

Differences in the generation of industrial waste from economic activities in Ukraine and the EU and the prospects for the integrated use of mineral raw materials

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Abstract. The paper presents the comparative analysis of the amount of waste generated in Ukraine and European countries (except for radioactive waste) based on the official EU and Ukrainian statistical data. The data on waste generation are compiled according to the following classification: by economic activity and household, waste category, grades of hazard, and regions. In Ukraine, 352.3 million tons of waste was generated in 2018. By 2018, almost 13 billion tons of waste had been accumulated at the managed dumpsites, including about 12 million tons of hazardous and over 200 million tons of household waste. In the European Union, 2.6 billion tons of waste was generated in 2018. Over 70% of it was generated by 10 countries: Germany, France, England, Poland, Romania, Italy, Sweden, the Netherlands, Spain and Finland. By economic activity, the largest amounts of waste in Ukraine are generated by the mineral extraction and processing industry, the smallest – from water treatment and construction. In the EU countries, these values are somewhat different. For example, in Germany and France, the largest amounts of waste are generated from construction and manufacturing, the smallest – from agriculture, forestry and fishery. By waste category, the waste generated both in the EU countries and in Ukraine is mineral and solid waste. In Ukraine, the largest amounts of waste are produced and accumulated in the Dnipropetrovsk, Donetsk and Zaporizhzhia regions which accommodate large enterprises for extraction and mineral processing of iron and manganese ores, titanium-zirconium placers, coal, dolomite, and metallurgical limestone, as well as metallurgical and ferroalloy plants.

1 Introduction

Rapid global economic growth at the end of the last millennium led to excessive use of non-renewable natural resources and increase of human impact on the environment. The amount of generated waste became one of the challenges facing humanity in the nearest future.

In accordance with the national waste management programmes, the European Union and Ukraine make inventories of the waste generated both by economic sectors and households. The waste inventories reflect the socio-economic differences and different approaches to treatment and identification of waste types. The list of waste used in Ukraine does not fully correspond to that in EU. In 2014–2017, Ukraine took initial important steps to change the situation through commitment of compliance with the EU Directives as a part of the Association Agreement with the EU and adopting the National Waste Management Strategy until 2030.

Waste statistics play an important role in understanding and monitoring respective changes in the production/consumption processes towards more sustainable solutions.

The data used in the article were taken from the Eurostat and Ukrstat databases for 2018.

The amount of waste generation in different countries varies depending on the economic activity and society's production and consumption patterns. The largest amount of waste is generated in countries with developed mining and metallurgical industries. At the same time some countries with high level of household consumption demonstrate significant generation of household and construction/deconstruction waste. Although the three biggest economies – Germany, the United Kingdom and France – have the highest generation of waste in absolute figures, no direct link between economic production and waste generation is observed for all EU countries. For example, in smaller economies like Bulgarian and Romanian, the waste generation in mining and metallurgical industries is amongst the highest.

Limited natural resources, environmental impact of rapidly growing amounts of waste require urgent measures aimed at waste reduction.

Waste management is a key environmental concern both in Europe and Ukraine. The situation in Ukraine has already proven to be critical in many cities and regions due to a lack of proper waste management infrastructure

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and adequate government policy, business approach and public response.

2 Results and discussion

According to the State Statistics Service of Ukraine (Ukrstat), over 300 million tons of waste have been generated annually from 2014 to 2018, including 0.6 - 0.7

million tons of hazardous waste and over 10-11 million tons of household waste. By 2018, almost 13 billion tons of waste have been accumulated at the managed dump-sites in Ukraine, including about 12 million tons of hazardous and over 200 million tons of household waste (the data for the temporarily occupied Crimea and some territories of Donetsk and Luhansk regions are not included) (Table 1) [1].

Table 1. Waste generation and accumulation at the managed dump-sites in Ukraine, mln. tons.

