

Article

Potential and Investment Attractiveness of Implementing Climate Projects on Disturbed Lands

Svetlana S. Morkovina ¹, Nataliya V. Yakovenko ^{1,*}, Sergey S. Sheshnitsan ¹, Denis Kuznetsov ¹, Anton Shashkin ¹, Alexander Tretyakov ² and Julia Stepanova ¹

¹ Faculty of Economics, Voronezh State University of Forestry and Technologies Named after G.F. Morozov, 8 Timiryazev Str., Voronezh 394087, Russia

² St. Petersburg Research Institute of Forestry, 21 Institutsky Ave., St. Petersburg 194021, Russia

* Correspondence: n.v.yakovenko71@gmail.com; Tel.: +7-919-188-92-32

Abstract: Forest restoration projects can be categorized as climate projects, investments in the implementation of which exceed the investment costs of forest-climate projects, which reduces their attractiveness to investors. An algorithm for assessing investment costs of climate reforestation projects on disturbed lands has been developed. The potential of territories for the implementation of such project initiatives is available in all regions of Russia and amounts to more than 381 thousand hectares. For five studied polygons of disturbed lands (Kuzbass basin, Moscow basin, Western Siberia basin, as well as basins of Chelyabinsk and Belgorod Regions), the aggregated costs for the implementation of measures to create carbon-depositing plantations and ground cover were calculated. Investment costs for restoration of 1 hectare of disturbed land under the climate project vary from 82.6 thousand rubles to 116.9 thousand rubles. Cost analysis shows that the carbon intensity of investment in such projects on disturbed lands is quite high ($C_{cii} > 1.0$). The highest investment potential is observed in the Kuzbass basin, where C_{cii} is 2.01. To organize and implement the afforestation project on disturbed lands of the Kemerovo Region, investments in the amount of 66.7 thousand rubles/ha for capital expenditures and 24.7 thousand rubles/ha for current expenses will be required. The payback period of such an investment project, taking into account the discount rate, is 13.1 years, and during the study period (20 years) the income from the project will cover 228% of the spent funds. These data confirm that the investment potential of forest-climatic projects on disturbed lands is quite high.

Keywords: forestry; climate projects; project activities; investment costs; disturbed lands



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1. Introduction

One of the key factors of sustainable socio-economic development of Russia is the organization of rational use and preservation for future generations of land potential, which is the basis of its national wealth and a reliable foundation of the entire economy.

To date, the country has not formulated a clear and understandable land policy, has not formed an effective system of state management of land resources, and its main institutions, primarily such as forecasting and planning for the use and protection of land re-sources, land management, monitoring of the state of land, and land market infrastructure, are incapable of functioning.

The problem of disturbed lands and their restoration is one of the most pressing environmental and socio-economic challenges of our time and sustainable development of society. Intensive industrial development, mining and other anthropogenic impacts lead to a significant deterioration of land resources, which causes the need for comprehensive measures for their reclamation. Land degradation is a complex process influenced by many factors, and there is currently a lack of research in the scientific community that clearly links land degradation to climate change. In this regard, studying the implementation of

forest-climate projects on disturbed lands is of particular importance. In Russia, interest in climate projects began to be actively expressed from 2020 to 2021 during the development of corporate decarbonization plans, as well as in connection with the adoption of the Strategy for Socio-Economic Development of Russia with Low Greenhouse Gas Emissions until 2050 [1], which places great emphasis on increasing the net absorption of greenhouse gases by managed ecosystems.

Climate projects include forest-climatic projects (forest conservation, prevention of emissions from forest fires, afforestation and reforestation, sustainable forest management and forest intensification, etc.), agroclimatic projects (no till or mini till technologies, reduction of carbon losses from erosion, etc.), and other types of natural solutions (restoration of disturbed and degraded lands, watering of drained wetlands, etc.) [2].

Natural climate projects should consider not only the goals of maximizing net carbon sequestration, but also related sustainability objectives: maintaining biodiversity, supporting local communities under the IUCN Global Standard for Nature Based Solutions [3], and the Climate, Community and Biodiversity Standards [4].

