

*The object of this study is military waste management models as a system of actions and processes aimed at choosing how to handle it. The task to devise ways to reduce military waste under conditions of increasing volumes and rates of its accumulation is considered. The policy of military waste management in the countries of hostilities was investigated; it was concluded that there are no effective mechanisms and schemes for managing such waste. Trends in the increase in the amount of military waste have been identified and a forecast of their further growth under the conditions of modern wars has been formed. The current legislative support for the implementation of waste management policies formed in the process of physical and moral deterioration of military equipment and ammunition in military units was analyzed. It was determined that the main subject of management of such waste is the state represented by state authorities and management. Models to manage military waste formed in the process of hostilities have been proposed. These military waste management models are based on the criteria of economic, social, and environmental efficiency. Special features of the research results are that the proposed models provide for the transfer of rights to perform certain stages in the waste management chain by subjects of the non-state sector of the economy. Distinctive features of the reported results are that they present alternative models for managing military waste formed in the process of warfare. The choice of model is determined by the priorities of the defense and policy of post-war reconstruction of the country's economy. The area of practical use of the results is the system of public administration bodies, which forms proposals for changes to the legislation in terms of forms of cooperation between the state and non-state sectors in the field of military waste management*

**Keywords:** *military waste management, waste management model, recycling, circular economy, military equipment*

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# CONSTRUCTION OF MODELS FOR MANAGING MILITARY WASTE GENERATED UNDER THE CONDITIONS OF WAR

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## 1. Introduction

Military conflicts are terrible not only in view of the loss of life and damage to the health of the population and the economy of the country but also obvious and implicit

dangers to the human environment. The consequences of military conflicts include the accumulation of military waste, environmental losses, epidemiological outbreaks, destroyed industrial infrastructure. There is also a decline in the nation's overall health, a decline in employment, and an

increase in poverty. These phenomena are accompanied by an unrestrained increase in the state budget deficit, as well as an unpredictable increase in the level of budget social payments. In particular, the increase in military waste requires the adoption of a set of security actions for further handling it since most military waste is dangerous and can pose a threat to the environment.

A system of collective security aimed at supporting the prevention of war has formed a global persuasiveness in the low likelihood of protracted wars and military conflicts. Such beliefs were reflected not only in the defense policy of individual countries of the world but also in the legislative regulation of both the processes of providing military equipment and the management of military waste. As a result, in the laws of most countries of the world there is no concept of military waste, or it is interpreted as waste resulting from the moral or physical wear and tear of military equipment and weapons. The world scientific community also did not provide a clear definition of this concept. Thus, for example, [1] treats as military waste any outdated military equipment that is no longer used (aircraft, ships, weapons, etc.) and can either be disposed of or preserved as a historical monument.

Military waste is all types of military equipment and weapons that were formed in the process of their physical and moral wear during operation or have completely lost their functional ability during hostilities, and which are to be disposed of or removed.

The inability to timely and effectively dispose of military equipment leads to the fact that it accumulates in the places of hostilities, and also partially moves to landfills. These processes lead to an increase in the volume and amount of military waste, which negatively affects water, forest resources, soils, and the atmosphere. This situation poses a threat to the environmental safety of countries.

In most countries participating in military conflicts, dumps of destroyed military equipment are evidence of the lack of economic interests or legal opportunities for their disposal. Under conditions of low volumes of waste generated, fixing the function of their disposal by the state forms guarantees of long-term safety. In the context of the progressive accumulation of significant amounts of military waste, the involvement of private enterprise to perform certain functions in the system of management of such waste ensures the speed and completeness of their disposal. The implementation of this approach requires the formation of alternative models of military waste management, the choice of which is due to the priorities of the policy of post-war recovery of the country's economy, the needs of the defense sector, and financial resources.

The results of such studies are necessary in practice because they determine the models of military waste management formed as a result of war.

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## 2. Literature review and problem statement

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The area of military waste management is influenced by a number of legislative and regulatory acts, which can be divided into two groups:

- 1) those that regulate relations in the field of handling military equipment and weapons unsuitable for further use;
- 2) those laws that regulate relations in the field of waste management.

The first group includes the Law of Ukraine "On the Legal Regime of Property of the Armed Forces of Ukraine" [2], which determines the full state ownership of military waste. At the same time, the State Target Defense Program for the Disposal of Weapons, Military Equipment, and Other Military Property (except for conventional types of ammunition and liquid rocket fuel components) for the period up to 2017 [2] determines the most appropriate option for the disposal of military waste, a combination of two methods:

- 1) priority use of components suitable for the repair of existing equipment by the Armed Forces of Ukraine, and in the absence of the need for certain spare parts on the part of the Armed Forces, converting them for scrap;

- 2) disposal of hazardous chemicals by processing them at specialized enterprises.

However, under the conditions of active hostilities, this concept should be finalized since the volume of equipment that must be disposed of increases significantly, the process of its logistics, analysis and preparation for disposal is complicated, the production capacity of enterprises capable of processing this equipment is destroyed, etc. In addition, this group of regulations includes the Resolution of the Cabinet of Ministers of Ukraine [3] and the Order of the Ministry of Defense [4]. These documents prescribe a mechanism for the disposal of unusable Ukrainian military equipment. However, no legislative and regulatory document establishes the ownership of destroyed enemy equipment and does not clearly regulate the process of handling this type of waste.

The second group of laws includes the Laws of Ukraine: "On Waste" [5] and "On Waste Management" [6]. Their detailed analysis showed that they do not contain a clear definition of the concept of military waste and provisions that would regulate relations in the field of disposal of waste generated as a result of hostilities, both from destroyed enemy equipment and from the equipment of the Armed Forces of Ukraine, taking into account the peculiarities of collection, transportation, treatment, preparation for the disposal of such types of waste in war.

In world practice, there is no reference model for military waste management. Similarly, there are no modern European practices for the formation of this kind and the amount of military waste. The literature fragmentarily reveals the issue of military waste management. Countries that are manufacturers of military weapons or are participants in military conflicts face the problem of recycling outdated and unsuitable military weapons. In the countries on the territory of which hostilities are conducted, this problem becomes particularly acute since the issue of technological waste disposal is due to doubled volumes of their accumulation, taking into account the broken equipment of both sides of the military conflict. Military waste consists of destroyed as a result of hostilities, decommissioned, outdated equipment and weapons, weapons confiscated and handed over by the population for disposal, equipment and weapons that cannot be restored.

World experience in military waste management demonstrates different approaches and tools for implementing this process. Researchers apply different methodological approaches to assessing the effectiveness of the process of disposal of military equipment and note certain possibilities for implementing strategies for the destruction of equipment under the conditions of hostilities.

Thus, paper [1] indicates that when aircraft become unusable, they are usually sent to Davis Mountain Air Force Base

near Tucson in Arizona. Due to its size, dry desert climate (which helps avoid metal corrosion), and lack of population, this area has become the operating base for the Boneyard Military Aircraft Storage and Disposal Center, which is the largest aircraft storage facility in the world. Shortly after the end of World War II, when the economy was working permanently on a military footing, a well-known entrepreneur in Tucson began buying surplus aircraft from the administration of the said Center and remelting them. At that time, metallurgical enterprises received significant profits due to high aluminum prices. However, sometime in the early 1950s, that company also began restoring aircraft to present them at exhibitions and sales. This business still exists near Boneyard, thanks to decades of accumulated knowledge related to the repair and restructuring of various aircraft. Study [1] also focuses on the historical and cultural value of outdated technology, using it as museum exhibits to preserve the memory of the Second World War. However, the issue of disposing of a large amount of military waste under the conditions of hostilities for a long time remains unsolved.