Year	Total waste generation	Hazardous waste	Household waste	Total waste accumulation at managed dump-sites	Hazardous waste	Household waste
2014	354.803	0.7	10.748	12115.241	11.951	166.112
2015	312.267	0.6	11.492	12281.353	11.996	170.306
2016	295.870	0.6	11.563	12451.659	12.102	174.514
2017	366.054	0.605	11.271	12442.169	12.198	201.145
2018	352.334	0.627	10.000	12972.428	12.217	227.435

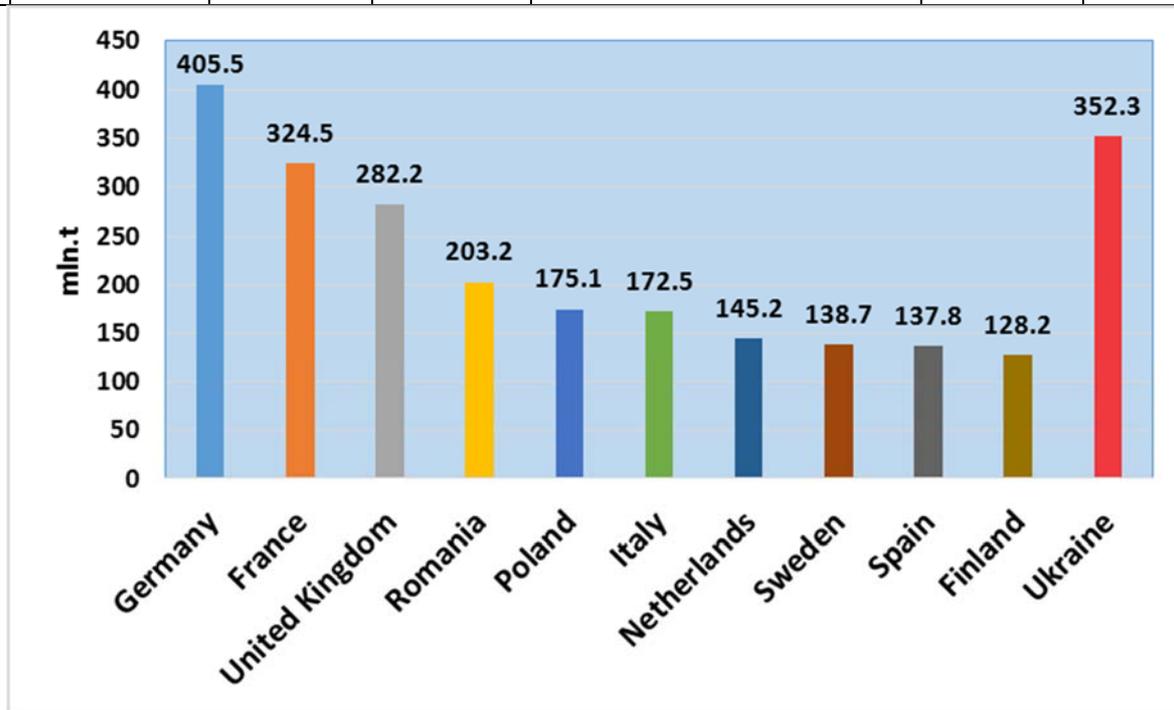


Fig. 1. Waste generated by some EU countries and Ukraine.

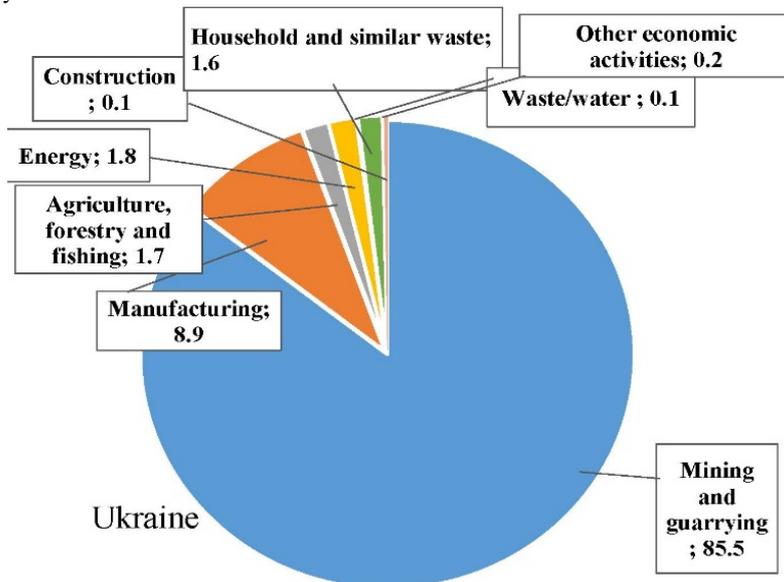


Fig. 2. Waste generation by activity in Ukraine, mln. tons.

According to Eurostat data, 2.6 billion tons of waste was generated in the EU (EC-28) in 2018 (Fig. 1). More than 70% of it was generated by 10 countries: Germany, France, United Kingdom, Romania, Poland, Italy, the Netherlands, Sweden, Spain, and Finland [2].