In this part, reclamation projects aimed at afforestation on degraded lands can be considered as natural-climatic design solutions that meet the requirements of sustainable development of territories.

The term “reclamation” first appeared in the early 20th century. However, the first attempts to restore disturbed land date back to the end of the 19th century in Germany. In the United States in 1937, a large-scale planting of coal mines was carried out. In Germany, as early as 1923, 242 ha of waste dumps in a lignite basin were planted with greenery [5].

Initially, as Russian and foreign experience shows, land reclamation was defined as a process in which “a complex of various works (engineering, mining, reclamation, agricultural, forestry, etc.) is carried out during a certain period and is aimed at restoring the productivity of disturbed areas and returning them to various types of use” [6].

The term “special procedure of soil restoration for agricultural or field use” was first used by V. Lazareva, who studied foreign experience of reclamation and introduced this term in her scientific work [7]. This concept partially corresponds to the well-known term “cultivation” and is close to the stage of biological reclamation.

This understanding of reclamation is also reflected in the works of V.V. Tarchevskogo and E.M. Lavrenko, who use the terms “industrial botany” and “industrial biogeocenology” [8].

Motorina, L.V.; Ovchinnikov, V.A. believed that: “reclamation is a process aimed not only at partial transformation of post-mountain disturbed lands, but also at creation of even more productive and rationally organized territory included in cultural anthropo-genic landscapes. Hence, it is the optimization of the anthropogenic landscape and improvement of the environment” [9].

In the 21st century, the understanding of reclamation has changed. The term “reclamation” is increasingly being replaced by the terms “revitalization”, “renaturation” or “restoration” (according to the US National Academy of Sciences), which means the creation of a renewed landscape with high aesthetic value [10–12].

According to E. Kalita and J. Barua, the concept of “reclamation” in the context of the circular economy and sustainable development trends in the 21st century that: “environmental remediation means the reduction/removal of pollutants or contaminants from water and soil to protect living systems and the environment from further deterioration for the sake of a sustainable future” [13].

Bringing disturbed lands into a condition suitable for forestry with plantations of various directions is a key task of forest reclamation.

Afforestation on disturbed lands is one of the key areas of forest restoration, which provides, among other objectives, restoration of ecological balance, productivity, and bio-diversity of disturbed areas. In the former Soviet Union, afforestation work began actively in the middle of the 20th century and was widely developed thanks to the efforts of leading scientists.

One of the first who laid the foundations for afforestation on disturbed lands was Academician V.V. Dokuchaev. His work in soil science emphasized the importance of forest plantations in stabilizing soil conditions, preventing erosion, and improving microclimates. V.V. Dokuchaev and his followers made a significant contribution to understanding how forest eco-systems can be used to restore degraded lands.

In the 70–80s of the 20th century, afforestation on disturbed lands reached the greatest development thanks to the studies of such scientists as V.V. Tarchevsky and E.M. Lavrenko.

V.V. Tarchevsky [14] actively researched the processes of ecosystem restoration and developed methods of planting forests in degraded areas. He also studied the possibility of using different tree species on soils with low humus content, and sometimes without it, directly on the soil-forming rock. His work has shown that even on poor soils, it is possible to create sustainable forest ecosystems that will contribute to the restoration of natural functions of disturbed lands.

E.M. Lavrenko, in turn, has made a great contribution to the development of the theory and practice of afforestation. His research in industrial botany and industrial biotechnology helped to better understand how forest plantations can be integrated into restoration projects and which tree species are most suitable for different types of disturbed lands [15].

Afforestation included the establishment of plantations to improve microclimate, protect soils from erosion, and restore water balance and biodiversity. Forest reclamation allowed trees to be planted on poor soils, which was particularly important in the conditions of most mining areas.

The predominant development of forest reclamation was explained by natural and climatic conditions that favored forest growth and resilience.

