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INDUSTRIAL WASTE MANAGEMENT ON EXAMPLE OF UKRAINE IN THE LIGHT OF ACHIEVING SUSTAINABLE DEVELOPMENT GOALS

This study object is industrial waste issue on the example of Ukraine: accumulation level, structure and its treatment possible ways. An analysis of waste sources available statistics on and their quantity was conducted. It is considered industrial wastes main component composition and corresponding types processing directions in Ukraine and abroad are analyzed.

It is established the industrial waste accumulation level trends in Ukraine to increase year by year, and it's comparison with Gross Domestic Product shows an raw materials increase in the economy. Minor Downward Trends (2008–2009 and 2014–2016) illustrate decline in the industrial production during respective period. The largest industrial wastes producers are mining and processing industries. Six categories of industrial waste were identified, accounting for 4/5 of their total amount. These are sludge, «tails» and other iron ore wastes, iron ore mining wastes, limestone mining residues and waste from mining operations.

Only iron ore tails enrichment technologies have been implemented at a sufficient level in Ukraine at present, but their processing level in terms of resource and energy savings is insufficient. The large relevant technologies have been introduced outside Ukraine and the most effective are includes maximum processing stages depth and included to technological production cycles.

Based on this study results it is notes the best and most effective in the realities of Ukraine areas of waste management towards the implementation of 17 sustainable development goals are multi-component processing of six main categories of waste from the mining and processing industries. This approach avoids legal conflicts and has the highest environmental and economic effect.

Keywords: *sustainability, industrial waste management, environmental impact, resource efficient technologies, energy efficient technologies.*

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1. Introduction

At the beginning of the 21st century, the development of industry around the world has reached significant proportions. However, manufacturing intensification, in addition to production increasing, volumes of trade and, consequently, economic growth, has another side. All commodity production, including mining and processing industries, are based on natural resources operation, which in addition to the production of marketable products, includes such additional components as consumption of raw materials and energy also a waste production. Despite of modern technologies, most industries remains an inefficient, and further economic development intensification especially among developing countries inevitably leads to more raw material and energy resources exploitation and increases pollutant emissions and more waste production.

For the first time, on December 18, 1962, the United Nations General Assembly adopted Resolution 1831 (XVII) «Economic Development and Nature Conservation» [1]. The document notes the environmental measures are should be taken in advance or at least simultaneously with economic development based on national legislation and international law. Those resolution provides largely coincides with the current concept of «sustainable development», but only in September 2015, at the 70th session of the UN General Assembly, 17 Sustainable Development Goals were approved [1].

Let's consider this question on the example of Ukraine. The last, as a United Nations global partner and a country with great industrial potential, has committed itself to implementing strategy and 17 goals of sustainable development achieving. Long period of intensive development within the Soviet Union «planning economy», as well as economic difficulties in restorating and industry rebuilding after independence are objective factors creating specific conditions for quality reorganization in industry and bringing it in to the line with international standards.

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A number of economically developed countries have already undertaken on the path of sustainable development, moving their own industrial waste management strategies. Thus, the modern European «integrated» waste recycling approach is based on United Nations Environmental Programme (UNEP) defined «integrated waste management» as a «framework of reference for designing and implementing new waste management systems and for analysing and optimising existing systems» [2]. Integrated waste management means minimal use of energy and raw materials from the «environment» in the system, with parallel reduction of emissions and solid wastes. American «regulatory» approach to waste management [3] is based on the development of detailed instructions and state processes regulation. In contrast, the Japanese approach is based on «common performance standards» that have no clear formal boundaries [3]. The latter is considered more efficient, primarily due to the greater export-oriented Japanese economy, in contrast to the US economy. In addition European Union (EU) countries experience called «industrial symbiosis» is interesting for Ukraine [4]. Latter is appeared as a self-organizing business strategy among companies willing to work together for improving their economic and environmental performance. Such cooperation strategies adoption are associated with increased waste management costs, most of which are driven by policy and legal requirements.