As can be seen in the chart, the amount of waste generated by some European countries in 2018 in million tons was as follows: Germany - over 400, France - over 300, UK – about 280, Romania - about 200, Poland and Italy - more than 170, Netherlands, Spain and Sweden - about 140, Finland - more than 120. In Ukraine, the amount of waste generated was over 350, which is less than in Germany and more than in France and the United Kingdom.

According to Eurostat data, in 2018 the following amounts of waste (mln. tons) were generated by each of the following European countries: Turkey – 90, Greece, Belgium, Austria and Serbia – from 40 to 70, Czechia, Estonia and Denmark - over 20, Hungary, Ireland, Portugal – from 14 to 18, Luxembourg, Slovakia, Norway – from 12 to 14. From 1 to 6 million tons were generated by other EU countries.

The State Statistics Service of Ukraine keeps records of waste generation and accumulation at the managed dump-sites in accordance with the National Waste Classifier. Waste is classified according to different parameters (by economic activity, waste categories, hazard classes, required disposal operations, and households). The same inventory strategy is used in the European Union.

Based on the State Statistics Service data [3], the chart in Fig. 2 presents waste generation by economic activity in Ukraine.

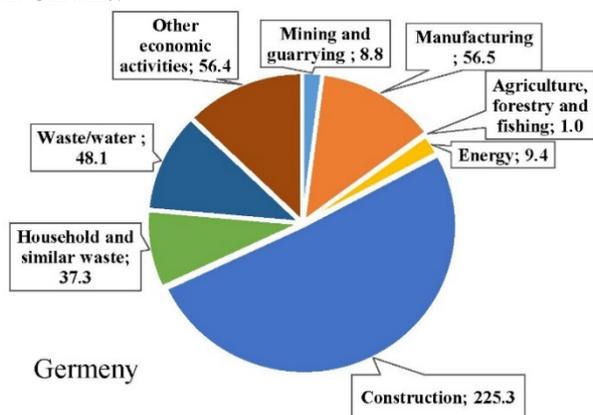


Fig. 3. Waste generation by economic activity in Germany, mln. tons.

The largest volumes of waste in Ukraine (million tons) are generated by quarrying and mining – 301.4 (74.3%), and manufacturing – 31.5 (17.5%), the later includes metallurgical and chemical enterprises, food industry etc. Household waste amounts to 5.5 million tons (1.1%). For comparison, in Germany and France, the largest volumes of waste are generated by construction industry – 225.3 million tons (55.6%) and 240.2 million tons (70.2%), and the manufacturing industry – 56.5 million tons (13.9%) and 22.4 million tons (6.6%) respectively. The household garbage volume is 37.3 million tons (9.2%) in Germany and 29.7 million tons (8.7%) in France (Figs. 3, 4) [2].

According to the State Statistics Service of Ukraine [1], the main sources of waste generation and accumulation in Ukraine are the following economic sectors (Table 2). Thus, the largest amount of waste in Ukraine is generated by quarrying and mining operations – over 300 million tons. It makes on average 74.3% of the total waste. At that, 80% is the waste from metal ore extraction (iron, manganese, titanium-zirconium). According to the National Waste Classifier, metal ore mining and quarrying waste in Ukraine include slurry and tailings, waste from pellets and flux production (dust, powder, etc.), red mug from alumina production, and non-ferrous metal ore processing waste.

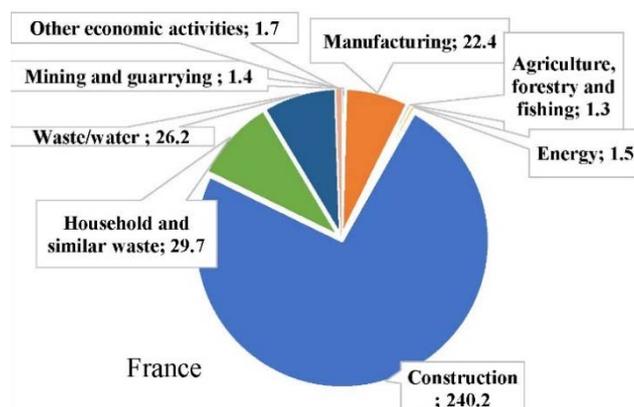


Fig. 4. Waste generation by economic activity in Germany, mln. tons.

Table 2. Dynamics of waste generation by economic activity in Ukraine, mln. tons.