Up to 1000 ha of lands were disturbed annually in the USSR as a result of mining operations, with open-pit mines accounting for 33.9%, external dumps for 42.5%, and internal dumps for 13.0%. Successful reforestation projects not only helped to restore natural functions to disturbed lands, but also to improve their aesthetic and recreational value, which helped to improve the quality of life of the local population.

In addition, afforestation has played an important role in mitigating climate change and improving the ecological resilience of regions. Forest plantations have functioned to absorb carbon dioxide, improve soil water-holding capacity, and create favorable conditions for wildlife.

Current research continues to develop approaches to silviculture, taking into account new science and technology. Scientists are exploring the use of biodiversity, new tree species, and innovative planting methods to improve the effectiveness of afforestation on disturbed lands [16–18].

However, there are no comprehensive studies on the potential of implementing climate projects on disturbed lands of various purposes in the modern domestic literature, and therefore the issues discussed in this article are of particular importance.

Climate projects aimed at restoring disturbed land are becoming increasingly relevant in the context of global climate change and sustainable development. The investment attractiveness of such projects plays a key role in their successful implementation. This review is a study of current trends, challenges, and prospects in the investment attractiveness of climate projects on disturbed lands.

The economic attractiveness of climate projects on disturbed land is determined by potential returns and economic benefits. According to studies, investments in restoring disturbed land can lead to increased agricultural productivity, improved water resources, and increased land value. However, high initial investment costs and long payback periods remain major barriers for private investors.

For example, the authors [19,20] analyze the economic aspects of reforestation projects, including the costs of planting trees and the potential benefits of carbon credits.

Huang, Y et al. in their article [21] review the cost-effectiveness of forest climate projects and provide a return on investment analysis in the context of global climate change.

Economic incentives play an important role in the success of afforestation projects [22,23], especially in the initial phase, as it takes several years for newly planted forests to generate income through marketable products [24,25]. Zhang, C. et al. [26] recommend that national governments make significant efforts over a long period of time to provide incentives in the form of payments for planting [27], and several countries have already made national investments in reforestation projects [28].

Investment in climate projects also depends on political stability and the existence of a legal framework that supports environmental initiatives. Stable and predictable legal conditions, tax incentives, and public subsidies help to attract private investment. For example, some countries have developed national policies and programs to encourage investment in ecosystem restoration [29].

Social and environmental benefits also play an important role in assessing investment attractiveness. Restoration of disturbed land can lead to improved public health, job creation, and improved quality of life. In addition, successful projects help to strengthen social capital and increase the level of public participation in environmental initiatives [30,31].

Despite the many potential benefits, there are a number of challenges facing climate projects on disturbed land. The main challenges include lack of financial resources, difficulty in project management, and uncertainty in predicting outcomes. Research shows that poor project management and inadequate funding can lead to failure and inefficient use of resources.

The investment attractiveness of climate projects on disturbed lands depends on many factors, including economic, legal, social, and environmental aspects. Despite the existing problems and challenges, a proper project management approach and support from the government and the private sector can significantly increase their success and attractiveness. Supporting such projects is an important step towards achieving sustainable development and improving environmental quality.

The aim of the study is to substantiate the potential for the implementation of climate projects on disturbed lands for various purposes and to assess the investment attractiveness of project solutions aimed at absorbing greenhouse gases.

2. Study Area and Data Sources

2.1. Study Area

The object of the study is disturbed lands of the subjects of the Russian Federation (Figure 1).

Land disturbance occurs with the following major activities:

- development of mineral deposits, peat, mineral raw materials, soil dumps, quarries, etc., formed as a result of mining;
- pollution by waste from industrial enterprises;
- land construction (linear, including power lines, construction of railroads and highways);
- hydraulic engineering construction (construction of bridges and dams, co-construction of water reservoirs and dams);
- subsoil use (development and exploitation of mineral deposits, laying of pipelines, construction of embankments and dumps);
- industrial forestry (cutting of forests and their plantations, laying of clearings and temporary roads);
- agricultural development (agro-ameliorative construction);
- geological exploration, testing, exploitation, and other works related to soil disturbance;
- storage and burial of industrial waste;
- disturbed lands affected by fires, most common in areas occupied by forests, less common in wetlands with sparse stands;
- other disturbed lands [32].