Studies [7, 8] consider the destruction of military waste accumulated in the locations of the US military (US military solid waste in places of deployment). Such wastes include packaging waste, medical waste, building materials, food waste, canvas, semi-finished products waste, and plastic water bottles. According to the authors of the above studies, the lack of a sufficient number of safe waste treatment methods outside military bases in open space, combined with a limited amount of necessary equipment for waste management, such as incinerators, leads to negative consequences. In particular, open incineration in “burning pits” as a method of processing and reducing the amount of solid household waste generated during military conflicts in Afghanistan and Iraq has harmed the environment and human health. There is evidence that civilian contractors based at the Balad Central Logistics Center in Iraq burned nearly 200 tons of solid waste a day during the peak phase of the 2008 military conflict. The authors of the above papers proved a significant negative impact on the health of the military themselves as a result of the application of such measures [7, 8]. However, these articles do not provide other models for the use of military waste.

Study [9] proposes to replace the traditional method of destroying obsolete ammunition, which involves burning them using incinerators with complex gas cleaning systems that are extremely hazardous to the environment and energy-consuming. The authors propose a method of disposal of obsolete ammunition using the principle of a circular economy, namely the use of part of an explosive for the manufacture of explosive mixtures used in civilian industrial production. The energy material in obsolete munitions is often in a usable state and is of considerable value.

The considered solution is based on the extraction of energy material into emulsion explosives based on ammonium nitrate (a common type of civilian explosive used for mining and construction). The results show that the reuse of ammunition by valorizing energy materials significantly reduces the environmental impact in all areas, compared to the conventional recycling process.

Disposal of military equipment and ammunition is carried out in accordance with NATO standards developed within the framework of the demilitarization program [10].

Study [11] attempted to count the number of heavy weapons remaining in Central and Southeastern Europe

since the Cold War. The authors of the work point out that among several ways of destroying military weapons, the most common among European countries is the transfer to private companies of the right (full or partial) to dispose of equipment, weapons, and ammunition. Such companies are selected based on the results of bidding procedures. However, approaches to the formation of a methodological platform for the implementation of military waste are not given in that study.

The positive results of the implementation of this policy of disposal of heavy weapons were demonstrated by the Czech Republic, which transferred the equipment to be demilitarized to a third-party commercial company on an outsourced basis. This method made it possible to dismantle and recycle its excess heavy weapons (ground systems). German experience in the disposal of military equipment confirmed the effectiveness of the participation of the private sector in the management of military waste.

As part of Montenegro's MONDEM (Montenegro Demilitarization) demilitarization program, an outsourcing model was used to dispose of surplus weapons. The cutting of tanks at the places of their basing and transportation of steel for re-processing at the foundry was carried out by enterprises on the terms of their licensing and at the expense of the agency of the United Nations Development Program (UNDP) and the Organization for Security and Cooperation in Europe.

From work [12], one can identify a number of important additions to the possibilities of handling military waste. For example, Hungary's experience in the disposal of heavy weapons, which has remained since the communist regime, provided for the creation of a joint-stock company, the controlling stake in which belongs to the state. The study considers in detail one of the methods of disposal of military waste, namely the destruction of conventional weapons by this enterprise. The destruction took place both on the company's own territory and at military facilities where such equipment was stored. The latter method turned out to be slightly more profitable due to the savings in transport costs, conventional weapons, and their transformation into scrap metal turned out to be cost-effective according to Western European standards [12]. However, other ways to study models of military waste management remained uncovered.

Albania, as part of the demilitarization program, has converted three weapons and ammunition factories into state-owned arms processing plants. On the territory of Albania, four demilitarization programs were implemented, funded by NATO and with the assistance of individual European countries, which allowed for large-scale disposal of ammunition.

Paper [13] notes that in March 2004, the Council of Ministers of Bulgaria approved the National Program for the Disposal/Processing and Destruction of Surplus Munitions in the Republic of Bulgaria. Most of the military-industrial complex of Bulgaria is privatized. In addition, a plant was built on the territory of Bulgaria, which had production facilities for processing surplus ammunition throughout Bulgaria. The demilitarization process was mainly funded by the United States and the United Nations. A feature of the model of disposal of military waste in Bulgaria is that not a single enterprise for the processing of military waste is subordinate to the Ministry of Defense. Such enterprises have a public, private, or mixed form of ownership and receive contracts for the processing of ammunition on a bid-

ding basis. In addition, ammunition cannot be exported for demilitarization without re-export. Despite the rather large study, the work lacks the methodological foundations of the concept of disposal of military waste.

For Ukraine, the experience of Bosnia and Herzegovina, which suffered especially during the war of the 1990s and the collapse of the former Yugoslavia, is indicative. The implementation of the country's demilitarization program was carried out at the existing facilities of state-owned enterprises, and later commercial industrial enterprises were involved in the process of disposing of military weapons. For example, in 2004, the Mittal Steel Zenica plant helped the Stabilisation Force in Bosnia and Herzegovina remelt small arms and light weapons collected during Operation Harvest, turning them into molten steel for processing into other products [13]. UNDP, NATO, and the U.S. Embassy have provided financial, technical, training, and political support to the Bosnian government's arms control and demilitarization initiatives. However, despite this, since 2006, the potential of Bosnia and Herzegovina in this direction has been implemented rather slowly.

Thus, based on the review of available theoretical sources [1, 7–13], it can be concluded that the problem of determining models of military waste management remains unresolved and insufficiently investigated in the professional literature. That is why it becomes necessary to develop a scientifically based approach to improving the level of efficiency of military waste management by developing variable approaches to the choice of waste management models generated under the conditions of hostilities.

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### 3. The aim and objectives of the study

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The aim of this study is to build models for the management of such waste. This will allow state bodies to state a policy of managing military waste on the terms of world achievements and taking into account national economic conditions.

To accomplish the aim, the following tasks have been set:

- to determine the volume of military waste generation in the context of modern wars and the policy of military waste management;
- to develop a concept for building a model for managing military waste generated during the war.

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### 4. The study materials and methods

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The object of this study is a set of alternative systems for military waste management, formed taking into account the volume of its supply, demand, and technological recycling capabilities. The main hypothesis of the study assumes that analyzing the available volumes of military waste generation in the context of modern wars and assessing the policy of military waste management will make it possible to use this experience to form a model of military waste management.

To ensure the reliability of the study under conditions of ongoing hostilities and the lack of statistics on the destruction of each type of military weapons, the object of analysis selected was all types of destroyed military equipment, the statistics of which are provided by the General Staff of the Armed Forces of Ukraine. Taking into account the available statistics, the generalization of the scale of formation of mil-

itary waste was carried out on the basis of the volume of destroyed military equipment, the ownership of which does not belong to the Ukrainian military agencies. However, taking into account the territory of its accumulation, the obligation to choose the method of handling the destroyed equipment lies with Ukraine.

In the Ukrainian legislation, the regulation of waste management processes is carried out on the basis of the waste classifier [14], the Laws of Ukraine: “On Waste” [5] and “On Waste Management” [6]. However, none of the legislative acts reflected the concept of military waste.

In the classifier of waste, a group of waste generated as a result of unpredictable events, which includes waste generated as a result of man-made disasters (accidents), natural disasters and phenomena, is distinguished. The classification of waste is necessary due to the fact that it serves as a prerequisite for the legislative definition of its management processes.

The absence of the concept of military waste in the country's legislation leads to the impossibility of an official statistical assessment of the volume of its formation.

In 2021, the Ministry of Environmental Protection and Natural Resources of Ukraine began work on the formation of a new national classifier NK 005:2021 “Waste Classifier”, which is planned to introduce a group of military waste.

Before the adoption of changes to the waste classifier, military waste belongs to the group of “hazardous waste” as having one or more properties that make it hazardous (according to the “List of properties that make waste dangerous” [6]). Waste generated by hostilities can be explosive, flammable, can have a high level of toxicity and carcinogenicity, which can pose a significant threat to life, human health, and the environment. Such properties of military waste may impose restrictions on the activities of business entities when performing certain management processes (for example, inspection, explosive inspection, disinfection, collection, sorting) or enhanced state control over their organization. This property of military waste affects the formation of models for the organization of all operations in the chain of their management.