<i>Economy sectors</i>	2014	2015	2016	2017	2018
Total	355.00	312.27	295.87	366.05	352.33
Type of economic activity	348.69	306.21	289.52	360.20	346.79
Agriculture, hunting, and provision of related services	8.4	8.7	8.7	6.2	6.0
Mining (Total)	297.2	252.1	237.3	313.6	301.3
Mining of metal ores	281.5	238.1	222.5	293.7	282.5
Mining of hard coal, lignin and peat	13.0	12.1	10.5	12.9	10.8
Mining of other ores	2.7	1.9	4.3	7.0	8.0
Manufacturing industry (Total)	29.50	25.60	28.20	29.60	28.80
Iron and steel production	23.4	20.7	22.3	22.0	21.8
Chemical industry	1.1	0.7	0.8	1.2	1.2
Food industry	5.8	5.1	5.7	6.8	6.2
Other branches of mining industry	4.5	4.5	5.3	2.2	2.3
Production and distribution of energy, gas and steam, and air conditioning	6.0	6.6	7.5	6.2	6.3
Other types of economic activities	5.0	2.2	1.8	2.0	1.6
Households	6.3	6.0	6.3	5.9	5.5

The group of waste from hard coal, lignin and peat mining includes substandard coal, slurry and tailings from

concentrating mills. Other group of waste generated by Ukrainian enterprises comprises waste from mining of granite, limestone, chalk, dolomite, refractory clay, building stone and others.

On average, the manufacturing industry generates 17.5% of waste, over 69.2% of which come from the

metallurgical industry (blast-furnace, steelmaking and ferroalloy slags and slurries, etc.).

The structure of metal-containing waste generated by the mining and metallurgical industries and accumulated at the managed dump-sites is shown in Fig. 5 and 6 [4, 5].

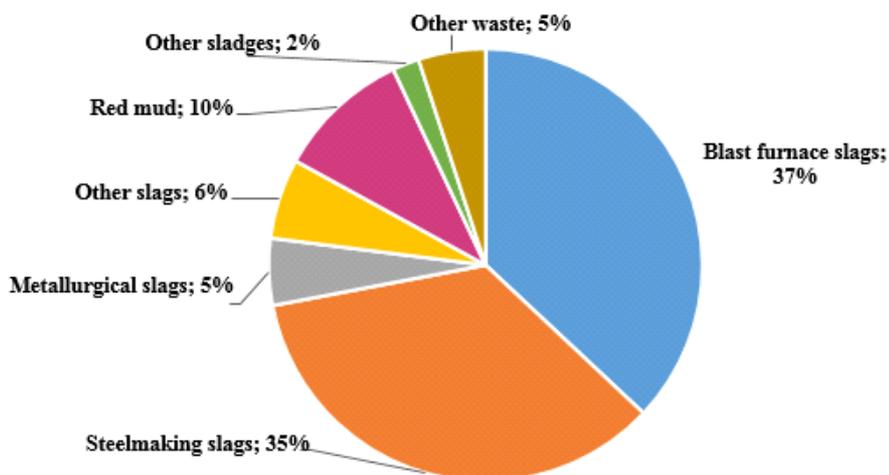


Fig. 5. Structure of waste generated from major metals production, %.

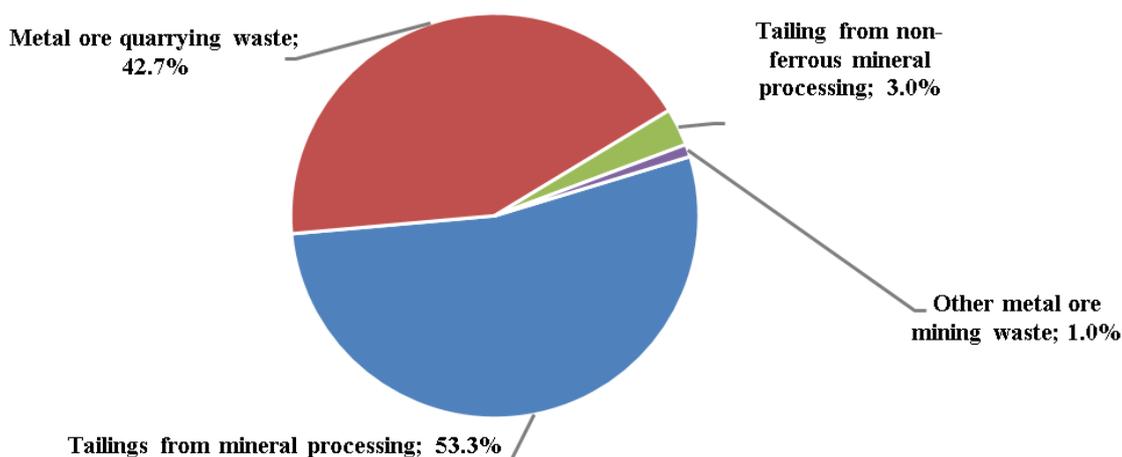


Fig. 6. Waste generated by metal ore quarrying and mining, %.



