Reducing environmental damage through the use of unmanned aerial vehicles as the best available technology

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Abstract. The article examines the possibilities of using unmanned aerial vehicles as the best available technologies in the field of agriculture and mining. The object of the study is the use of unmanned aerial vehicles as the best available technology. The main areas of application of this technology are identified: agro technical operations, aerial photography of mining operations. The technology of unmanned aerial vehicles is compared with the technologies of ground agricultural machinery. The research methodology includes an expert evaluation of the unmanned aerial vehicle technology belonging to the class of the best available technologies by the criteria: the level of environmental impact, resource saving, the use of low-waste, non-waste processes, the existence of at least two objects, economic efficiency. Expert evaluations were processed using the apparatus of fuzzy sets, which make it possible to construct membership functions. This allowed us to prove that the technology of unmanned aerial vehicles belongs to a fuzzy set of the best available technologies. The results of the research show that the use of unmanned aerial vehicles provides a saving of resources, especially non-renewable combustible minerals, reduces emissions and discharges of pollutants into the atmosphere, and also reduces soil erosion. Unmanned aerial vehicles should be included in the national directories of the best available technologies for the mining industry and agriculture.

1. Introduction
In industrially developed countries, resource-type regions, to date, significant environmental damage has been accumulated, the ecological situation is tense. This strengthens the scientific and practical interest in environmentally safe and low-waste technologies. These technologies allow obtaining the same economic, production results with a sharp decrease in the load on the environment. To create environmentally friendly technologies there are scientific and technical and organizational and economic prerequisites. Scientific prerequisites are associated with the creation and development of fundamental principles for obtaining new materials, technical processes, physical-chemical and mechanical basis for the transformation of matter and energy. Organizational prerequisites are associated with increased interest in reducing environmental damage under the influence of state regulation, legislative requirements, and social responsibility. For the characterization of environmentally safe or low-waste technologies, the notion of "best available technologies" became widespread [1, 2, 3].

Under the best available technology, it is customary to understand the technology of production, determined on the basis of modern scientific achievements and the best combination of environmental protection criteria, provided that the technical feasibility of its application is available [4]. The best available technology is an economically efficient technology with minimal environmental damage. When implementing the best available technologies, the joint responsibility of producers and consumers is taken into account in the course of the production, sale and use of products [5]. The introduction of the best available technologies is the main direction to improve environmental safety, to achieve the effect of decoupling. The best available technologies are the basis for progressive environmental regulation, which ensures minimization of environmental damage. Legislation on environmental protection of the world's leading countries, including Russia, seeks to stimulate enterprises with...
maximum environmental damage to the transition to the best available technologies. These investment projects can be considered as projects of dual purpose or double effect (economic and environmental). However, this process has a long-term perspective.

The criteria that allow attributing technology to the best available technologies are: minimum level of negative environmental impact on the environment on a unit of production (level of emissions, discharges, disturbance of natural landscapes, etc.); resource saving, saving of non-renewable natural resources, in particular, fuel and mineral raw materials; use of low-waste or non-waste processes; existence of at least two objects on which technology can be applied; economic efficiency of use. Rapid development of research and development leads to the active emergence and use of new technologies that do not always have time to be evaluated according to the criteria of the best available technologies. Because of this, they do not fall into the basic directories and classifiers of the best available technologies that regulators use. As a result, a number of advanced technical solutions are not integrated into the national system of the best available technologies. This forms an urgent scientific and applied problem.

One of the progressive technologies that contribute to reducing environmental damage is the use of unmanned aerial vehicles [6, 7]. The very principle of unmanned aerial vehicles is not new (the lethal vehicles without the presence of a human operator on board were used in the 1930s), but their active introduction into civilian industries began in the 2000s. The main areas of application of unmanned aerial vehicles are various kinds of survey of surfaces, inventory of objects, carrying out of territorial measurements, etc. The application of this technology is developing in agriculture, mine surveying, logistics, as well as insurance and entertainment.

But the main advantages of the technology of unmanned aerial vehicles in the literature are higher economic efficiency, high availability, the possibility of obtaining large amounts of data, cheaper formation of information bases per unit of information [6, 7, 8]. Indeed, in comparison with classical (manned) aircraft, unmanned aerial vehicles are not only much cheaper, but also satisfy a wider range of needs, give new opportunities to producers and consumers [9, 10]. However, unmanned small aircraft has many features of the best available technology in terms of resource intensity, reducing environmental damage, economic efficiency. At the same time, the theoretical and applied aspects of the use of unmanned aerial vehicles as the best available technologies in various types of economic activity have not been studied to date. Therefore, the purpose of this study is to justify the rationality of using unmanned aerial vehicles as the best available technology for forming the ecological foundations of progressive technological schemes. The area of research is the scope of unmanned aerial vehicles in particular, agriculture and mining.