Global strategies and approaches for industrial waste management analysis in different countries and even on different continents shows a single right solution lack. Even one of the most ecologically oriented strategies (EU countries) has its drawbacks. Thus, a detailed sustainable development reporting analysis of a number European companies [5] revealed a number of drawbacks. Study shows the last ones although containing detailed information on a wide range of environmental, social and economic issues, generally had inconsistencies calling into question their transparency and undermining their credibility.

Thus, *study object* is industrial waste issue on the example of Ukraine: accumulation level, structure and it's treatment possible ways. This *work aims* current state of waste management in Ukraine analysis and solving of possible environmentally and economically associated tasks connected with their recycling to achieve sustainable development goals.

2. Methods of research

This study is based on the analysis of statistical data presented on the State Statistics Service of Ukraine website [6]. For data processing were used «Statistica» program and Office 365, in particular Excel to create graphs and charts.

Modern methods of industrial waste processing both in Ukraine and abroad are given on the relevant literature data basis.

3. Results of research and discussion

Seventeen goals of sustainable development are clearly divided into three main blocks: social, economic and block dedicated to environmental conservation. All three blocks are closely connected each with other but there are four basic goals without which further development is simply impossible. There are environmental or «ecological» goals:

– goal 14 – conserve and sustainably use the oceans, seas and marine resources for sustainable development;
– goal 15 – protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss;
– goal 6 – ensure availability and sustainable management of water and sanitation for all;
– goal 13 – take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.

Conducted analysis of statistical data [6] results shows that the largest issues are the rational use of natural resources, energy and environmental protection.

Thus, the amount of accumulated industrial waste analysis showed (Table 1) no clear trend to reduce the amount of industrial waste in recent years (data presented only since 2017) and 2019 is a record year for their accumulation. Total accumulated waste amount is increasing, and amount of disposed waste (including incinerated and disposed of in specially designated areas) is decreasing.

Waste structure analysis (Fig. 1) shows them related to two main categories:

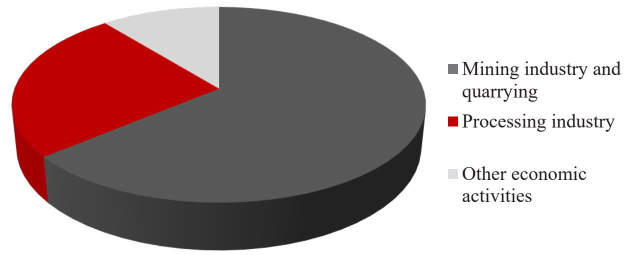
1) mining waste and quarrying;
2) waste from the processing industry. Total fraction of them was at 89.1 % in 2002 and 96.7 % in 2019. Based on earliest available data (2002) comparing with the latest ones (2019), let's observe a significant increase in the mining industry waste fractions (63.9 % in 2002 compared to 89.7 % in 2019) compared to processing industry waste (25.3 % in 2002 compared to 7.06 % in 2019).

Waste accumulation dynamics analysis by years (Fig. 2) is a confirmation that their number is increasing (from 130080.0 thousand tons in 2002 to 390563.8 thousand tons in 2019). Slight downward trends in 2008–2009 and 2014–2016 illustrate the decline in industrial production associated with the effects of the global economic crisis (2008–2009) and military action in eastern Ukraine (2014–2016). At the same time, it is worth to notes some trend in a processing industry waste accumulation reduction from 51408.6 thousand tons in 2002 to 30751.8 thousand tons in 2019.

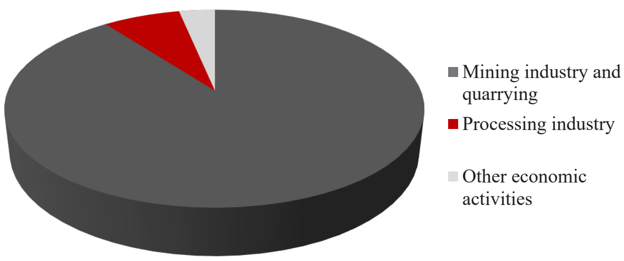
Table 1

Total amount of waste in Ukraine: generated, disposed of, in particular incinerated and disposed of in specially designated places in Ukraine (thousands of tons)