Fig. 7. Waste from iron ore quarrying.

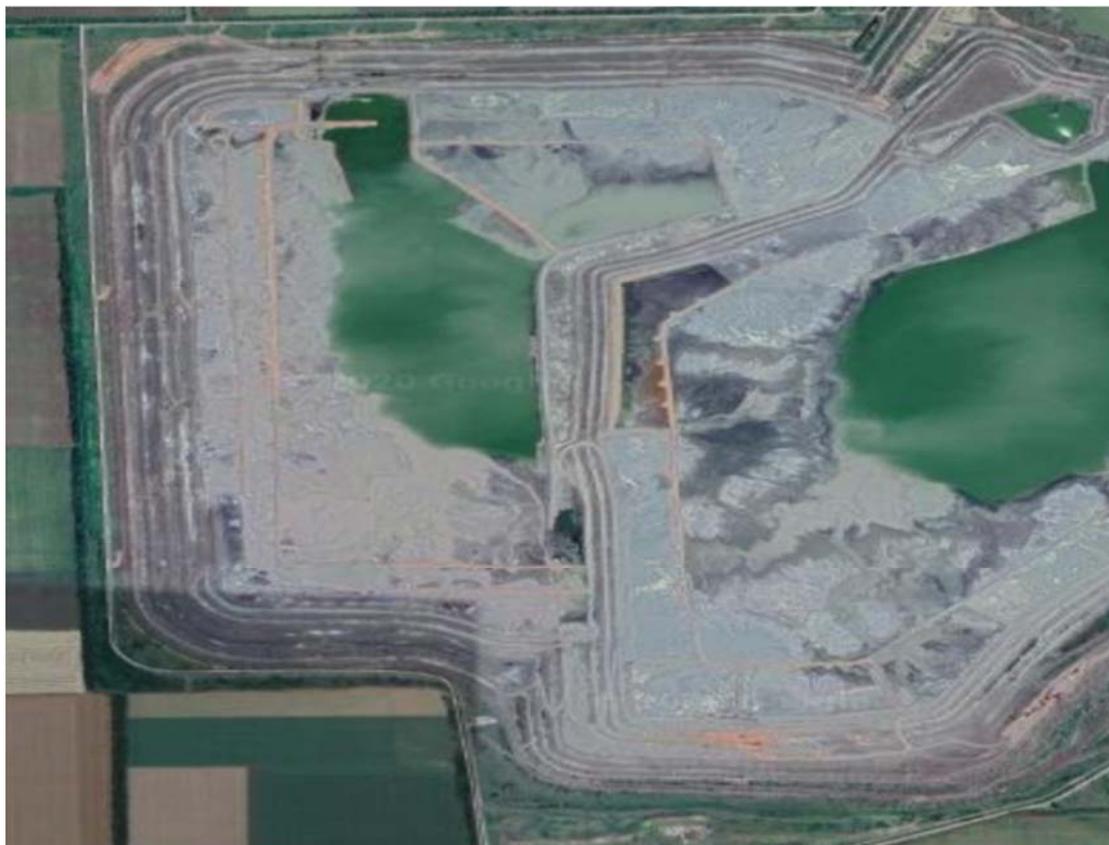


Fig. 8. Managed dump-sites with iron tailings.



Fig. 9. Waste from mineral processing of Irshansk Mining and Processing Plant.

The predominant part of the waste (78%) from major metals production is metallurgical and ferroalloy slags. Metallurgical sludge is the dust captured by air purifying equipment using liquid filters. It is stored in sludge collectors. After settling, the water is discharged into the surface water bodies, while the solids, if not reused, are accumulated at the managed dump-sites. Red mugs are generated at two enterprises – Mykolaiv alumina refinery and Zaporizhzhia alumina processing plants which produce alumina from bauxite. As can be seen from the chart (Fig. 6), the red mug makes 10% of the total waste from the major metal production.

One of the ways to reduce the amount of waste at the stage of extraction and processing of the metal ores in Ukraine is the integrated use of the mineral resources and the utilization of enrichment waste.