The lands of industry and other special purposes account for 40% of the total area of disturbed lands. The share of disturbed lands of agricultural purposes is 20.4%, the lands of reserves and settlements account for 20.1% of the total area of disturbed lands. The lands

of the forest fund account for 19.2% of disturbed lands and the share of lands of specially protected territories and objects is 0.1%.

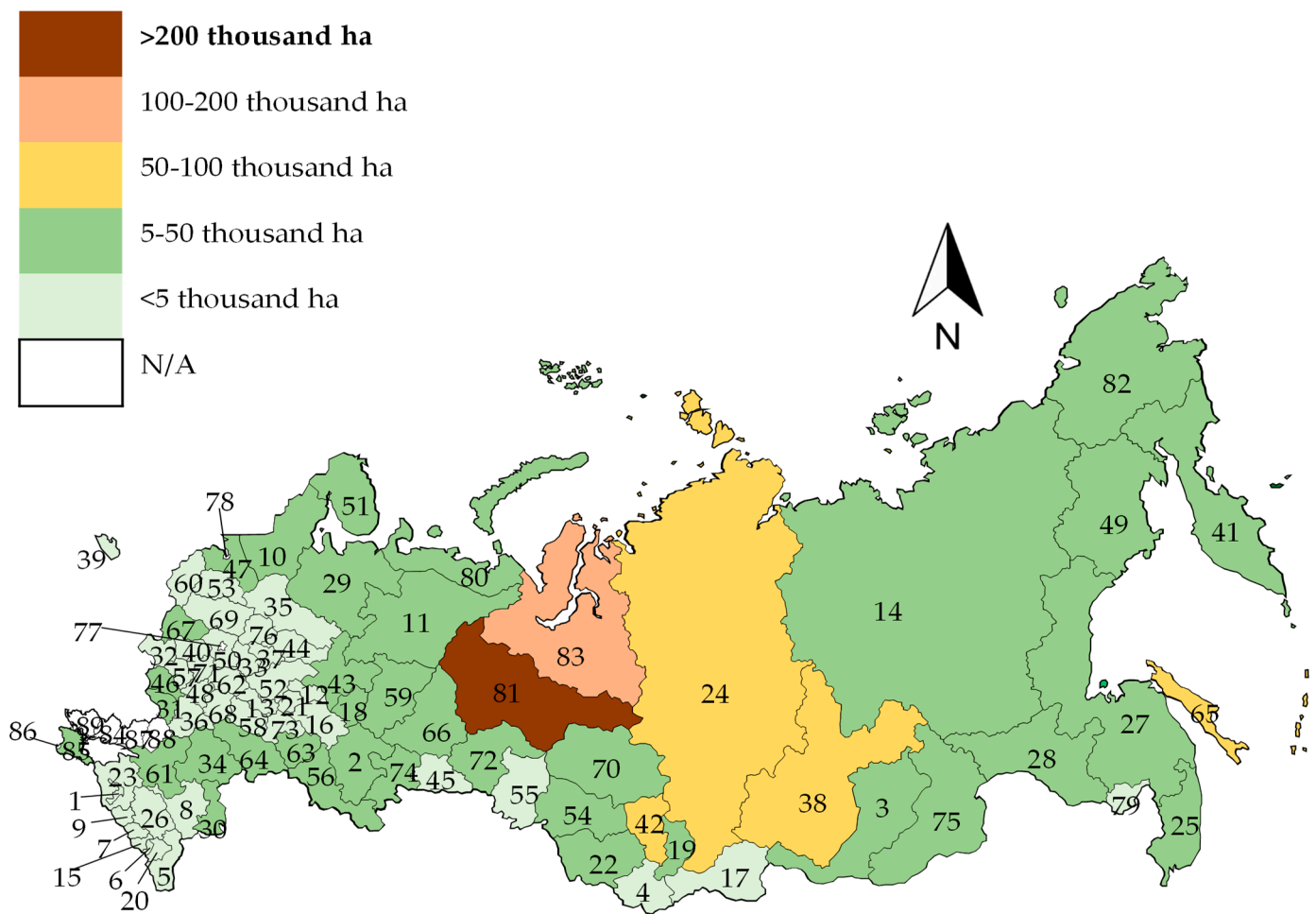


Figure 1. Disturbed lands of the subjects of the Russian Federation.

1 Republic of Adygea (Adygea)	46 Kursk Region
2 Republic of Bashkortostan	47 Leningrad Region
3 The Republic of Buryatia	48 Lipetsk Region
4 Altai Republic	49 Magadan Region
5 Republic of Dagestan	50 Moscow Region
6 Republic of Ingushetia	51 Murmansk Region
7 Kabardino-Balkarian Republic	52 Nizhny Novgorod Region
8 Republic of Kalmykia	53 Novgorod Region
9 Karachay-Cherkess Republic	54 Novosibirsk Region
10 Republic of Karelia	55 Omsk Region
11 Komi Republic	56 Orenburg Region
12 Republic of Mari El	57 Oryol Region
13 Republic of Mordovia	58 Penza Region
14 Republic of Sakha (Yakutia)	59 Perm Region
15 Republic of North Ossetia—Alania	60 Pskov Region

16 Republic of Tatarstan (Tatarstan)	61 Rostov Region
17 Republic of Tyva	62 Ryazan Region
18 Udmurt Republic	63 Samara Region
19 Republic of Khakassia	64 Saratov Region
20 Chechen Republic	65 Sakhalin Region
21 Chuvash Republic—Chuvashia	66 Sverdlovsk Region
22 Altai Region	67 Smolensk Region
23 Krasnodar Region	68 Tambov Region
24 Krasnoyarsk Region	69 Tver Region
25 Primorsky Region	70 Tomsk Region
26 Stavropol Region	71 Tula Region
27 Khabarovsk Region	72 Tyumen Region
