Progressive Technologies of Waste Utilization as Drivers of Sustainable Development

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Abstract. The article considers technological approaches to solid waste utilization from the perspective of beneficial effects. The waste utilization management is explored in the context of dominant principle of the circular economy: waste should be processed into secondary resources, reducing environmental risks. The author's novelty is separation of waste processing methods according to the specifics of participation in utilization processes: primary (preparatory stage) and secondary (stage of waste processing). Primary (preliminary) methods are collection and storage without being an active recycling stage. It is emphasized that waste separate collection is an important condition for creating a responsible "garbage culture" in society. Secondary methods (recycling) are next stage with mechanical, chemical and thermal impact on the waste for processing in order to obtain a useful effect. Recycling methods are represented by progressive technologies: high-temperature pyrolysis with barbotage process, gasification, air-and electro-separation, bio-thermal composting and digital technologies for waste management. It is noted that reducing of landfills, implementation of recycling, and digital methods are pivotal trends in developed countries. Concluded that citizen's conscientiousness and progressive waste technologies are necessary conditions for the transition to sustainable development.

1. Introduction

Responsible waste management is an integral part of ensuring the environmental safety of each country and our planet as a whole. Increasing the volume of waste is a serious problem that is being solved using modern technological methods of utilization. Reducing of landfills, separate garbage collection and implementation of effective methods for waste recycling are relevant tasks. Development of eco-friendly and cost-effective recycling technologies is a direction of research and business decisions in many countries, including Russia.

Modern researchers suggest new approaches to waste circulation by producing energy and recycled materials. Improved methods of grinding, pyrolysis, gasification and composting allow to obtain energy, feedstock for petrochemicals and materials for other industries. The expansion of digital technologies opens the prospect of smart waste processing.

The purpose of this study is to explore methods and technologies of solid waste utilization from the position of ecological pressure reduction. The objectives of the study are systematization of waste utilization methods, comparison of waste recovery methods used in different countries, overview of progressive waste processing technologies with minimal impact on the ecosystem.
2. Materials and methods

One of the most important challenges for sustainable development is the need to improve the waste utilization industry. For Russia this issue is particularly relevant: more than 60 million tons of waste are produced annually, and waste disposal sites are expanding by 300-400 thousand hectares [1]. Using waste as a source of secondary resources and energy is a necessary step in the transition to circular economy. Russian studies emphasize the importance of principles and conditions for the development of "closed-cycle" economy, which is based on "3 R" – Reduce, Reuse and Recycle (reduction of resource intensity and environmental hazards of production, reuse or sharing of products, recycling of waste) [2].

Solid domestic waste (SDW) is a heterogeneous composition. Waste varies in size, properties and degree of harm. The waste structure is approximately the same in all countries: food scraps – 20-30%, paper-forming components – 20-25%, plastics – 5-10%, glass – 3-5%, textiles – 3-5%, metals – 3-4%, other – 10-15% [3]. Due to the lack of a separate garbage collection system in Russia, hazardous components are present in SDW. These are used batteries, electronic scrap, thermometers, fluorescent lamps, medical waste. Low environmental culture and irresponsible attitude to waste disposal is a serious social problem.

Waste disposal and recycling are complex sanitary, technical, economic, social and environmental measures. Joint efforts of authorities, business and citizens can solve such serious task. Population growth, increased production and consumption make it necessary to find environmentally friendly and low-cost methods to utilize of waste. Currently, there is no unified classification of waste handling approaches. In table 1 the author proposes a systematization of SDW-management methods based on the analysis of [3-7]. The author's novelty is dividing of methods according to the specifics of participation in utilization processes: primary (preparatory stage of recycling) and secondary (with waste processing).

Table 1. Systematization of SDW-utilization methods.

| Hierarchy of utilization methods | Technologies and their subspecies |
|---------------------------------|-----------------------------------|
| Primary (preliminary) methods   | 1. Sorting or separation by type of waste (manual, mechanical, air, hydraulic, magnetic separation, laser-optical robots). |
| (passive stage of processing, preparation for further transformation) | 2. Storage (storage in landfills, arrangement of polygons and dumps, stockpiling). |
|                                 | 3. Export (transportation to another location or country). |
| Secondary (handling) methods   | 1. Mechanical processing (grinding, pressing, briquetting). |
| (active stage of processing, technologies are aimed at recycling waste) | 2. Chemical processing (chemical cleaning, biology-chemical composting). |
|                                 | 3. Temperature treatment (incineration, melting, pyrolysis, gasification, plasma processing). |