Waste management is a set of measures for the collection, transportation, treatment (restoration, including sorting, and disposal) of waste, including the supervision of such operations and the subsequent care of waste disposal facilities [6]. All stages of hazardous waste management, namely, the formation, collection, transportation, and treatment should be carried out in a way that is safe for human health and the environment.

Producers and owners of hazardous waste are obliged to store hazardous waste separately from other types of waste, to ensure the collection, transportation, treatment of waste independently [6].

A business entity in the field of waste management for conducting economic activities for the management of hazardous waste is obliged to have a permit to carry out waste treatment operations and a license to manage hazardous waste [6].

Despite the presence of criterion features for determining hazardous waste and general legal requirements for the organization of management of such waste, the grouping of waste and hazard classes applies to waste from the area of production and consumption. The management of military waste is associated with existing and future risks, which requires special actions to neutralize risks and dispose of



waste. Thus, there is a need to introduce the concept of military waste into the legislative field, and in the classification of types of economic activity (CTEA) – groups of military waste. Such a legislative basis will make it possible to develop a mechanism for managing each type of military waste, taking into account the degree of its danger and the form of ownership of such waste.

The results of the study were obtained on the basis of the application of general scientific methodology, namely the method of dialectics, the causal method, systemic and structural-functional approaches to the knowledge of the essence of economic phenomena and processes. In defining the concepts of “military waste” and “model of military waste management”, the method of scientific abstraction was used.

For the processing of statistical data, methods of analysis, generalization, comparison, and synthesis are used. For a visual interpretation of the research results, the data were summarized and systematized by the tabular and graphical method in accordance with the requirements of representativeness, validity, and relevance.

One of the important tasks of analyzing models of military waste management is to study the dynamics of the development of phenomena that are decisive for a set time period. Thus, using the historical and logical method, an analysis of waste management policies was carried out in different countries in which hostilities were carried out.

The analysis of the regulatory support for the process of disposal of military waste made it possible to determine seven possible models for managing military waste generated as a result of hostilities.

The information base of our study is the Laws of Ukraine; orders, resolutions of the Cabinet of Ministers of Ukraine, websites of international organizations, domestic ministries, the State Statistics Service of Ukraine, as well as monographs, professional publications, information and analytical materials from conferences.

## 5. Results of the study of military waste

### 5.1. Volumes of military waste generation in the context of modern wars and the policy of waste management

Russia's open military attack on Ukraine began at 4 a.m. on February 24, 2022. Due to the significant resistance of the Armed Forces of Ukraine and territorial defense, in the first days of military aggression, Russian military units suffered heavy losses in equipment. Subsequently, there was an increase in resistance, and, accordingly, the number of destroyed Russian military equipment increased. The dynamics of the formation of military waste according to [15] in the study period (from 24.02.2022 to 02.11.2022) are given in Table 1 and shown in Fig. 1.

Information on the volume and accumulation of waste from destroyed military equipment (tanks, ACVs, artillery systems, MLRS, air defense systems, aircraft, helicopters, ships (boats), cars and tank trucks) is listed and summarized in Fig. 2 [15, 16].

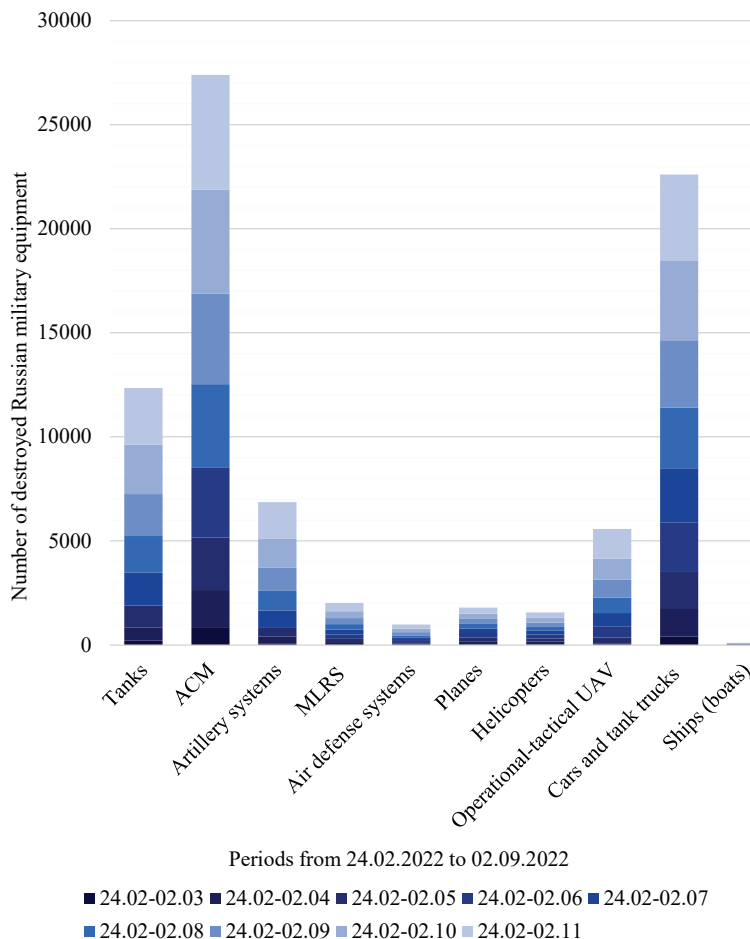


Fig. 1. Volumes of destroyed military equipment in the specified periods (according to [15])

Thus, the analysis of data from the Ministry of Defense of Ukraine according to the methodology of the Ministry of Ecology and Natural Resources [16] made it possible to determine the total amount of waste from destroyed equipment in the amount of 208 thousand tons.

The model of the dynamics of changes in the volume of waste from military equipment is shown in Fig. 3.

The coefficient of reliability of approximation indicates that the change in the period affects 75 % on the change in waste volumes. The relative error of calculations on average is 13.4 % (if we analyze the period 16.05 – 31.08.2022, the relative error decreases to 8.8 %). The residual mean quadratic approximation error is 3531, which indicates the quality of the model.

Analysis of the rate of change in the volume of waste from military equipment makes it possible to conclude that in the coming months the volume of waste will increase by almost 2000 tons per period (every two weeks).

If the destroyed equipment is disposed of, it can be used to restore the country's infrastructure. We are talking about 75 thousand tons of carbon and stainless steel; 2.5 thousand tons of aluminum; 1 thousand tons of copper; more than 360 tons of titanium and magnesium, as well as 10 kg of platinum, 18 kg of gold, and 1.2 tons of silver [17].

In every country in the world, military waste is the property of the state. Control over the disposal of such waste is carried out by the relevant authorities of the states. For the most part, the disposal of weapons and military equipment is carried out in military units or at state-authorized enterprises.