Period	Total amount of waste	Total disposed of waste	Incinerated waste	Disposed of in specially designated places	Total amount of waste , accumulated in specially designated areas
2017	366054	100056.3	1064.3	169801.6	12442168.6
Including wastes of I–III hazard classes	605.3	305.5	8.7	107.1	12197.6
2018	352333.9	103658.1	1028.6	169523.8	12972428.5
Including wastes of I–III hazard classes	627.4	276.5	11.9	114.9	12217.2
2019	441516.5	108024.1	1059.0	238997.2	15398649.4
Including wastes of I–III hazard classes	553.0	252.1	10.6	93.3	12305.1



a



b

Fig. 1. Waste generation by types of economic activity: *a* – 2002; *b* – 2019

Analysis of waste generation per unit of GDP at constant prices of 2011 at purchasing power parity (Fig. 3) amount shows an increase in raw material production in Ukraine. However, value added decreases, which affects on GDP and evidences of extracted raw materials processing level decrease. In other words, a part of Ukraine's raw materials production increases, which indicates an increase in raw materials part in the economy.

In Table 2 are shown waste categories which parts in total amount were highest than 1 %. Thus, as of 2017–2019, the main category was iron ore quarry waste. Total parts of it are 55.03, 57.09 and 61.3 % of whole waste amount per regarding years. At the second place are sludge and «tails» of iron ore beneficiation accumulations. Totally six categories of waste presented in Table 2 compile from 80.8 % (2018) to 83.38 % (2019) its whole amount produced per year.

As a fact, based on the analysis results, the most priority tasks becomes obviously which achievement will give the most significant results, is recycling of existing and reducing future trends in new industrial waste accumulation. In particular, the categories are presented in Table 2. This issue solution in Ukraine includes three components: legal, economic and environmental.

Issues of the legal plane lies in the state bodies' competence, or conditionally speaking «State competence». According to Subsoil Code of Ukraine [7] Article 5 (State Fund of Subsoil and State Fund of Mineral Deposits), places of waste from extraction, enrichment and mineral raw materials processing, reserves of which are estimated and industrial importance are known deposited regards as man-made mineral deposits. Such man-made mineral «deposits» which are estimated and have industrial importance estimated is a State Fund of Mineral Deposits which is a part of the State Subsoil Fund.