The chart shows that 96% of the waste generated by quarrying and mining is the metal ore waste and tailings from mineral processing (Fig. 7, 8).

The annual generation of iron tailings is over 130 mln. tons. Recycling of the tailings through ferrous concentrate and construction sand production will allow to decrease considerably the amount of the stored waste.

The problem of metal ore quarrying and mining in Ukraine is that host rock is not used. For example, in case of selective extraction and separate storage, talcum, garnet, muscovite and quartz concentrates can be produced from talc-, garnet- and muscovite-shales, respectively. Clays can be used for production of expanded clay and ceramics. The host rock can also be used for production of building sand and natural pigments (ferrous oxide, ocher, seladonite etc.). Mineralogy and chemical composition of some host rocks have been studied and described in detail in [7-12, 14, 15].

Clay, sands and limestone-shells from the overburden can be attributed to the resource potential of the manganese ore production waste in Ukraine, which can be selectively extracted and subsequently used in the national economy. In addition, more than 400 million tons of manganese-containing sludge have been accumulated in sludge storage facilities, with a mass fraction of Mn 10.5 - 17.5%. By sludge processing applying different schemes, it is possible to obtain manganese concentrate with a mass fraction of Mn from 35-41% (high-gradient magnetic separation with flotation) to 50% (magnetic-chemical technology) with an extraction of Mn 65-68% and 64%, respectively.

The enrichment waste prevails in the total amount of wastes from extraction and enrichment of heavy mineral

titanium-zirconium sands. The overburden from the development of titanium-zirconium placer deposits in Ukraine (clay, loam, sand) is acceptable to be used for reclamation works.

Ore minerals in the technogenic sands of the Malyshevskiy deposit (the Volnogorsk MMC) are represented by zircon, rutile, leucoxen and ilmenite. Mostly they are concentrated in the fraction – 0.16 + 0.06 mm. Disten, sillimanite, staurolite and tourmaline have relatively significant contents.

Studies of the material composition of the waste from the Irshansk group of deposits have revealed that 60 wt.% of sands are represented by 0.5-0.125 mm grains; 5-15 wt.% is the metallic fraction, 85-95 wt.% – the non-metallic one. The ore minerals are mainly ilmenite, rutile, ilmenorutil and zircon. The presence of zircon as the main mineral carrier of zirconium is confirmed by the mass fraction of the latter in the waste (0.05 - 0.5 wt.%). We consider that these technogenic sands can be used to produce titanium and zirconium as well as quartz sand (Fig. 9).

Eurostat and the State Statistics Committee of Ukraine keep records of waste generation by material as well. Subdivision of wastes by material based on EU and Ukrainian data (2016) is presented in Table 3 [2, 3].

Table 3. Waste generation by waste category in Ukraine and EU countries.

Country	Total volume in a country, mln. tons	%	Mineral and solid waste, mln. tons	%	Chemical and medical waste, mln. tons	%	Animal and plant waste, mln. tons	%	Sludges, mln. tons	%	Reprocessing of waste, mln. tons	%	Equipment, mln. tons	%
Total EU, million tonnes	2454.72	100.0	1796.6	73.19	54.15	2.21	95.28	3.88	20.71	0.84	246.13	10.03	17.83	0.73
Germany	400.07	16.30	261.39	65.33	8.92	2.23	15.62	3.91	1.49	0.37	39.38	9.84	2.43	0.61
France	323.47	13.18	261.76	80.92	4.96	1.53	11.81	3.65	1.21	0.37	34.90	10.79	2.44	0.75
England	277.26	11.29	141.64	51.09	4.80	1.73	10.29	3.71	4.17	1.50	43.11	15.55	3.80	1.37
Poland	182.01	7.41	122.71	67.42	2.99	1.64	3.19	1.75	0.66	0.36	13.56	7.45	0.70	0.39
Romania	177.56	7.23	163.36	92.00	0.95	0.54	0.86	0.49	0.20	0.11	5.82	3.28	0.13	0.08
Italy	164.00	6.68	65.46	39.91	14.29	8.71	7.85	4.79	6.08	3.70	28.10	17.14	3.03	1.85
Sweden	141.62	5.77	101.83	71.90	1.29	0.91	2.38	1.68	0.40	0.28	6.31	4.45	0.85	0.60
Netherlands	141.02	5.75	104.04	73.77	2.40	1.70	15.20	10.78	0.66	0.47	8.39	5.95	0.54	0.39
Spain	128.96	5.25	67.03	51.98	2.66	2.06	9.14	7.08	1.46	1.13	12.56	9.74	1.21	0.93
Amount	1935.97	78.87	1289.21		43.26		76.35		16.32		192.14		15.13	
Other countries	518.75	21.13	507.39	26.81	10.89	97.79	18.93	96.12	4.39	99.16	53.99	89.97	2.70	99.27
Ukraine	295.87		226.20	76.4	1.44	0.49	13.89	4.69	3.90	1.32	