Table 1

Number of destroyed Russian military equipment (according to [15])

Type of destroyed equipment	Periods from 24.02.2022 to 02.09.2022								
	24.02–02.03	24.02–02.04	24.02–02.05	24.02–02.06	24.02–02.07	24.02–02.08	24.02–02.09	24.02–02.10	24.02–02.11
Tanks	211	631	1048	1363	1582	1768	2009	2377	2714
ACM	862	1776	2519	3354	3737	4014	4366	4975	5525
Artillery systems	85	317	459	661	800	936	1126	1405	1733
MLRS	40	100	152	207	246	259	289	337	387
Air defense systems	9	54	80	95	105	117	153	176	198
Planes	30	143	194	210	217	223	234	264	277
Helicopters	31	134	155	175	186	191	205	227	258
Operational-tactical UAV	3	87	271	521	653	739	853	1015	1438
Cars and tank trucks	415	1312	1824	2325	2614	2914	3247	3796	4153
Ships (boats)	2	7	8	13	15	15	15	15	16

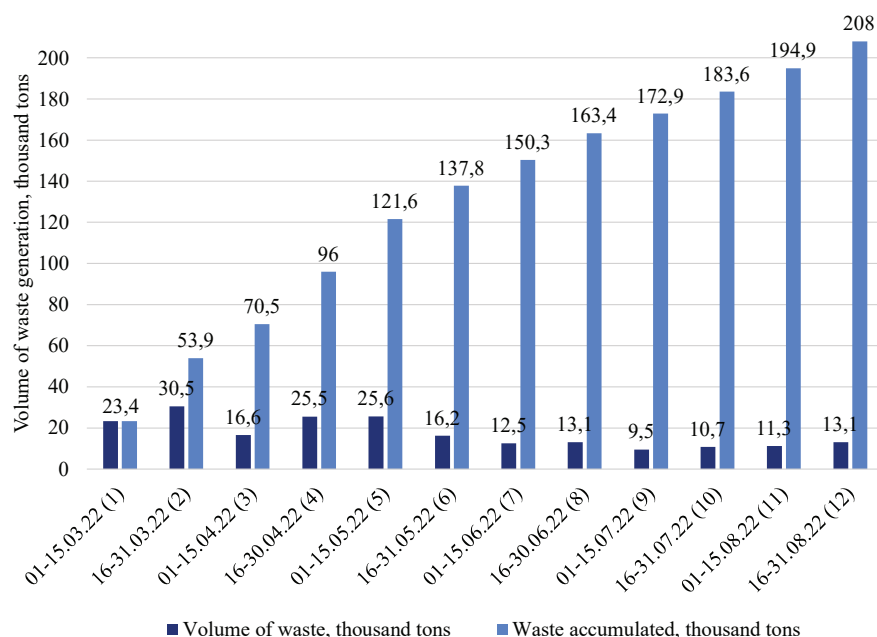


Fig. 2. Dynamics of volumes and accumulation of waste from destroyed military equipment for March – August 2022 (according to [15, 16])

Organizational forms of disposal of military waste in Ukraine are defined in the State Target Defense Program for the Disposal of Weapons, Military Equipment, and Other Military Property (except for conventional types of ammunition and components of liquid rocket fuel) for the period up to 2017 [17]. Military waste is subject to state ownership. The Program provides several scenarios for their disposal:

1) disposal of weapons, military equipment, and military-technical property on the terms of its sale on a competitive basis;

2) disposal of weapons, military equipment, and military-technical property as a result of which scrap of ferrous and non-ferrous metals, scrap containing precious metals, and other secondary raw materials are formed;

3) complex recycling with the division of property into three groups, which, respectively, include weapons, military equipment, and military-technical property:

- those that after disassembly (defection, restoration) can be used for the operation or repair of standard weapons and military equipment in the Armed Forces;

- those that after disassembly (defection, restoration) can be used for further implementation in the external and domestic markets;

- those the need for which is absent in the Armed Forces and at industrial enterprises and which can be processed into scrap of ferrous, non-ferrous metals, scrap and waste containing precious metals and other secondary raw materials;

4) disposal of hazardous chemicals by processing them at specialized enterprises [2].

This concept states that the first method is not cost-effective due to the high cost of preparing the property for disposal. It should be noted that revenues to the state budget in the form of taxes will be less than the cost of secondary resources, which is supposed to be obtained as a result of the use of two other scenarios. The second option will make it possible for the state to receive income only in the amount of the cost of scrap metal and secondary waste. The third option will make it possible to save budget funds by reusing suitable components and assemblies for the needs of the Armed Forces of Ukraine, as well as selling their excess quantity at a price higher than the price of scrap metal. According to the concept, the combination of the second, third, and fourth methods is recognized as the most effective.

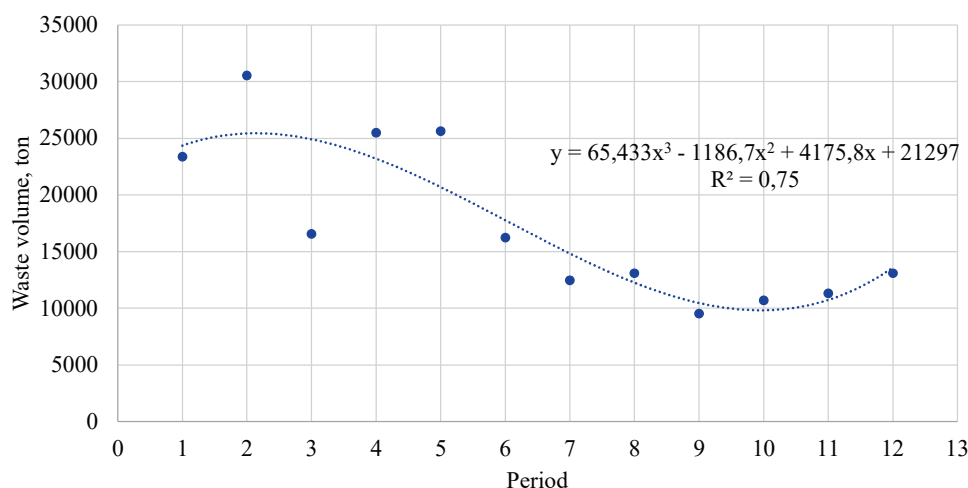


Fig. 3. Dynamics of changes in the volume of waste from military equipment for the period March–August 2022 (according to [15, 16])

However, with the deployment of a full-scale war on the territory of Ukraine, the question arises of the effectiveness of the use of methods of recycling of military equipment prescribed in the concept. In particular, due to the significant amount of such waste; the complexity of the analysis of equipment that was destroyed; destruction of industrial infrastructure that can ensure the process of recycling of equipment; problems of logistics of destroyed equipment to places where it is possible to disassemble it, prepare for disposal and recycling. In addition, not all metallurgical enterprises of Ukraine are technologically capable of processing all types of scrap metal formed as a result of disassembly of military equipment. Alloy steel components can be processed by only one enterprise, PRAT Electrometallurgical Plant Dnipropetsstal. The implementation of an excess number of components and assemblies may be complicated at this time since under martial law there is an increased demand for them from the Armed Forces of Ukraine. It should be noted that in Ukraine there is a mechanism for the alienation of military property [3, 4, 18] through an authorized enterprise, however, war can create significant obstacles to work. That is why the waste management policy should be revised and expanded to take into account the challenges that have arisen in connection with Russia's war on the territory of Ukraine. In addition, when choosing a model for managing military waste generated during the war, it is necessary to take into account the general economic, social, and environmental consequences of the choice.

## 5.2. The concept of building a model for managing military waste generated during the war

Based on the organizational, technological, and economic capabilities of the state, as well as on the experience of the countries participating in hostilities, the following models of state policy of military waste management can be identified:

1. Participation of the state in the implementation of the whole complex of actions in the waste management system (collection, transportation, disassembly, cutting, sorting, disposal (or recycling)).

2. Disposal of waste in specially designated landfills.

3. Transfer of functions of military waste management to business entities and the formation of a special regime of their activities for the time of waste processing.

4. Formation and placement of state order for the processing of military waste at metallurgical enterprises of Ukraine.

5. Construction of small enterprises for the disposal of military waste (using electric arc furnaces and the use of converter technology) in places of localization of hostilities.

6. Public-private partnership.

7. Export of military scrap metal.

As the analysis of the regulatory and legal support for the process of disposal of military waste shows, now the legislation provides for the use of a model of state participation in the implementation of the whole range of actions in the waste management system.

The state undertakes to plan, carry out organizational measures, finance, and control the entire process, from waste collection to its processing. Entities engaged in this type of activity must have a state form of ownership and finance with budget funds. On the one hand, this model has its advantages from a security point of view, as well as from the position of maximum satisfaction of the demand of the Armed Forces of Ukraine in components for the repair of equipment that can be obtained as a result of the analysis of destroyed equipment.