2. Results and Discussion

To develop classifications and directions for using the best available technologies, the main method is the expert method. This is due to the complexity, poor structuring of information on environmental damage and the economic efficiency of technology. The method of expert assessments allows us to formalize the verbal statements of experts in natural language. At present, special working groups are used to compile directories of the best available technologies, which in fact mean an expert method. To assess the technologies of unmanned aerial vehicles for compliance with the criteria of the best available technology by the "snowball" method, an expert group was formed from among specialists in agriculture, the coal industry, fundamental science and public administration. The required number of experts is calculated by the formula:

\[ N = \frac{1}{2} \left( \frac{2}{\alpha} + 5 \right) \]  

where \( \alpha \) is an admissible error, \( N \) is the number of the expert group.

At \( \alpha = 0.05 \), the number of experts \( N \) will be 33 people. A group with such a number was formed. To process the data obtained, we used the method of constructing the membership functions associated with the theory of fuzzy sets. This theory is based on a multivalued logic with an arbitrary number of truth values. It is known that the usual (clear) subset \( A \) of the set \( X \) can be associated with the membership function (2):
In the theory of fuzzy sets, the possibility of working with judgments in natural language, which does not have clear formalized characteristics, is considered. A fuzzy set is understood to mean the set (3):

$$A = \{x, \mu_A(x) | x \in X \}$$

where $X$ is a universal set; $\mu_A(x)$ is the membership function characterizing the degree of belonging of the element $x$ to the fuzzy set $A$.

Therefore, a fuzzy set is a collection of ordered pairs, including elements $x$ of the universal set $X$ and corresponding membership functions $\mu_A(x)$. The membership functions are mathematical functions that can be piecewise linear, Z- and S-shaped, U-shaped. In the study, the S-shaped membership function (spline function), which is given by expression (4), is used to process expert estimates.

$$f_{sI}(x; a, b) = \begin{cases} 0, & x < a \\ \frac{1}{2} + \frac{1}{2} \cos \left( \frac{x-b}{b-a} \pi \right), & a \leq x \leq b \\ 1, & x > b \end{cases}$$

The criteria for assigning technology to the best available class, according to the order of the Ministry of Industry and Trade of Russia of March 31, 2015, No. 665 «On approval of methodological recommendations for the definition of technology as BAT», are: the level of environmental impact, resource saving, use of low-waste, non-waste processes, the existence of at least two objects, economic efficiency. The last criterion also reflects the productivity of the technology, taking into account the ratio of the production result and the costs of the enterprise.

By processing expert assessments of the five criteria for classifying technologies as the best available technologies, the following data were obtained (Table 1, 2, Figure 1).

**Table 1.** Data of the expert assessment of the compliance of unmanned aerial vehicle technology with the criteria of the best available technology (number of expert answers in the interval)

| Evaluation Criteria                        | Number of responses in the interval |
|--------------------------------------------|------------------------------------|
|                                            | does not meet the criteria | weakly matched | average criterion | meets the criterion | fully meets the criterion |
| Level of environmental impact               | 2 | 0 | 7 | 19 | 5 |
| Ensuring resource conservation             | 1 | 2 | 5 | 21 | 4 |
| The use of low-waste, non-waste processes | 0 | 4 | 3 | 20 | 6 |
| The existence of at least two objects      | 3 | 2 | 0 | 23 | 5 |
| Economic efficiency                         | 2 | 2 | 2 | 18 | 9 |
Table 2. Accumulated response rate

| Evaluation Criteria                          | The accumulated response frequency in the interval |
|---------------------------------------------|---------------------------------------------------|
|                                             | does not meet the criteria | weakly matched | average criterion | meets the criterion | fully meets the criterion |
| Level of environmental impact               | 0.06                               | 0.06           | 0.27             | 0.85                | 1.00                       |
| Ensuring resource conservation              | 0.03                               | 0.09           | 0.24             | 0.88                | 1.00                       |
| The use of low-waste, non-waste processes   | 0.09                               | 0.15           | 0.15             | 0.85                | 1.00                       |
| The existence of at least two objects       | 0.09                               | 0.15           | 0.15             | 0.85                | 1.00                       |
| Economic efficiency                         | 0.06                               | 0.12           | 0.18             | 0.73                | 1.00                       |

Figure 1. The functions of unmanned aerial vehicle technology belonging to the set of the best available technologies by all criteria

