prisons, treatment-and-prophylactic and medical-diagnostic institutions. For

Table 3. Analysis of sources of other waste generation.

No.	Sources of other waste generation	Vologda Oblast	Yaroslavl Oblast	Arkhangelsk Oblast
1	Agriculture, forestry, fishing facilities	361	94	58
2	Mineral extraction facilities	11	9	8
3	Manufacturing facilities	1236	1262	212
4	Consumption, production and non-production facilities	1503	1262	700
5	Facilities for providing electricity, gas and steam	282	139	144
6	Water supply and sewerage facilities	136	449	55
7	Construction and repair facilities	156	271	133
9	Other facilities	515	2454	273
	Total	4059	9829	1583

Table 4. Analysis of waste generation by hazard classes.

№	Type of waste	Hazard class	Waste generation, tons		
			Vologda Oblast	Yaroslavl Oblast	Arkhangelsk Oblast
1	Municipal solid waste	IV-V	493 509	649491.7	521 662.1
	including bulky waste	V	48 948	194 826	52166.21
2	Waste from construction and repair	III-V	1 847 958	548 591	3 395 764.6
3	Waste from agriculture, forestry, fishing facilities	III-V	845 383	666 540	113 745.4
4	Waste from mineral extraction facilities	IV	597 946	331	68 918 599.2
5	Waste from manufacturing facilities	II-V	11 674 383	180 415	1 674 551
6	Production and non-production consumption waste; materials, products that have lost their consumer properties	I-V	295 930	111 473.4	54 914.4
7	Waste from providing electricity, gas and steam	IV-V	13 679	12 212	351 398
8	Waste from water supply, sewerage, waste collection and treatment activities	III-V	179 920	48 792	11 691.6
9	Other production and consumption waste	II-V	2 745	21 694	11691.6
Total			15 951 453	2 239 467.32	75 047 61

example, the website of the Vologda Oblast Health Department presents 132 medical institutions, the amount of waste, including epidemiologically hazardous waste, is about 8.5 thousand tons per year. It is not clear which section of the territorial scheme of Vologda Oblast takes into account the dormitories of educational institutions: “general educational institution” or “hotels”. There is no data on train stations and airports.

The correctness of the unit for measuring the waste accumulation rate of members of gardening partnership raises doubts, according to the authors, it is necessary to take into account the number of people living in summer cottages.

3 Results

Addition of objects to the territorial scheme

We propose to add the following sources of waste accumulation to the territorial scheme:

- Apartment residential buildings in settlements with a population of up to 50 thousand people;
- Apartment residential buildings in settlements with a population exceeding 50 thousand people;
- Apartment residential buildings in rural areas;
- Individual dwellings with central heating in rural areas;
- Individual dwellings with individual heating in rural settlements;
- Individual dwellings with central heating in urban-type settlements;
- Individual dwellings with individual heating in urban-type settlements.

This will result in a more differentiated calculation of standards for the accumulation of MSW and tariffs for garbage disposal. The proposed approach would remove social tension among the population, in particular, those living in rural areas. The waste generation rate and, as a consequence, the tariff for MSW management will become more reasonable.

Table 5. Morphological composition of municipal solid waste.

Components	Share in the total volume, %	
	Vologda Oblast	Yaroslavl Oblast
Food waste	8	28.17
Paper (cardboard)	17	8.17
Polymer materials, incl. polymer films (polyethylene, polypropylene polyethylene terephthalate (bottles, etc.) polypropylene (without films) polyvinyl chloride other plastics	26	14.12 2.19 1.82 1.82 2.68 5.61
Glass	8	14.5
Wood	6	3.53
Textile	6	0.38
Metal black scrap metal (including tin bottles) non-ferrous scrap metal (including aluminum bottles)	4	1.73 0.83 0.9
Estimates from the territory (earth, sand, stones, plant waste)	5	9.62
Plant waste		4.82
Leather, rubber		3.42
Hazardous waste (batteries, accumulators, containers from solvents, paints, mercury lamps, etc.)		1.26
Tetrapak		0.71
Others	20	8.51

Analysis of sources of other waste generation

Analysis of sources of other waste generation shows a wide scatter of information on the number of objects (Table 3). The number of mining facilities in the analyzed territorial schemes is approximately the same and arises no discussion. However, the number of manufacturing, consumption, production, and non-production facilities, objects of other activities requires clarification. So, the amount of manufacturing facilities in Vologda Oblast and Yaroslavl Oblast is almost 6 times more than in Arkhangelsk Oblast. However, in Arkhangelsk Oblast, the amount of water supply and sewerage facilities is 2.4 times less than in Vologda Oblast and 8.2 times less than in Yaroslavl Oblast.