Taking into account the state in which the budget of Ukraine will be in the post-war period, the implementation of this model is possible on the condition of attracting foreign investments from partner countries and NATO. The organization of the processing process will also be problematic since the company authorized by the Cabinet of Ministers does not have the necessary capacities to implement the full cycle of military waste management, and metallurgical enterprises that could participate in this process are privately owned.

The implementation of this model of military waste management is possible under the following conditions:

- assessment of the volume of military waste generated as a result of the war;

- assessment and analysis of the technological capabilities of the state in the disposal of military waste;

- calculation of the need for metal products to ensure the strategic goals defined by the defense policy of the state.

The literature rather limitedly covers the issue of processing military waste in countries that have had active hostilities over the past decades, for example, in Afghanistan, Iraq, Bosnia and Herzegovina, Georgia, Transnistria. This situation is primarily due to the fact that the problem of disposal is not solved, and the equipment remaining after active hostilities accumulates in landfills near the place of deployment of military bases. Such a scenario is one of the likely but undesirable for Ukraine since Ukraine had a critical amount of landfills before the outbreak of hostilities and this problem was described in the National Waste Management Strategy in Ukraine until 2030.

The implementation by the state of all operations related to the disposal of military waste has a number of advantages in the form of a set of economic, environmental, and social effects and restrictions that hinder the use of this model in Ukraine (Fig. 4).

The limitations of the implementation of this model are the lack of state technological capacities capable of disposing of military waste.

The implementation of the model of placement of military waste in landfills is the least costly but it threatens the environmental safety of not only Ukraine but also neighboring countries. In Ukraine, only the non-recycling of household waste has led to the allocation of significant land areas for landfills. Thus, as of 2022, there were 33,000 unauthorized and 6148 uncontrolled landfills in Ukraine (their total area exceeds 9 thousand hectares) [19], which is one third more than the area of San Marino.

The placement of military equipment at specially designated landfills is a cheaper way to handle military waste but the increase in their number and area will further aggravate the problem, which had already acquired a critical state before the start of the war. Each military conflict, the emergence of new technological solutions increases the area of military equipment dumps. The world already has a tank dump in Usuriysk, near Kabul, in the Netherlands, in Kubinka, at sea off the coast of Ireland, a dump of aircraft in Arizona [1]. The use of the model of placement of military waste in landfills of military equipment will increase the world statistics of such landfills, thereby increasing the level of environmental hazard (Fig. 5).

The implementation of this model has a number of advantages that form the criteria for the attractiveness of its use. The absence of technological costs, demand risks ensure minimal efforts to implement this model, leading to the loss of secondary resources that can be used in the process of recycling military waste.

The model of transfer of powers for the management of military waste to business entities provides for the following actions:

- performance by state-owned enterprises of separate operations in the chain of military waste management (verification of safety and possibility of disposal);
- involvement of business entities in the implementation of certain operations;
- control by the state over the activities of such entities.

The implementation of this model can become a kind of direction of support for business entities in the post-war period and the growth of state budget revenues. Indeed, today enterprises in this field demonstrate a sharp drop in the scale of their activities. According to the Ukrainian Association of Secondary Metals, the volume of scrap harvesting in Ukraine in January–April 2022 decreased by 50.4 % compared to the corresponding period of 2021 – to 620.1 thousand tons [20].

### *Model 1. Participation of the state in the implementation of the whole complex of actions in the military waste management system*



Fig. 4. Advantages (+) and limitations (–) of the implementation of model No. 1

### *Model 2. Placement of military equipment at specially designated landfills*

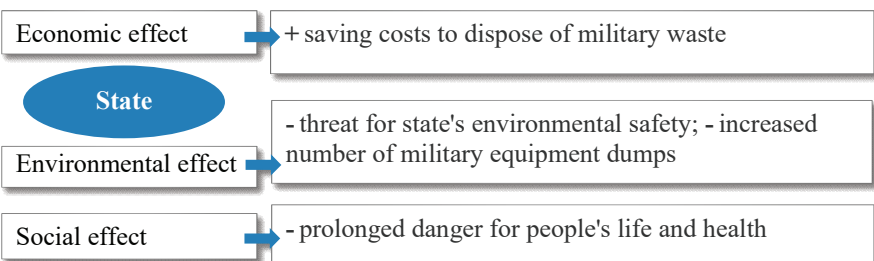


Fig. 5. Advantages (+) and limitations (–) of the implementation of model No. 2

When implementing the third model, the state may transfer the authority (for the collection, transportation of waste from combat sites, disassembly, and preparation of military equipment) for disposal to specialized private enterprises on contractual terms in compliance with all requirements for the management of such waste. In this case, the functions of the state, implemented through special services, will be:

- checking the destroyed equipment for explosiveness before the start of the process of its transportation to the disassembly sites;
- supply of parts suitable for the repair of military equipment and weapons to Ukroboronprom enterprises that will repair and restore equipment of the Armed Forces of Ukraine.

When performing all other operations, the state reserves the function of monitoring their implementation.

However, now this scheme has a number of significant obstacles, the elimination of which before the end of hostilities is difficult. A significant part of the capacities that could be involved in the process of recycling of military equipment is located in the occupied territories or in the territories where active hostilities are taking place. As a result of the hostilities, a number of production facilities were destroyed that could participate in this process after the cessation of hostilities and de-occupation, and the process of their restoration is quite long and costly.

The implementation of this model of military waste management requires the following measures:



- introduction of a legally enshrined mechanism and regulatory basis for the distribution and consolidation of the functions of the disposal process between the state and specialized private companies;

- determining licensing requirements for participants in the process;

- regulation of the process of transfer of rights to perform each stage related to the disposal of destroyed military equipment;

- development of a mechanism for controlling state authorities over the implementation of disposal operations.

The distribution of powers in the management of military waste between the state and business entities will make it possible to attract private entrepreneurship to the field of waste management, the competitive selection of business entities will ensure the growth of entrepreneurial initiative and the choice of the best way to perform individual operations in the waste management chain. The effectiveness of such a model will be realized in a set of budgetary, infrastructure, social effects for both the state and the business entity (Fig. 6).

Despite the significant advantages of using this model, there are restrictions on its use, which are associated with the existing legislative consolidation of the ownership of military waste by the state. However, the legislation regulates relations related to military waste generated in military units and belonging to the military weapons of Ukraine. None of the legislative acts establishes the ownership of waste generated from the destruction of enemy military weapons and equipment in the country. Accordingly, the implementation of this model implies the need to adopt the procedure for handling destroyed military equipment and weapons or to consolidate ownership of them by the state with the possibility of transferring certain functions to business entities.

The model of setting up small enterprises for the disposal of military waste in places of localization of hostilities requires a significant amount of financial investment and a long time frame. This model cannot be implemented until the complete cessation of hostilities. However, from the standpoint of rebuilding the economy of the most affected regions, creating new jobs, filling budgets of different levels with tax revenues, this scheme may be one of the most effective after the end of the war.

The advantages of this model are associated with a change in the defense strategies of most countries of the world and a possible increase in global militarization, which will lead to the accumulation of significant amounts of morally and physically outdated equipment in the long term. As the analysis of scientific information showed, the problem of the availability of capacities for the disposal of military equipment remains unresolved in the world, which leads to their accumulation in landfills. The country's reconstruction model, which includes the construction of new modern metallurgical enterprises,

will make it possible for Ukraine to determine its place in the global market for military waste disposal services. This strategy is relevant in view of the long-term prospects of Ukraine's participation in the formation of a new system of world economic relations. Thus, the implementation of the model of construction of new metallurgical enterprises is based on the priorities of the new post-war industrial and defense policy of the state. Expansion of technological capacities for the remelting of military waste, in addition to additional resources, will make it possible to obtain a social effect in the form of an increase in the level of employment of the population, the return of citizens of Ukraine temporarily displaced abroad (Fig. 7).