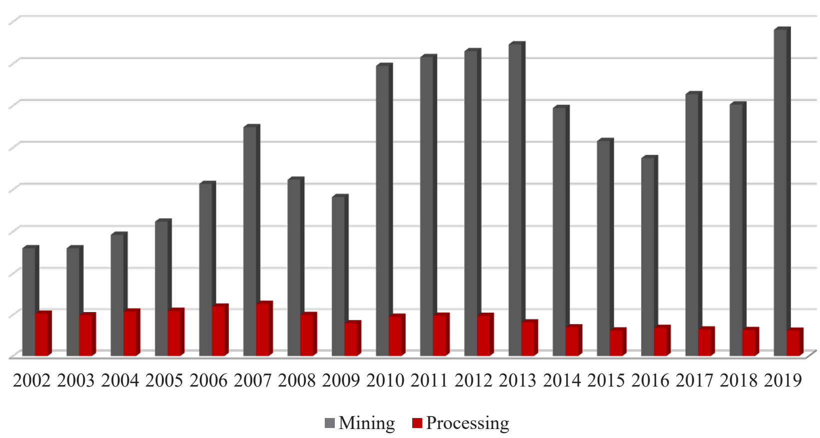


Fig. 2. Waste production dynamic in mining and processing fields

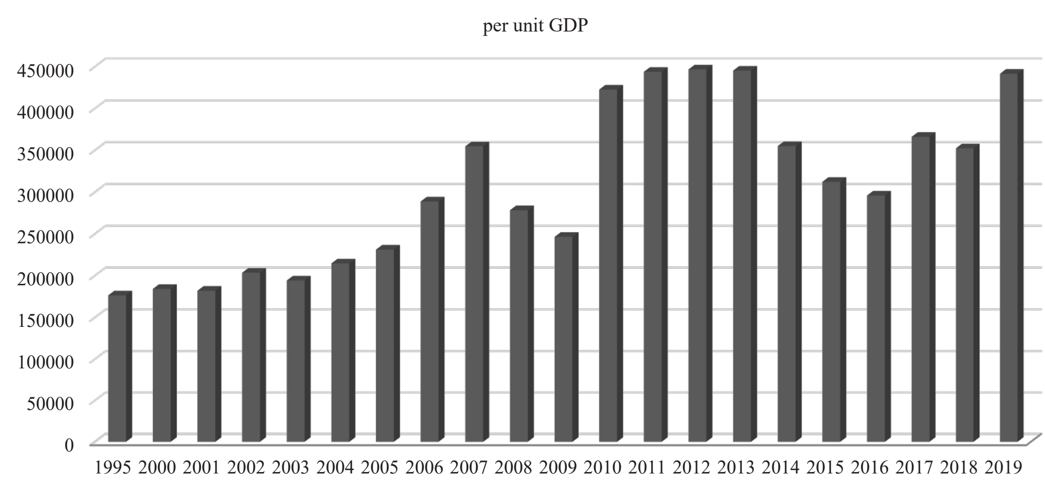


Fig. 3. Waste production amount per GDP at constant prices of 2011 at purchasing power parity

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Table 2

Main categories produced waste amount according to classification (in % of solid waste total amount per regarding year)

Number deification	Waste categories	2017	2018	2019
1010.2.9.03	Wastes from coal enrichment of concentrators and briquettes factories	2.29 %	–	–
1310.2.3.01	Sludge and «tails» of iron ore enrichment	14.56 %	15.3 %	13.3 %
1310.2.3.01	Iron ore quarry waste	55.03 %	57.9 %	61.3 %
1310.3.1.10	Iron ore waste other	1.01 %	1.02 %	0.98 %
1412.2.9.01	Remains (dust, crumbs, debris) of limestone mining in quarries	1.05 %	2.12 %	1.3 %
1450.2.9.32	Wastes (rocks, earth) generated during mining operations in the process of creating mines (quarries) and quarries	8.75 %	4.46 %	6.5 %
–	Total	82.7 %	80.8 %	83.3 %

Thus, at the firs needs to regulate relations in the areas of the state control over using and protection of subsoil, formation and using of man-made deposits and processing of mineral resources.

According to Article 40 [7], explored mineral deposits, including man-made, or their areas, mineral reserves of which are estimated, includes in the State Fund of Mineral Deposits and transfer to industrial development in prescribed by the Cabinet of Ministers of Ukraine manner. The state registration of deposits, reserves and manifestations of minerals procedure was approved by the Cabinet of Ministers of Ukraine of January 31, 1995 No. 75. Accounting data are presented in the state cadastre [8]. Procedure in a practice is difficult and bureaucracy. Three interrelated aspects significantly complicating it are the lack of «industrial waste» clear definition. Like household waste, the latter belongs to solid waste. A clear line between «industrial waste» and «household waste» in Ukraine are not finalized. In particular, this flows into another plane – an industrial waste is not the same type, but often, on the facilities of production, different types of waste are mixed each with other. For exemplar, sludge and «tails» of iron ore enrichment often are polluted by flotation waste which has hydrocarbons disposition which further significantly complicates their processing. The third aspect is insufficient accounting system of man-made deposits industrial waste structure and the reliable data of the waste chemical composition lack [9].

In economic field is question of waste processing expediency because the main tasks are development and introduction of effective in financial and also in ecological plane ways of industrial waste processing. As well as development and implementation of production technologies providing the maximum possible recycling of waste, reduce energy consumption and save natural resources, as well as minimal impact on the environment. Thus, based on data analysis (Table 2), waste should be divided into two groups:

1) wastes from the production of metallized raw materials (sludge and «tails» of iron ore enrichment and other iron ores waste);

2) wastes from field development and mining (wastes from field development and iron ore mining, limestone mining residues (dust, crumbs, fragments) and wastes (rocks, ground) produced in the process of creating mines (mineries) and quarries).

For the first group of industrial waste more effective processing way is up-enrichment scoping additional iron-containing minerals extraction and reception of additional amount of concentrate. Processing of the second group of industrial waste is focused mainly on the building materials and mortar mixtures to fill the space production [9].