28 Amur Region	73 Ulyanovsk Region
29 Arkhangelsk Region	74 Chelyabinsk Region
30 Astrakhan Region	75 Trans-Baikal Region
31 Belgorod Region	76 Yaroslavl Region
32 Bryansk Region	77 the federal city of Moscow
33 Vladimir Region	78 federal city of St. Petersburg
34 Volgograd Region	79 Jewish Autonomous Region
35 Vologda Region	80 Nenets Autonomous Region
36 Voronezh Region	81 Khanty-Mansiysk Autonomous Region—Yugra
37 Ivanovo Region	82 Chukotka Autonomous Region
38 Irkutsk Region	83 Yamalo-Nenets Autonomous Region
39 Kaliningrad Region	84 Zaporozhye Region
40 Kaluga Region	85 Republic of Crimea
41 Kamchatka Region	86 The federal city of Sevastopol
42 Kemerovo Region—Kuzbass	87 Donetsk People’s Republic
43 Kirov Region	88 Luhansk People’s Republic
44 Kostroma Region	89 Kherson Region
45 Kurgan Region	

2.2. Data Sources and Processing

The data of the Russian Register, as well as statistical data on disturbed lands of the Russian Federation were used as input data.

The following methods were used in the preparation of the study materials:

- analysis and synthesis—to identify disturbed lands and their main characteristics for the implementation of climatic projects for afforestation on disturbed lands;
- statistical—for the formation of indicators characterizing the project potential of disturbed lands;
- groupings—to analyze the project potential and investment attractiveness for the implementation of climatic projects for afforestation on disturbed lands;
- cartographic and graphic—to visualize the results obtained;
- economic and statistical—for making calculations on the investment attractiveness of project solutions for afforestation on disturbed lands.