Economic incentives for investment in new construction are provided for by the Law "On State Support of Investment Projects with Significant Investments in Ukraine" (No. 1116-IX of December 17, 2020). In order to be able to use the system of benefits defined by this law, there is a need to include activities in the field of metallurgy in the list of requirements for investment projects with significant investments.

The model of military waste management, which provides for a state order for the processing of military waste at metallurgical enterprises of Ukraine, is based on the preservation of ownership of metals obtained as a result of their remelting by the state. According to the Commercial Code of Ukraine, state procurement is a means of state regulation of the economy. State procurement is carried out by forming on a contractual (contract) basis the structure and volume of products (works, services) necessary for priority state needs, as well as placing state contracts for the supply (purchase) of these products (performance of works, provision of services) among business entities, regardless of their form of ownership.

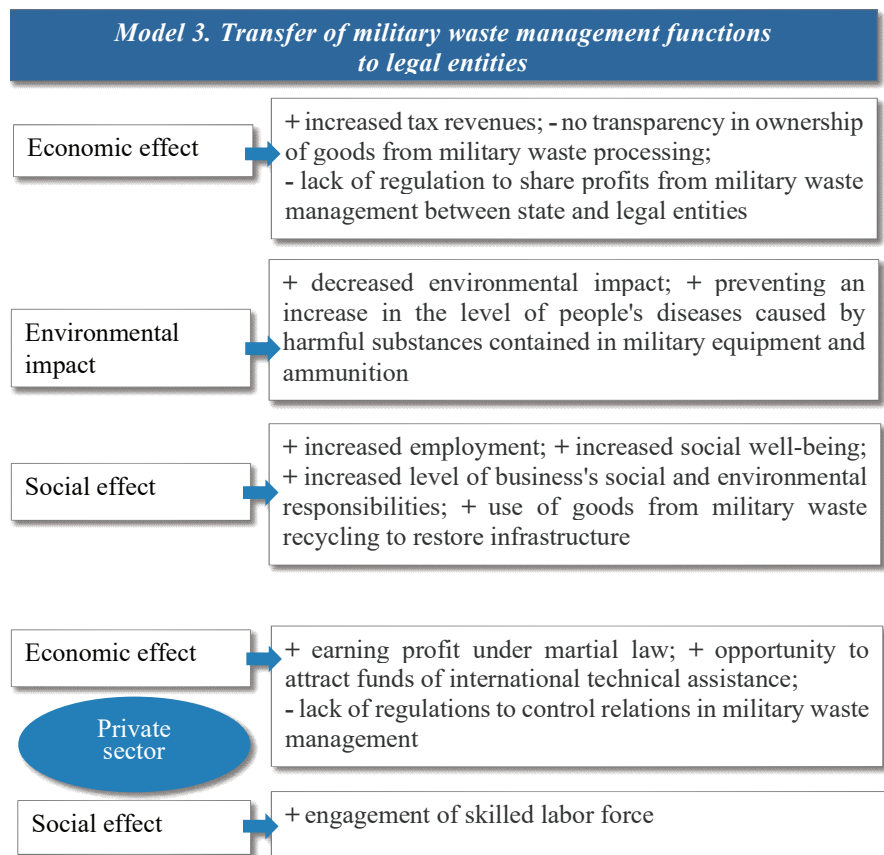


Fig. 6. Advantages (+) and limitations (–) of the implementation of model No. 3

This form of relationship may provide for various forms of financing, for example, financing at the expense of loans under state guarantee; full coverage of expenses for budget funds or funds of international technical assistance. Enterprises that have a contract for state procurement may receive tax benefits or be partially or completely exempt from paying taxes. Performing work under the state order requires obtaining special permits (licenses). Such a model can be cost-effective both for the state and for business entities, since as a result of its application, the problem of processing military waste is solved, business is supported under martial law and budget revenues are ensured (Fig. 8).

The implementation of this model involves amendments to the Law of Ukraine "On Public Procurement" [21], namely changes under the conditions for forming an order for the disposal of destroyed military equipment.

The public-private partnership model provides for a balance of interests of the state and the private sector. This model is a system of relations between public and private partners, in the implementation of which resources are combined. At the same time, there is also an appropriate distribution of risks, responsibilities, and rewards (compensations) between partners for mutually beneficial cooperation on a long-term basis. The interaction consists in the creation (restoration) of new and/or modernization (reconstruction) of existing objects that require investment, and in the use (operation) of such objects [22].

The relationship between the state and the private partner should be based on an agreement on joint activities or property management, as well as concession and mixed agreements. The private partnership scheme can be implemented both through the interaction of the state and private enterprises, and a combination of the previous model, which provides for the construction of facilities for the processing of military waste on the terms of public-private partnership, can be appropriate. Public-private partnership will attract foreign investment in the construction of new, small, modern metallurgical enterprises, or contribute to the creation of joint ventures. Moreover, the canvas of the implementation of this model was formed in the pre-war period. For the disposal of military waste, it was planned to create a joint venture with the participation of the Ukrainian state enterprise Ukrob-

oronservice and the German company Battle Tank Dismantling GmbH Koch. On the territory of Germany, Battle Tank Dismantling GmbH Koch was granted the right to buy military equipment from the state for its disposal and transferred the right to sell the metal. Despite the fact that this organizational model has not been implemented in Ukraine, the plan for its implementation indicates the existence of economic interest in public-private partnership.