As indicated in table 3, over 2 billion tons of waste is generated annually in EU countries. The total volume of waste generated in all 28 EU countries in 2018 was 2.6 billion tons. Mineral and solid waste constitutes the largest part of the total waste generated in all countries – from 39.9% in Italy to 80.9% in France. In Ukraine, they constitute 76.4% of the total waste generated.

In the EU countries, various amounts of waste are generated from waste recycling – from 6% in Netherlands to 16% in the United Kingdom. In Ukraine, the amount of waste from waste recycling is only 0.07%.

Fig. 10 shows waste accumulation at managed dump-sites in different regions in Ukraine [3].

The chart shows the amount of waste accumulated at managed dump-sites in different regions in Ukraine. Based on this amount the regions were divided into 3 groups. The first includes areas accommodating hundreds of millions of tons of waste. The second – tens of millions of tons. The third – less than 10 million tons.

Having the well-developed industry Dnipropetrovsk region accommodates the largest volumes of waste. The plants extract and enrich iron, manganese, titanium-

zirconium ores and coal. There are also metallurgical and ferroalloy plants.

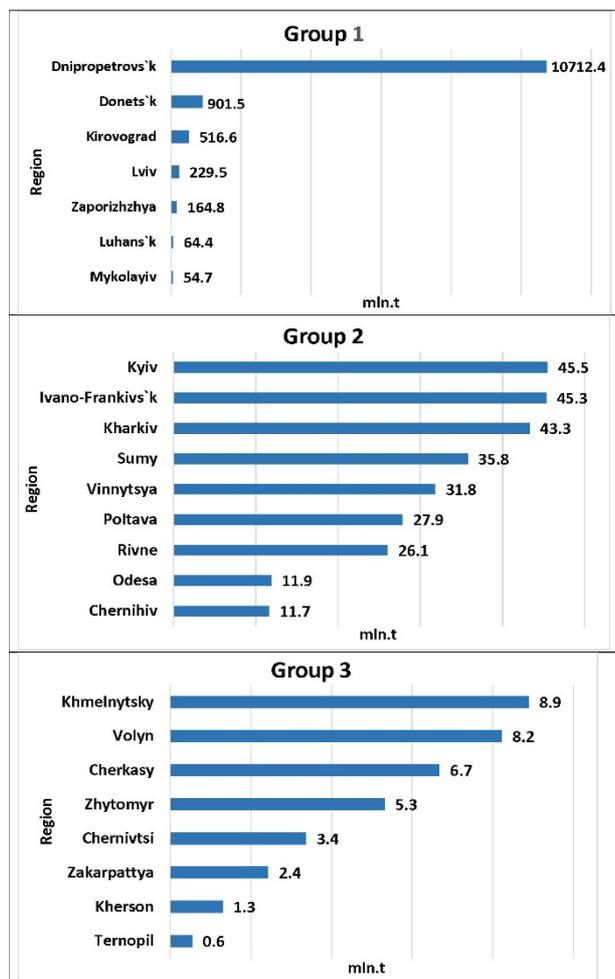


Fig. 10. Waste accumulation in different regions in Ukraine.

As can be seen from the chart, Dnipropetrovsk region accumulated 10 billion tons of waste at the disposal sites.

According to our estimates. More than 90% of it is waste from extraction and processing of iron and manganese ores (Kryvbas mining and processing integrated plant, Nikopol manganese ore field and metallurgical plants).

In Donetsk region, at the territory controlled by the Ukraine authorities most of the waste is accumulated at the coal mining and enrichment plants, coke plants and metallurgical plants. Dokuchaiv flux-dolomite plant which accumulated huge amounts of waste by 2013 is located at the temporarily occupied territories and the data are not available.

In Kirovohrad region, 99.9% of waste is accumulated at three enterprises: Petrivskiy quarry of the Central mining and processing complex, gulch "Shcherbakivska" and mine "Inhul'ska" of the Eastern mining and processing plant. Petrivskiy quarry's disposal sites accommodate almost 80% of the waste accumulated in Kirovohrad region.