There are three main ways of sludge and «tails» up-enrichment: flotation, advanced gravity separation, and high–intensity magnetic separation. At a present time in Ukraine are realized only two such projects:

1. Sand processing of sludge storage on the Central Mining and Processing Complex (Central MPC; Kryvyi Rih City, Ukraine) with concentrate production using advanced gravity separation [10].

2. The project «Reclamation of man-made deposits» which was implemented by «Metal Union» company (Zhovti Vody Town, Ukraine) in 2005 [11].

Both projects are successful in economic field but not effective in ecological advantages achieving. For exemplar, average particle size distribution of sand in Central MPC are 0.25 mm (approximately 40 %). The magnetite iron content in this fraction is about 3 %. Using of two stage grinding and three stage magnetic enrichment allowed to obtain a concentrate yield of 25.1 %. But the richest in total iron content are fractions with particles from 0.05 to 0.25 mm. These particles mass fraction is about 60 %, and the magnetite iron content in is more than 30 %. Another explored man-made deposit is the Northern MPC (Kryvyi Rih City, Ukraine) [12], its «tails» particle size is between 0.001 and 3 mm. Enrichment using high-intensity magnetic separation methods allows to obtain a concentrate with a yield of 22.5 %, and using the method of advanced gravity-magnetic separation – 24,5 %.

Currently known works based on the methods of sludge and «tails» selective flocculation development [13–15]. Their total advantage is high enrichment effectiveness (from 32 to 39 % in dependence on flocculants [15]) of small fractions, which form the basis of explored man-made deposits in Ukraine [10, 12]. The magnetite iron content in such fractions is 10 times higher than the content in fractions with larger particle size.

The most complete recycling question of waste of enrichment lies not only in the economic but also in the environmental field. After all, the ecological effect is currently measured not only by the environment impact through pollutants or waste production, but also by the resources using and energy cost. Accordingly, the most promising and important in industry greening are more complete waste recycling technologies.

Second industrial waste group is mainly focused on the production of building materials and mortar mixtures to fill the space. Wastes from field development and iron ore mining, residuals of limestone mining in quarries and wastes from mining operations in mines creating are potential sources for the construction industry. World practice also has a rich application for limestone and limestone-containing materials. It is a raw material for the chemical industry, soil conditioner, a component in the production of glass, fluxes, building materials, even as a filler in toothpastes or paints, as well as in the production of Portland cement [16–18]. Using prospects of waste from operations in iron ore and limestone-containing materials mining in a concrete and asphalt mixtures production, as well as for the production of ceramic bricks are analyzed in detail for Ukraine's facilities [19, 20]. However, quite often, the environmental component in using relevant waste as a raw material is ignored. One of the based obstacles in widespread industrial waste using as a building material is the presence of unmined metals [21], which can lead to both chemical and radiation environmental pollution. After all, metals under the natural leaching processes influence can get into the environment, polluting the soil and surface or even groundwater. A combined system of iron ore enrichment with the processes of preparation of hardening mixtures used to fill man-made voids in underground mining is proposed by authors. According to the proposed technology, «tails» activation is carried out in disintegrators. In this case, the substance accumulates additional energy, the amount of which can reach 30 % of the total energy amount spent on processing. Activated «tails», after metal extraction to the necessary sanitary requirements level, even without of cement addition meet the minimum geomechanical conditions and can be used to fill man-made voids [21]. Another example of waste preparation for recycling is the experience of Nippon Steel & Sumitomo Metal [22], which developed special materials for cheap and simplified paving. Production is based on the control of the latent hydrate properties of steel slag. The key features of the process are to properly control the mixing ratio and grain size of blast furnace slag and basic oxygen furnace slag. Blast furnace slag deoxidizes under the influence of alkaline a basic oxygen furnace slag, and calcium ions migrates from the basic oxygen furnace to blast furnace slag, interact with moisture or due to artificial moistening and form solid compounds of calcium carbonate. This slag product called KATAMA™ SP is used for paving.

These examples demonstrate a possibility of additional or reuse of solid waste from mining and metallurgical production for their complete processing. It is obvious that the effectiveness of the result, both economically and in terms of environmental impact, depends on the initial conditions. Thus, energy and resources can be used more efficiently than under the undifferentiated approach (when waste is stored for «possible» recycling, and in Ukraine's reality is mixed, which further significantly complicates their recycling) if a strategy for full further recycled products using will work out.