The experimental data on the expert assessment of the unmanned aerial vehicle technology belonging to the best available technologies show their compliance by all criteria. The form of the membership functions is such that the area of the right subspace considerably exceeds the area of the left subspace. On most criteria, the type of membership graphs is very similar, since most peer evaluations are assigned to intervals 4 and 5 (compliance and full compliance with the criteria of the best available technologies). And the most significant is the membership function according to the criterion of "economic efficiency". Here, the cumulative response rate in the intervals 1-3 is only 0.18; 82% of assessments refer to the relevance of the technology to this criterion and its full compliance. Therefore, the assessment shows that unmanned aerial vehicles are the best available technologies for a number of economic activities, in particular, agriculture and mining.

Consider the basic spheres of application of the technology of unmanned aerial vehicles as the best available technology. To this end, we will focus on those economic activities where this technology
provides a reduction in environmental damage - agriculture and mining. These fields of application retain their positions in the economy, but require the solution of environmental problems.

To select the best available technology, the following technologies were compared:

1. Technologies of agro technical operations (soil cultivation, planting of crops, fertilizers, chemicals) using ground and air equipment, respectively. The result of the application of technology is the implementation of agro technical operations required in crop production.

2. Technologies of aerial photography of mining operations using ground and air equipment, respectively. The result of applying the technology is obtaining information about the state of the "mountain environment - technology" system, which is necessary for making engineering decisions.

Let us dwell on the potential of the corresponding technologies in more detail.

Unmanned aerial vehicles in agriculture are used to monitor the growth and development of plants, the state of agricultural landings (instead of satellite imagery); carrying out agro technical measures (sowing, sprinkling, application of nutrients) [11, 12]. Technologies of the first direction practically do not involve ecological damage and are not considered in this research. Replacing unmanned aircraft with traditional agricultural equipment (tractors, cultivators, etc.), by contrast, deserves close attention as the best available technology. The principle of operation of an unmanned aerial vehicle in this case is that instead of ground equipment with an internal combustion engine, air technology, usually with an electric motor, is used (although some large unmanned aerial vehicles can also be equipped with an internal combustion engine).

The ecological effect will be caused by a number of factors. First, a smaller mass and lack of environmental resistance for an unmanned aerial vehicle lead to less need for kinetic energy for movement. This helps to save energy in principle. Further, even less powerful electric motor in comparison with the internal combustion engine practically does not produce harmful emissions. More precisely, the production of electrical energy, as a rule, is accompanied by environmental damage, but it is much lower in comparison with an autonomous internal combustion engine. Replacing fuel cycle engines (petrol, diesel) with electric motors is a worldwide trend, reflecting the development of environmentally friendly technologies. Although this practice seems to move emissions and discharges of harmful substances into the early stages of the technological chain (generation of electrical energy at thermal, nuclear, hydraulic stations), the total ecological damage is reduced for a set of economies of scale.

Secondly, moving through the air instead of moving along the ground ensures that there is no pressure on the fertile soil layer, which also sharply reduces environmental damage. Soil compaction by ground agricultural machinery is one of the main causes of soil erosion, dispersion and loss of the fertile layer. And even the use of progressive no-till technology of cultivation of the land with the exception of the overthrow of the formation does not completely exclude the compaction of soil by the movers of agricultural machinery. The transition from the movement of agricultural units on the ground to travel by air is a fundamental breakthrough solution to the problem.

Thirdly, the qualitative growth of information on the development of plants can significantly reduce the introduction in the agro-industrial landscape of unusual, in a certain sense, foreign substances – fertilizers, especially pesticides. Traditional agro technical methods of fertilizing soils, destroying pests, fighting diseases are based on unified methods of introducing certain chemicals with minimal feedback. Survey of crops with the help of unmanned aerial vehicles will allow to accurately determining the need for nutrients, the degree of infection with pests in various areas of agricultural land. As a result, only a minimum amount of new substances is introduced into the agrarian landscape.

At the same time, with the use of unmanned aerial vehicles, a new environmental problem is emerging – the recycling and recycling of batteries, which are usually used as an energy carrier for the device. However, modern hybrid batteries with the possibility of multiple recharging have less weight and more efficiency, so the amount of utilization will most likely not exceed the need for recycling of standard low-antimony and calcium batteries (they are usually used in agricultural machinery). In addition, in agricultural machinery (tractor), diesel engines are most often used, which require the use of batteries with larger capacity and starting current. Therefore, the mass of such batteries is much
higher. If, on the other hand, the unmanned aircraft motor is powered by solar panels, it is possible to obtain a significant lengthening of the battery life in the absence of self-discharge.