To obtain estimates of the absorption capacity of forest species with respect to greenhouse gases, we used literature data, as well as data on the current growth of phytomass of existing plantations, expressed in t/ha per year and presented in the general tables of biological productivity of full (normal) stands of tree species typical of forests of the subjects of the Russian Federation, on the territory of which climate projects on afforestation on disturbed lands will be organized.

Carbon dioxide (CO₂) and carbon (C) uptake and accumulation were calculated using software product Version 1.0 developed by Centre for Ecology and Forest Productivity of the RAS, 2009 “Calculation of carbon uptake by forest plantations created as a result of afforestation and reforestation project activities. Forecast variant of calculation” [33,34].

For the forecast calculation, the program was entered as primary (initial) data:

- Area of plantation, ha, initial age in growth progress tables, years, final age in growth progress tables, years, age step in growth progress tables, years, soil type code, soil type, time elapsed since cessation of tillage, years.
- Considering the layout and composition of the plantation on the projected terraces (20 m × 500 m), the area of the plantation is 0.52 ha for main species, 0.25 ha for associated species, 0.1 ha for shrubs, and the area belonging to the edges of the terraces at 1.25 m is 0.13 ha.
- The age step in the growth progress tables is 10 years, and time elapsed since cessation of treatment is 15 years.
- Breed composition and mixing schemes were introduced depending on natural-climatic and soil conditions of the studied Region.

To fill in the values of height, diameter, and stocking for species, data from general and regional growth progress tables were used. The selection of species composition was based on the silvicultural and biological characteristics of forest-forming species that can be used as main species, as well as other tree species and shrubs used as companion species in the creation of forest crops.

Taking into account that, according to the rules, reclamation of disturbed lands should be carried out in two consecutive stages, which are technical and biological, and taking into account the requirements of the National Standard R 57447 [35], it is assumed that on the lands allocated for the design of climatic projects for afforestation, the restoration of the soil layer has been carried out.

The methodology for calculating project activities for afforestation on disturbed lands includes several key steps and aspects:

- Assessment of the current condition of the land plots.
- A detailed study of areas affected by human activities, such as mining or deforestation, is carried out. Soil cover characteristics, degree of degradation and other important parameters are determined.

Define project goals and objectives:

- Specific reforestation objectives are formulated, such as restoring biodiversity, improving soil quality, reducing carbon footprint, and supporting ecosystem services.
- Objectives are set for the selection of optimal reclamation methods and expected project outcomes.

Data collection and analysis:

- Data are collected on land use, changes in land use, area of disturbed land, and its characteristics.
- Ecological and climatic data are analyzed, including the level of carbon stock in soils and biomass, and the potential for restoration of ecosystem services.

Assessment of economic efficiency and investment attractiveness of climatic reforestation projects on disturbed lands.

The criteria for the effectiveness of climate projects on disturbed lands are both generally accepted quantitative and qualitative indicators of investment project implementation

(net income, project payback period, internal rate of return) and specific indicators—the output of carbon units and its derivative—the coefficient of carbon intensity of investment costs.

In determining the economic efficiency of project solutions, the cost of the project is calculated, including the costs of soil preparation, planting, and plant care, as well as projected revenues from the sale of forest products or ecotourism development.

Next, the financial indicators of the project, such as the present value of investment (NPV) and internal rate of return (IRR), payback period of investment costs, etc., are evaluated.

As an indicator of the effectiveness of investment in afforestation on disturbed lands, the coefficient of carbon intensity of investment costs was used, which is the ratio of additional greenhouse gas absorption achieved within the framework of the implementation of forest-climatic projects for the reproduction of natural capital of forests and investment costs [36].

2.3. Methods

The coefficient of carbon intensity of investment costs is the volume of greenhouse gases accounted for as a result of measures aimed at increasing the absorption of greenhouse gases, which falls per unit of investment costs formed during the implementation of the climate project and is determined by the formula:

$$C_{cii} = S_c / C_c$$

C_{cii} —coefficient of carbon intensity of investment;

S_c —total amount of carbon sequestration, reduced to the n -th year;

C_c —current costs of forest restoration of disturbed lands, reduced to the n -th year (investment costs).