In the XXI century, a comprehensive approach to the processing of domestic waste has developed. Most countries use several types of waste management methods. To apply any one method or technology for waste utilization is not effective. When considering disposal methods, criteria such as environmental friendliness and cost-effectiveness are evaluated. Analysing information about the proportion of different methods of solid waste disposal in some countries, it can be concluded that Russia has an inefficient and retrograde system of waste utilization (table 2). In developed countries, a progressive model of SDW-utilization is being formed: reducing the quantity of storage and incinerated waste, and switching to recycling. The world practice of environmental management has proved that it is preferable to save energy concentrated in waste by recycling it [8]. In the study [9] noted that legislative changes, technologies and citizen's conscientiousness are drivers of environmental changes. It is extremely important to develop these components in Russian practice.


Table 2. Percentage of SDW-utilization methods in some countries, %.

| Country   | Primary methods (storage in landfills and polygons) | Secondary methods           |
|-----------|------------------------------------------------------|------------------------------|
| Kazakhstan| 97                                                   | -                            |
| Russia    | 90                                                   | 6                            |
| USA       | 54                                                   | 12                           |
| Sweden    | 50                                                   | -                            |
| Switzerland| 49                                                   | -                            |
| Germany   | 38                                                   | -                            |
| France    | 31                                                   | 34                           |
| Japan     | 18                                                   | 37                           |
| Belgium   | 5                                                    | 33                           |
| Denmark   | 4                                                    | 54                           |

Progressive technologies for SDW-utilization are object of different researches. Emerging technologies allow to reduce the harmful effects and to obtain economic benefits. According to experts, more than 60 % of urban waste is a potential secondary raw material that can be processed and realized. SDW is a source of secondary resources, including ferrous, non-ferrous and rare metals, as well as a “free” energy, since household waste is a renewable carbon-containing energy raw material for fuel energy [10]. Another 30 % is organic waste that can be turned into compost. In this regard, eco-effective waste processing technologies are further considered.

1. Pyrolysis of solid waste with zero atmospheric emissions. Recycling polymer domestic waste is most effective through high-temperature pyrolysis (800-1000 degrees C° or more). It allows to split extremely toxic organic compounds (for example, polychlorinated biphenyls) into carbon dioxide, chlorine, nitrogen oxides and other low-molecular substances, while harmful emissions into the atmosphere are reduced to minimum. In Russia, a group of scientists led by Prof. G.S. Podgorodetsky developed a waste disposal boiler on the principle of the Vanyukov furnace (Vanyukov process, Romelt process), in which waste is barbotaged in a slag melt. SDW turns into generator gas, which does not contain dioxins and furans. Then this gas can be used instead of natural gas. This aggregate produces up to 2.5 tons of energy steam per hour, and 432 thousand tons per year. This makes it possible to produce more than 4320 megawatts of electricity [11]. The advantages of high-temperature pyrolysis technology using barbotage ("furnace-cyclone" system) are also considered in foreign works [7, 12, 13] as an alternative to waste incineration in boilers with standard grids.

2. Gasification technology for solid domestic waste. Gasification is a partial oxidation process that converts combustible waste into synthesis gas. Syngas is a material for producing a variety of environmentally friendly and expensive products, such as motor fuels, various fertilizers, synthetic natural gas, hydrogen, methanol and other different products [5]. In gasifier the waste is gasified and the slag in finely divided composition is supplied to the grate, where the combustion of all carbon particles in the slag. Then the gases are sent to the transition chamber, where the secondary air enters. After transferring the heat to the boiler, the combustion products enter the multicycle, where they are cleared of suspended particles, and then ejected by the chimney [14].

3. Technologies of air- and electro-separation for extraction of polymeric materials from solid waste. The separation of any multicomponent mixtures is based on the use of differences in properties of separated components. Polymer waste such as synthetic textiles and paper components can be separated from the total mass of solid waste by air separation. The material to be separated is fed to the chamber using a loading device, where low-density components are blown out of it using a horizontal air flow of
a certain speed. Three products are obtained during separation: concentrate (lightest fraction), industrial product (intermediate density fraction) and tails (heavy faction) [15].