Consequently, the use of unmanned aerial vehicles in agriculture fully meets the criteria for the best available technology: the absence or minimum level of waste, the use of less hazardous substances, the reduction or elimination of harmful emissions and discharges. Obtaining accurate estimates of changes in the ecological effect and environmental load will additionally justify the environmental effectiveness of the further introduction of unmanned aerial vehicles in agriculture. Due to the lower cost of one hour of operation, a higher economic efficiency of the technological operations is achieved.

In the mining industry (extraction of ore, nonmetallic minerals), unmanned aerial vehicles are used for geological exploration (mapping, scanning, reconnaissance, other functions, for example, sampling); operational planning of mountain preparatory and mining operations (design, monitoring and mapping, surveying measurements); monitoring of mining and geological conditions (behavior of the mountain environment and technological scheme); identification of risks and environmental threats (violations of technology, the environment, the presence of emissions). There is a practice of using unmanned aerial vehicles for direct carrying out individual mining operations (destruction of space, collapse of rocks, clearing of passages) [13, 14]. In this type of economic activity, unmanned aerial vehicles rather automate those works that were previously performed by specialists manually. Therefore, the potential for the formation of the best available technologies is estimated here below. Nevertheless, in some cases, unmanned aerial vehicles can also contribute to reducing the environmental load.

The first direction of reducing environmental damage is the exclusion of aerial photography and observations using classical aviation (helicopters). It is known that manned aviation assumes a significant consumption of combustive-lubricating materials (kerosene, gasoline), obtained from non-renewable raw materials. Their burning leads to emissions of harmful substances into the atmosphere. For a 30-minute runway, the engine of the most popular MI-8 helicopter emits 340 grams of carbon monoxide and up to 1,000 grams of nitrogen oxides (nitrogen oxide, nitrogen dioxide). When using unmanned aerial vehicles, these emissions are excluded. Environmental damage is reduced to the problem of utilizing fully used batteries.

The second direction is the reduction of environmental damage – control of spontaneous combustion of waste rock piles, stored masses of coal and other combustible minerals. Traditional methods of control are characterized by inadequate speed and precision. Spontaneous combustion of coal, slate, carbonaceous rocks, sulphide ores, peat leads to significant emissions of nitrogen oxides, hydrogen sulfide, methane, etc., which causes great harm to the health of the population. Due to demolition of precipitation products by atmospheric precipitation, additional contamination of soil and water occurs, large deformations of the land cover. Accelerating the monitoring of clusters of substances prone to spontaneous combustion and increasing the accuracy of this monitoring ensures faster measures to extinguish endogenous fires and reduce emissions. Thus, for the mining industry, the use of unmanned aerial vehicles contributes to resource saving and to reducing the negative impact on the environment. Consequently, this technology at the industry level meets the criteria of the best available technology. Unmanned aerial vehicles can be included in the lists of the best available technologies for relevant economic activities.

3. Conclusion

The development of the best available technologies in the country's economy requires the analysis, evaluation and integration of new prospective objects, processes and devices into national classifiers. The conducted evaluation of the technology of unmanned aerial vehicles proves their compliance with the criteria of reference to the best available technologies. The use of unmanned aerial vehicles ensures the saving of resources, especially non-renewable combustible minerals, reduces emissions and discharges of pollutants into the atmosphere, and also reduces soil erosion due to compaction, and contributes to the timely extinguishing of foci of spontaneous combustion. Consequently, unmanned aerial vehicles can be included in national guides for the best available technologies for mining and
Further development of the technology of unmanned aerial vehicles, according to the authors, requires comprehensive technical, ecological, economic research to determine technological schemes throughout the production cycle. The basis of these surveys should be the principle of minimal environmental damage throughout the entire technological cycle (rather than local sub-configuration in a separate link). This principle is well known in production management, logistics, supply chains; it is focused on the search for a common optimum. Extending the principle of minimum costs (damage) to the analysis of the best available technologies will allow identifying those technologies that reduce overall damage, analyze emissions and discharges at all stages of the process chain.

In particular, considering the damage from various options for the use of machinery in agriculture, it is necessary to take into account the costs for the production of all types of energy carriers (fuels and lubricants, electric power, batteries, etc.), their transportation, periodicity of use, utilization, etc. Otherwise, the problem of finding local optima in a certain type of economic activity arises with the growth of cumulative environmental damage. Undoubtedly, the traditional problems of development of unmanned aircraft, in particular, legal, provision of physical and information security, organization of insurance protection require further research.

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