When assessing the impact of waste on the environment, one should take into account not only the amount of waste by weight, but also the degree of their negative impact (Table 4). Vologda Oblast generates 1 847 958 tons of waste at 156 construction and repair facilities, Arkhangelsk Oblast generates 3 395 764.6 tons of waste at 133 facilities; Yaroslavl Oblast generates 548 591 tons of waste at 271 facilities. Thus, one waste generation facility accounts for 2009 tons in Yaroslavl Oblast, 25.232 tons in Arkhangelsk Oblast. The difference exceeds 12 times, while the volumes and density of construction waste are the same. The results obtained call into question the data given in the territorial schemes.

4 Morphological composition of waste

While planning measures and schemes for the treatment of municipal solid waste it is important to take into account the morphological composition of waste. Data on the composition of waste are relevant when considering the feasibility of introducing and arranging separate waste collection. One needs to know how many and what containers are needed to collect waste. The resource potential of waste is significant for the development of business plans for the construction of waste sorting facilities and waste processing plants [15]. It is especially important to separately treat polymer waste of various groups: polyolefins, polyvinyl chloride, polystyrene, PET bottles, since the technologies for their processing differ and depend on the physicochemical structure of the polymer [2,4]. Comparative analysis of the structure of municipal solid waste in Vologda Oblast and Yaroslavl Oblast is presented in Table 5. The territorial waste management scheme of Arkhangelsk Oblast does not include the component composition of waste.

The authors believe that the territorial scheme of Vologda Oblast should be supplemented by information about hazardous waste (batteries, accumulators, containers from solvents, paints, mercury lamps, etc.), black scrap metal (including cans), non-ferrous scrap metal (including aluminum cans), tetrapak, polyethylene terephthalate (bottles, etc.), polyethylene, polypropylene, polyvinyl chloride, and other plastics. This information will make it possible to assess the raw material potential

Table 6. Comparative analysis of waste accumulation standards in Vologda Oblast.

Object category	Unit of account	Waste accumulation rate according to TWMS data, kg/year	Accumulation normative according to the Order, kg/year
Retail facilities	1 m ²	18	17.8
Preschool education institution	1 item	45	44.22
General educational institution, higher educational institutions, institutions of additional and professional education	1 student	13	12.56
Cultural facilities	1 item	178	
	1 m ² of the total area	4	3.96
Sports facilities	1 item	22.5	22.4
Social protection facilities	1 item (short-period accommodation)	168	
	1 person (long-lasting accommodation)	276	
Public catering enterprise	1 item	134	129.23
Hotels, other temporary accommodation	1 item	168	171.22
Consumer service enterprise: barber shops, beauty salons, baths, saunas	1 item	70	69.99
Cemeteries	1 m ²	0.5	
	1 item	3	2.56
Parks	1 m ²	0.005	
Horticultural, gardening or dacha partnership	1 allotment	38	37.8
Transport infrastructure enterprises (parking spaces; train stations, airports)	1 m ²	125	Car service 286.01 Car station 539.23
Offices, administrative buildings, institutions	1 employee	84	83.61
Apartment residential buildings in Vologda and Cherepovets	1 person	301	338.9
Apartment residential buildings in municipal districts	1 person	168	338.9
Detached houses	1 person	301 (as per calculation 346)	262.43

of valuable secondary material and energy raw materials. It will also help to assess the possibility of developing processing industries on the territory of Vologda Oblast.