In Lviv region over 96% of waste is accumulated at four enterprises: JSC "Lviv Coal Company". 6 mines of

SE "Lvivvuhillia". Novoiavorivske SE "Ekotransenergo" and Dobrotvir'ska TPP.

In Zaporizhzhia region almost 90% of waste was accumulated at 5 enterprises. i.e. JSC "Zaporizhstal" (metallurgical (iron) slag and sludge), Zaporizhzhia TPP (coal ash), LLC "Remondis Zaporizhzhia" (household waste), JSC "Zaporizhzhia Ferroalloy Plant" (ferroalloy slag and dust from gas purification plants) and JSC "Zaporizhzhia Aluminum Production Plant" (over 10 million tons of red sludge).

In Luhansk region, at the territory controlled by the Ukrainian authorities there are coal enterprises which generate coal mining and enrichment waste.

The second group comprises the Ukrainian regions which accommodate the most powerful TPPs (Trypilska, Zmiivska, Ladyzhyn'ska and Burshtyn'ska). These TPPs produce 60-70% of the total waste generated in a region.

The third group includes regions in which 70-99% of the total waste is municipal waste.

It should be noted that the volume of accumulated waste in Ukraine is much higher than the mentioned above. This is because the State Statistics Service receives information only from operating enterprises. Large volumes of waste are stored at enterprises abandoned after disintegration of the Soviet Union.

According to the Ministry of Energy and Environmental Protection data, 35 billion tons of waste have been accumulated in the country. 14 of the largest waste generators are located in Dnipropetrovsk region, 9 - in Donetsk, 3 - in Poltava, 2 in Kirovohrad and Zaporizhzhia and 1 in Ivano-Frankivsk, Mykolaiv, Ternopil and Lviv regions.

6 out of 35 largest waste generators are Kryvbas mining and processing enterprises which exploit iron ore deposits (Table 4) [6].

Table 4. Largest waste generators and polluters of the environment in Ukraine.

№	Company name	Generated waste. mln. tons
1.	Northern Mining and Processing Plant	81.34
2.	Inhulets Mining and Processing Plant	63.48
3.	Central Mining and Processing Plant	61.56
4.	ArcelorMittal Kryvvi Rih	27.65
5.	Southern Mining and Processing Plant	26.92
6.	Yerystivskiy Mining and Processing Plant	14.95
7.	Novotroitske Ore Mining Company	6.74
8.	Ilyich Iron and Steel Works	6.23
9.	"Ukrmechanobr" Ore Mining and Processing Integrated Plant	3.86
10.	Pokrovskiy Mining and Processing Plant	3.26
11.	Total	295.99

The enterprises listed in the table except for PJSC "Ilyich Iron and Steel Works" are the mining and processing plants that predominantly accumulate overburden iron and manganese ore enrichment waste.

In Ukraine, 14 mln. tons of iron ore waste from mining and processing plants are dumped on over 7 thousand hectares. The article [13] presents a list of alternative

minerals which can be extracted from Kryvbas iron ore deposits. Technologic solutions for waste management and mineral extraction from tailings and host rock are described in the papers [16-18]. Enrichment technologies have been developed under laboratory conditions.

The problem of complex use of the deposits in order to reduce technogenic impact is predominantly the economic and political one. Extraction of iron ore concentrate from the enrichment waste at the Central mining and processing complex (Kryvyi Rih) has shown that its cost is 40% lower than the concentrate extracted from the quarried ore; its quality is only slightly lower.

We believe that it is possible to reduce the technogenic impact on the environment by recycling of tailings and more comprehensive and effective use of mineral deposits.

3 Conclusions

Analysis of industrial waste showed that the amount of its generation in Ukraine correspond to that in France, Poland and Romania (300-400 million tons per year). In Ukraine the largest amounts of waste are generated from the quarrying and mining (74.3%), and manufacturing (13.2%) industries. In Germany and France, for example, the largest amount of waste is generated from construction (55.6% and 70.2%, respectively), manufacturing (13.9% and 6.6%, respectively) and waste/water (11.9% and 6.8%, respectively).

The impact of industrial waste from mining and mineral processing on the environment can be reduced by application of innovative technologies in ore extraction and enrichment and in metallurgical industry. It will increase the degree of extraction of useful components from the mineral resources and improve the monitoring of waste disposal sites. Solution of the above problems depends on the legislation and the willingness of business to invest in diversification of production.

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