4. Bio-thermal composting. This method is based on natural, but accelerated reactions of garbage transformation in the process of oxygen at a temperature of about 60 °C. Waste as a result of reactions in a bio-thermal installlation (drum) turns into compost. The initial garbage, cleared of large elements, as well as metals, glass, ceramics, plastic, rubber is loaded into bio-thermal drums, where it is kept for 2 days. After that, the composted mass is again cleared of metals, crushed and stored for further use as compost in agriculture or biofuels. However, modern composting technologies do not allow cleaning of heavy metal salts, so compost from solid waste it cannot be used in agriculture [10]. In study [16] predicted that composting processes will be increasingly use for the disposal of agricultural, industrial and municipal solid waste. It is expected that biotechnical research will focus on the development of various enzymes and substrates for composting waste.

5. Digital technologies for waste management. Application of artificial intelligence, Internet of things, robotic systems and cloud-technologies in waste sorting, transporting and accounting makes it possible to use resources more efficiently. In Europe the usage of smart waste sensors is increasing: sensors are integrated into garbage bins and containers. Garbage bins equipped with sensors allow utilities to provide better service and optimize truck routes. Cloud technologies allow to store big data, to monitor important facts and to plan infrastructure elements for waste management. Some articles show that smart urban management in European countries has shown effectiveness [17, 18].

Considered technologies have advantages, but their use depends on economic efficiency. Thus, the cost of landfill disposal is still more attractive compared to investing significant funds in preventive measures, re-manufacturing and other innovative technologies. In order to improve the situation qualitatively, major changes are needed in stimulating of investment activity as part of the transition to circular economy.

3. Discussion of research results

In framework of sustainable development concept researchers pay attention to the significance of adapting the principles of circular economy, in which processing of SDW is an important element. In paper [19] is noted that the promotion of circular economy in the Russia will bring a positive environmental effect from reducing landfills and polygons, an economic effect from increasing energy and resource efficiency, as well as a social effect from creating additional jobs in new industries. Solid waste management is a prerequisite for the formation of quality of life.

In Russia, it is necessary to introduce garbage sorting at the level of households and businesses. A number of Russian regions are becoming points of attraction for different types of tourism and this can lead to increased pollution [20]. Therefore, it is topical to improve the "waste culture" and create an infrastructure for responsible disposal. Waste separation as a primary stage of SDW-utilization will allow more efficient recycle garbage into energy and secondary materials. When organizing separate collection of waste in places where it is generated, the percentage of secondary resources obtained from SDW can reach up to 56% [21].

The introduction of progressive recycling technologies requires funding. This issue can be solved through public-private partnerships. For example, environmentally responsible financing instruments are gaining popularity. Banks give "green" credits at reduced interest rates, "green" securities are issued in developed countries [22]. SDW-utilization projects can be considered environmental because as a result of their implementation will anthropogenic pressure reduction and decapling effect.

Recycling and development of smart solutions for SDW-management are strong global trends. Countries impose prohibition and restrictions on the use of packaging materials that are difficult to recycle. In developed countries, waste is considered as resource that needs to be used, not eliminated. Recycling products are used in the energy, petrochemical, construction and textile industries. In Japan and Singapore, artificial islands are created from compressed waste briquettes that has undergone thermal and mechanical treatment. In China, Canada, United States and some other countries the production of asphalt coating from recycled plastic and rubber crumbs is being introduced.
4. Conclusion

A strategic aspect of the sustainable development of countries is adjustment of system for solid domestic waste (SDW) managing on the principles of a closed cycle. Modern technological research is aimed at finding effective methods of waste disposal which could turn waste into energy and secondary raw materials without compromising the environment. The author's opinion is that utilization methods are involved in different ways in the recycling process. Primary (preliminary) methods are collection and storage without being an active recycling stage. However, at this stage waste separation is very important, which increases the effectiveness of further methods. Waste separate collection is the foundation for creating a responsible "garbage culture" in society. The secondary methods are next stage with mechanical, chemical and thermal impact on the waste mass for processing in order to obtain a useful effect.

Among the most environmentally effective technological methods of SDW-utilization are following: high-temperature pyrolysis with barbotage process, gasification, air- and electro-separation, bio-thermal composting, recycling of polymers in various industries and digital technologies for waste management. The implementation of technological methods and the reducing of landfills are dominant trends in developed countries. The synergy of citizen's conscientiousness and progressive technologies should become an effective measure on the way to clearing our planet of garbage pressure.

5. References

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