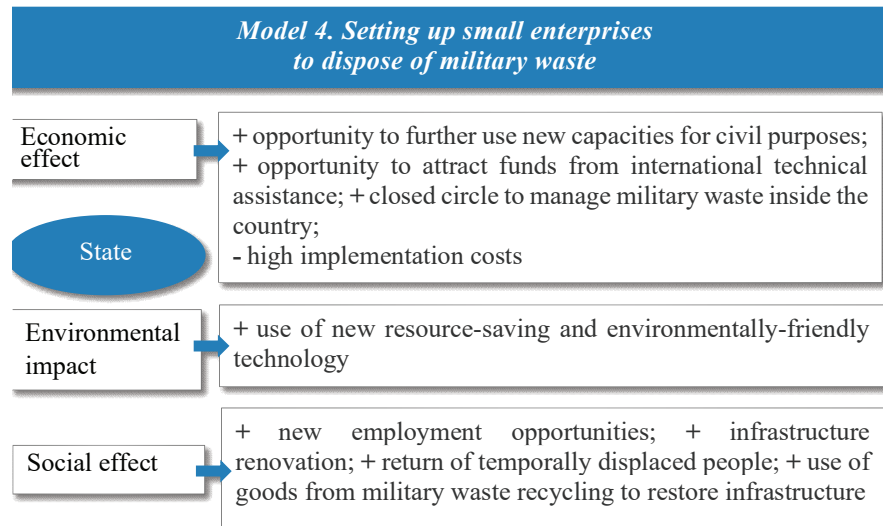


Fig. 7. Advantages (+) and limitations (-) of the implementation of model No. 4

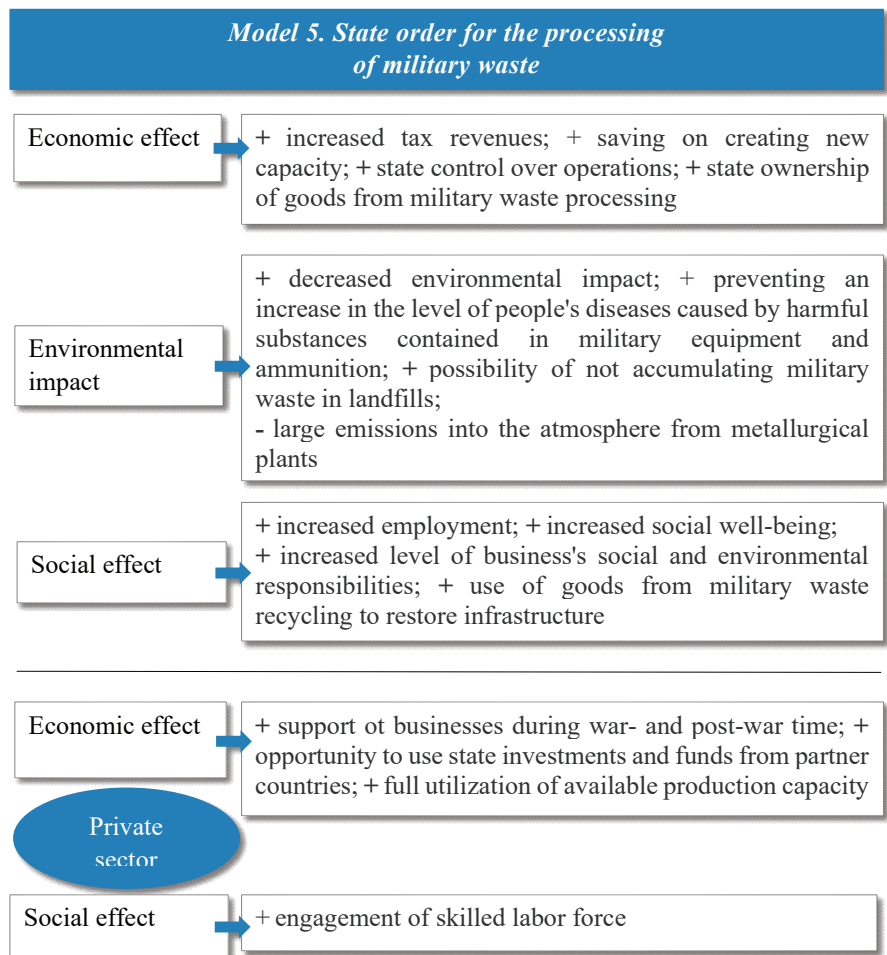


Fig. 8. Advantages (+) and limitations (-) of the implementation of model No. 5

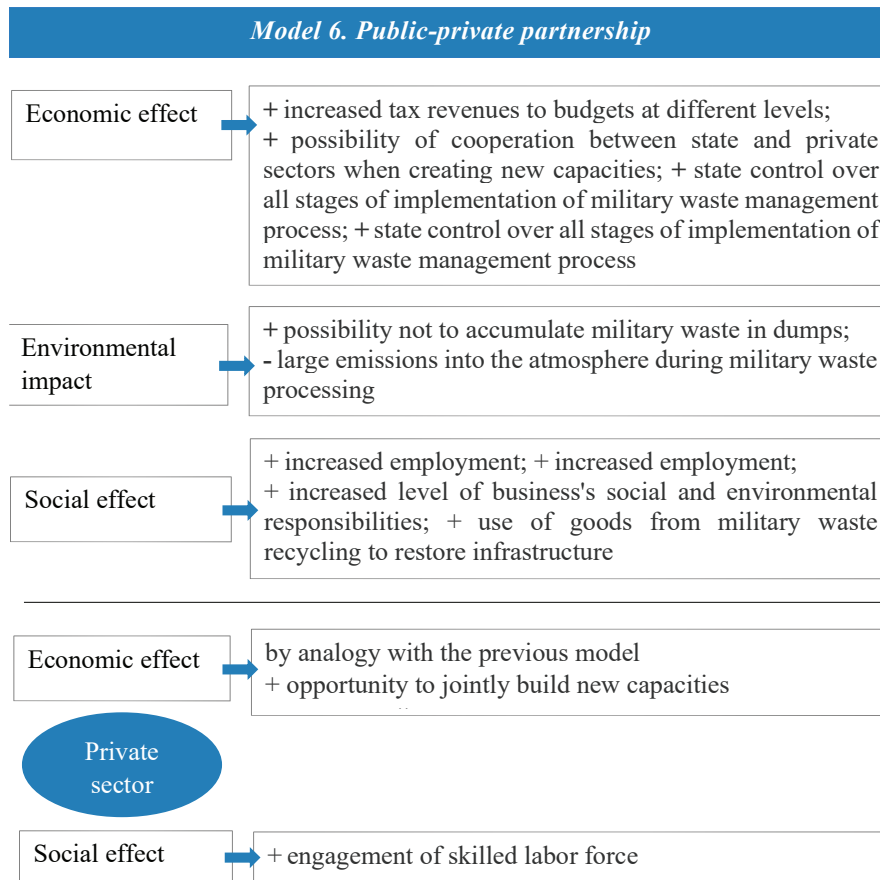


Fig. 9. Advantages (+) and limitations (–) of the implementation of model No. 6

The use of this model requires amendments to the Law of Ukraine “On Public-Private Partnership” in terms of partnership objects and consolidation of state functions in the management of the created metallurgical enterprise.

The implementation of the model of export of military scrap metal is due to the imbalance of supply and national demand for military scrap. In addition, the export of scrap metal is encouraged by the lack of necessary capacities for their processing. According to the Law of Ukraine “On Scrap Metal” [23], the export of scrap metal, which was formed in military units, military institutions, military educational institutions of the Armed Forces of Ukraine and other military formations, is prohibited. However, no legislative act defines a ban on the export of scrap resulting from the destruction of military equipment that does not belong to the Armed Forces of Ukraine.

The application of this model of military waste management should take into account the fact that certain processes that precede the export of scrap metal must be implemented in Ukraine. In particular, the process of collecting military waste, sorting, and checking for explosiveness, further logistics, as well as the possibility of using suitable spare parts and assemblies for the repair of equipment of the Armed Forces of Ukraine. That is why this scheme can be effective provided that it is combined with other models proposed in the study. Moreover, the movement of waste across the border of Ukraine is carried out subject to the consent of the Ministry of Environmental Protection and Natural Resources of Ukraine for the transboundary movement of waste. Such movement is regulated by the Resolution of the Cabinet of Ministers of Ukraine “Regulations on the con-

trol of cross-border transportation of hazardous waste and its disposal/disposal and the yellow and green list of waste” [24]. In addition, the division of waste into Yellow and Green determines different conditions for their transboundary movement.

The model of export of military waste refers both to low-cost and not to the country all the benefits from the use of military scrap metal (Fig. 10).

The problem of exporting military waste is its sorting and organization of logistics to the place of supply.

In order to avoid legislative conflicts that may arise when identifying the ownership of scrap metal formed from destroyed military equipment, it is necessary to amend the Law “On Scrap Metal”. Supplementing military waste with waste generated as a result of the destruction of enemy equipment and permission to export their scrap metal will be able to reduce the area of landfills on the territory of Ukraine.

The effectiveness of the choice of one of the directions cannot be stated unequivocally because each of them has its advantages, disadvantages, and prerequisites for its application.

Recycling of military scrap metal is associated with the availability of organizational, labor, financial costs, and technical capabilities. Before the outbreak of hostilities, Ukraine was included in the list of the main countries for the production of metallurgical products with the 14th rating of world steel production, which indicates the availability of all necessary prerequisites for the disposal of military scrap.

Awareness of the need for military waste management determines the choice of the method and participants in the waste management chain. The Ukrainian Association of Secondary Metals (UAVtormet) and the Austrian company Dobrowa Metalltechnik GmbH signed an agreement on the exchange of experience in order to introduce technologies for the processing and disposal of military scrap in Ukraine. The agreement on cooperation on a number of strategic and topical issues was concluded with the full support of the Federal Economic Chamber of Austria [25].

Realizing the fact that the entire system of relations of a market economy is based on the realization of the economic interests of its participants, the disposal of military waste should bring effectiveness in the economic, environmental, and social dimensions. At the same time, the priority of choosing performance evaluation indicators is determined by the subject of contractual relations. In addition, the choice of priorities is also due to the consideration of the obvious and implicit delayed benefits that the subject receives.