5 Comparative analysis of normative standards for waste accumulation

The issues of setting norms for MSW accumulation are now relevant for each territorial subject of the Russian Federation. The authors analyzed the waste accumulation standards in Vologda Oblast based on the data from the territorial scheme. The Order of the Department of the Fuel and Energy Complex and Tariff Regulation of the Region dated December 29, 2016. No. 174 (as amended on November 15, 2017 order No. 279) and dated October 30, 2017 No. 271 (table 6) was also considered [16].

Thus, the waste accumulation standard for Vologda Oblast residents living in apartment buildings in Vologda and Cherepovets, has been increased by 12.5% in comparison with that given in the territorial scheme. For the residents living in apartment buildings in municipal areas it increased by 202%; for the residents living in individual houses decreased by 13%. The

authors explain this situation by incorrect measurements of waste for objects of each category in each season, or the establishment of a standard based on estimated data - an average annual accumulation rate without measurements.

In accordance with the information provided in the territorial schemes and orders on the rates of MSW accumulation, the authors carried out an analysis by subjects: Vologda Oblast, Yaroslavl Oblast, Arkhangelsk Oblast (table 7).

6 Conclusions

Regional territorial schemes for municipal solid waste management should be improved. The results obtained are very relevant for Vologda Oblast, which is in the process of developing and approving a new Territorial Waste Management Scheme.

Therefore, to move to the real development of waste management industry, it is necessary to create waste management schemes that not only describe the current situation in the region but build a reliable and realistic forecast based on big data. The following should be done:

Table 7. Comparative analysis of waste accumulation standards for the Vologda Oblast, Yaroslavl Oblast, and Arkhangelsk Oblast.

Object category	Unit of account	The standard established in the territorial schemes/in the orders on the rates of MSW accumulation, kg/year		
		Vologda Oblast	Yaroslavl Oblast	Arkhangelsk Oblast
Apartment residential buildings, more than 12 ths. people	1 person	301/338.9	263.2/263.2	400.32/277.7
Apartment residential buildings	1 person	168/338.9	263.2/263.2	248.29/180.7
Detached houses	1 person	301/262.43	311.1/311.1	355.49/254.53/216.6 275.9/138.7/93.7*
Offices, administrative buildings, institutions	1 employee	84/83.61	15.48/15.48	36.71/44.7
Retail facilities	1 m ²	18/21.4	from 22 to 303 from 25 to 214.58	24.77/21.4
Preschool education institution	1 item	45/44.25	49.61/49.6	16.49/14.5
General educational institution, higher educational institutions, institutions of additional and professional education	1 student	13/12.56	25.04/25.04 143.36 Orphanage	26.57/9.6
Cultural facilities	1 item	178		
	1 m ² of the total area	4/3.96	3.8 – 48.14 / 3 – 188	3.19/3
Sports facilities	1 item	22.5/22.4	25.39/25.39	12.56/14.7
Social protection facilities	1 item (short-period accommodation)	168	188.05	
	1 person (long-lasting accommodation)	276	141.36	
Public catering enterprise	1 item	134/129.23	205.83/205.83	158.13/192.3
Hotels, other temporary accommodation	1 item	168/171.22	222.87/222.87	159.57/341.7
Consumer service enterprise: barber shops, beauty salons, baths, saunas	1 item	70/69.94	201.02 247.93(baths, saunas)/201.02 247.93(baths, saunas)	100.18/119.2 178/36(baths, saunas)
Cemeteries	1 m ²	0.5		
	1 item	3/2.56	11.31/11.31	6.41/5.2
Parks	1 m ²	0.005		
Horticultural, gardening or dacha partnership	1 allotment	38/37.8	262.79/262.79	77.98/72.5
Transport infrastructure enterprises	1 m ²	125/286.01 (car service) 539.23 (bus station)	260.25 632.52/632.5 (car wash) 1277.1/1277.1 (fuel filling station)	128.21/505.9

1) The range of waste generation sources should be expanded, and the sources of waste generation should be differentiated depending on the number of inhabitants in the settlement;

2) The standards for the accumulation of municipal solid waste should be differentiated according to the "population" category;

3) The standards for the formation of solid municipal waste in the region should be based on the indicators of territorial waste management schemes;

4) The indicators of the territorial scheme must be taken into account when setting the maximum tariffs in the field of solid municipal waste management.

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