Industrial enterprises can already include in their production cycles additional components that are the parts of the further solid waste processing. It is useful, for example, an experience of Nippon Steel & Sumitomo Metal in the production of pavements for sidewalks or parking lots, as well as many other products. The most significant advantage of this approach is the elimination of legal conflicts that may arise during further disposal, storage or waste recycling, as well as significant advantages in terms of resources and energy conservation. For example, using wasted steam for blast furnace and converter slag mixtures treatment to obtain construction composites is much simpler in production than re-firing slag and processing it into raw material.

Obtained results show Ukraine is increasing the amount of industrial waste from year to year. Reduced emissions and circulating water discharges may indicate a decline in industrial production. On the other hand, the increase in solid waste from quarrying and iron ore enrichment waste are indicators of a decrease in the processing depth, which confirms decline the processing industry part in waste generation. Due to the fact that the mining and metallurgical industries are budget-generating in the country this trend be reflected on GDP looks like threatening. Obviously, the main part of mined minerals after enrichment is sold as raw material. This trend contradicts to strategy of sustainable development, as it indicates about raw material nature of the state's economy and its growing non-competitiveness in international markets. At the same time, implementation of industrial waste processing projects analysis showed this area in Ukraine is undeveloped on a practice. Main reasons are lies in three areas: legal, economic and environmental. The lack of clear norms and regulatory mechanisms in relationship between entities in the field of waste recycling creates significant obstacles for relevant technologies implementation and makes such investments unattractive which leads implemented projects to have low environmental and economic potential. Obviously, this issue cannot be resolved exclusively in the legal field (by strengthening of state regulation and control).

Analysis shows different countries on different continents is building different strategies to achieve sustainable development goals. Ukraine, with its inherent features in the social, economic and political spheres can build its own strategy. The fundamental our proposed approach difference is the development of a strategy based not on the EU countries experience, but on the experience of Japan. An obtained data analysis shows Ukraine needs priority implementation of effective technologies for industrial waste generated processing by facilities of the mining and processing complex and metallurgy. An important prerequisite and criterion for success in such strategy implementation is an export-oriented heavy industry of Ukraine, as well as Japanese industry. The latter, as shown, having also an export-oriented type of economy, has at the same time significant achievements in the field of recycling in ferrous metallurgy, as well as fundamentally different by development and implementation of advanced waste treatment technologies. Industrial symbiosis can be an effective tool in implementing such an approach in the realities of Ukraine. For example, if a metallurgical enterprise is not interested in industrial waste further processing at its own facilities, it may «transfer» it to another enterprise that uses them as raw materials or as an energy source. This approach obviously will complicate the management system, but will avoid a number of legal issues (waste status, disposal, recycling, disposal, etc.).

This study is limited by a generalized approach and is only a preliminary analysis of the main achievements in the development of industrial waste management strategies within the context of sustainable development. It does not take into account the social and economic characteristics of the conditions for each of analyzed strategies implementation and their most significant limitations, instead of it is proposed a general possible vector for development.

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Further detailed analysis of each industrial waste type in the context of the main approaches to their processing is promising. And also development of potentially possible ways of industrial waste management in the realities of Ukraine with application of foreign experience, in particular Japan.

4. Conclusions

The study found the most global task in the realities of Ukraine is processing of industrial waste, the share of which is more than 90 % (in 2019 – 96.7 %) of the total solid waste in the country.

It is shown there are only five the main categories of waste, which can be divided into two groups by origin: waste from quarrying and mining, and waste of metallized raw materials production.

The main strategies and approaches to industrial waste management in different countries and in Ukraine in particular are analyzed, and an experience of Japan is revealed the most promising. The latter, like and Ukraine, has an export-oriented economy type and well developed industry of industrial waste deep processing.

This study may be useful in developing strategies for processing of industrial waste at Ukraine's metallurgical enterprises in terms of further detailed analysis the experience of Japan. One of the promising tools for strategy implementing can be recommended is industrial symbiosis.

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