When recycling military waste, all participants in the waste management chain have the main economic dimension of performance, the state has an economic, environmental, and social dimension. The state, as a body for regulating

and controlling the ecological state of the environment and the social condition of its citizens, takes into account all the results obtained by choosing the method of handling military equipment.

content of components made of carbon steel or cast iron in the tank on average does not exceed 30 %. Components made of non-ferrous metals, primarily the engine and its parts, electrical wiring, electronic systems make up to 15 %.

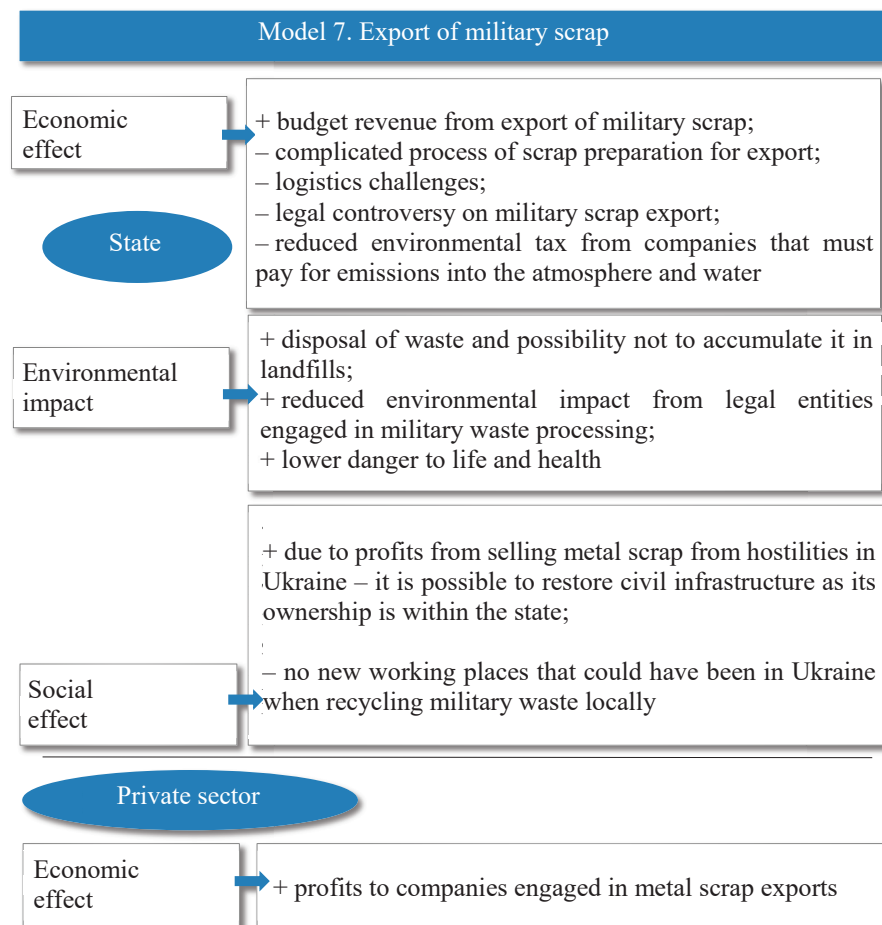


Fig. 10. Advantages (+) and limitations (–) of the implementation of model No. 7

Each of the models described in the study has its advantages and disadvantages, which should be taken into account at the selection stage. Under the conditions of unfinished hostilities, the most acceptable may be the use of a model for transferring the functions of military waste management to business entities. This model can be used at the stage of collection and transportation of military waste with the involvement of specialized government agencies that can check such waste for explosiveness.

## 6. Discussion of results of the study of military waste management models

As a result of Russia's invasion of Ukraine, over seven months of active hostilities, the average monthly military waste amounted to 26 thousand tons (Fig. 2), of which 11 thousand tons in the last period. In general, scrap metal from the possible disposal of destroyed equipment consists of tanks (up to 30 %), armored vehicles for transporting infantry (up to 40 %), road transport for various purposes (up to 15 %), and other equipment, including aviation (up to 15 %) [26]. Military equipment consists of various types of metals with a specific chemical composition, which limits the use of such steel in the usual metallurgical process. The

technological capabilities of waste management, the needs of the defense sector, the state budget and employment in the country should be taken into account. Generalization of the effects shown in Fig. 4–6 forms an understanding of the main advantages of using each of the proposed models and makes it possible to make a choice taking into account the priorities of economic, environmental, and defense policy.

The limitations of this study are the lack of sufficient world experience in managing waste generated as a result of war, and, as a result, insufficient scientific activity in solving problems of this problem. All this complicated the possibilities of systematization and wide generalization of best practices for the management of such waste.

The limitations of the study are the impossibility of calculating the break-even level and quantitative measurement of effects in the implementation of each of the waste management models under conditions of incompleteness of hostilities.

In the context of this study, military waste will not be considered as worn-out military facilities. In addition, the restrictions for this study were those types of military weapons, the volume of destruction of which is not statistically confirmed (weapons, ammunition, shells).

The disadvantages of the study are related to the neglect of the rights to waste assigned to various government agen-



cies. For example, the disposal and recycling of aircraft is under the control of SBU as some components are of strategic importance for the defense industry of the state. Disposal of ammunition and land military equipment is carried out by enterprises of the Ministry of Defense. The downed tank on the spot is examined by explosives for the presence of explosives, after which the Ministry of Defense transports it to its own sites where defense specialists dismantle the surviving parts for reuse. The remaining part of the tank is sorted by types of metals that can be sold at open auctions or transferred to defense enterprises.

Our study is not related to the technological features of the disposal of each type of military weapons, its results are generalizing in nature and can be used when choosing the method of handling each type of destroyed military weapons.

The development of this study is possible in the direction of achieving the principle of balancing the economic interests of all participants in the military waste management chain in the implementation of each of the models of their management.

## 7. Conclusions

1. Under the conditions of active hostilities on the territory of Ukraine, the monthly volume of military waste generation is about 20 thousand tons. This, on the one hand, is a potential source of secondary metals for the country's defense needs, and on the other hand, it requires choosing a rational way to handle it.

The models of military waste management in force in the pre-war period enshrined the exclusive right of the state to dispose of them. In the context of significant and rapid accumulation of environmentally and explosive military waste, there is a need to expand the ways of their disposal based on the best world experience and national capabilities. All this requires determining the volume of state demand for secondary metals for defense needs, and the legally defined transfer of certain rights to complicity in the disposal of military waste to privately owned enterprises.

2. The unpredictable processes of deployment of hostilities and the need to eliminate the consequences of the war determines the urgency of making a set of management decisions. These decisions will contribute to the formation of models of military waste management, which will be based on internal capabilities and take into account the environmental, economic, and social priorities of the country.

The most integrated performance of military waste management is achieved by combining models in accordance with the stages of the waste management chain. Thus, the model of public-private partnership can be used at the stage of disassembly, cutting, sorting, military waste. The model of formation and placement of the state order for the processing of military waste at metallurgical enterprises of Ukraine should be implemented at the stage of their disposal (or recycling). The model of export of scrap metal should be applied at the stage of sale of secondary metals obtained in the process of recycling military waste. The choice of a model of military waste management is subordinated both to the country's defense needs and is consistent with the policy of post-war reconstruction of destroyed cities and ensuring their economic development. Thus, the model of construction of small state-owned enterprises with modern recycling technologies makes it possible to create new jobs and increase the level of employment. Another model, which provides for the transfer of powers for the management of military waste to business entities, will stimulate the development of entrepreneurial initiative and reduce the level of social tension.

The implementation of each of the models of military waste management is ensured by legislatively enshrining the rights of the subjects of the enterprise to perform individual operations of military waste management. In addition, the joint participation of the state and entrepreneurship is possible only on the condition of balancing the realization of their economic interests.

## Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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## Data availability

Manuscript has no related data.

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