The coefficient of carbon intensity of investment costs allows comparing alternative climate projects in terms of their environmental significance and investment attractiveness.

Preference should be given to climatic projects with the highest value of the coefficient of carbon intensity of investment costs, providing, due to project activities, the greatest absorption of greenhouse gases by the forest plantations created per unit of investment compared to the alternative option.

3. Results

3.1. Disturbed Lands of the Russian Federation

Recultivation of technogenic landscape performs a set of works aimed at restoring the economic and aesthetic value of the disturbed landscape. In many cases, reclamation of disturbed lands is carried out near mining, chemical, metallurgical, and other industries, as well as large thermal power plants (Table 1).

In the context of this study, the potential of land resources in terms of disturbed land was assessed by federal districts and subjects for the period from 2018–2022, by land categories:

- agricultural lands;
- lands of the forest fund;
- lands of industry and other special purpose;
- lands of specially protected territories and objects;
- lands of reserves and settlements.

Disturbed land resulted from the:

- land construction (linear construction, including power lines, construction of railroads and highways);
- hydrotechnical construction (construction of bridges and dams, construction of water reservoirs, construction of dams);
- subsoil use (development and exploitation of mineral deposits, laying of pipelines, construction of embankments and dumps);

- industrial forestry (cutting of forests and their plantations, laying of clearings and temporary roads);
- agricultural development (agro-ameliorative construction);
- geological exploration, testing, exploitation, and other works related to soil disturbance.

Table 1. Classification of disturbed lands by reclamation directions.

Group of Disturbed Lands by Reclamation Directions	Type of Use of Reclaimed Land
Lands of the agricultural direction of reclamation	Cultivation of cereals and other agricultural crops Vegetable growing Cultivation of tonic, medicinal, and flower crops Horticulture Cultivation of flax and hemp Haymaking Grazing of farm animals Provision of agricultural production Storage and processing of agricultural products
Lands of the forestry direction of reclamation	Forest plantations Reserve forests Protection of natural areas
Lands of the water management direction of reclamation	Fish farming Hunting and fishing General use of water objects Special use of water objects Hydrotechnical constructions
Lands of the recreational direction of reclamation	Recreation Objects of cultural and leisure activities Parks of culture and recreation Natural-cognitive tourism Tourist services Hunting and fishing
Lands of nature protection direction of reclamation	Activities for special protection and study of nature Protection of natural areas
Lands of construction direction of reclamation	Residential development Public use of capital construction facilities Entrepreneurship Manufacturing activities Transport Special activities Land plots (territories) of public use
Lands of conservation and sanitary-hygienic direction of reclamation	Reserve

Logging (industrial forestry): Logging with the use of modern machinery has a significant negative impact on the soil cover of forest ecosystems. In the process of harvesting with a set of machines the water-physical properties of soils deteriorate—the volumetric mass increases almost twice—from 0.76 to 1.42 g/cm³, the total porosity decreases from 65% to 45%.

At clearings, the share of large aggregates in the soil mass increases. Disturbance of the accumulative part of the profile reduces humus reserves, which, together with the deterioration of soil physical properties, negatively affects the mobilization activity of a whole complex of microorganisms.

A sharp decrease in the total number of microorganisms leads to a decrease in ammonifiers, nitrogen fixers, cellulose-degrading bacteria, and, consequently, to a sharp decline in the enzymatic activity and respiration intensity of soils.

The pyrogenic factor (fires) brings significant changes to the appearance of modern forests and forest soils. Fires have direct and indirect impact on the main components of forest ecosystems: phytocenoses and soils.

Each of the types of negative processes identified at the work sites corresponds to certain zones of predominant manifestation in the relief, as well as certain types of soil and vegetation cover.

It should be noted that for each soil-vegetation complex, taking into account its orography, the development of one or another negative process of natural origin is characteristic, practically as a continuous phenomenon, locally manifested in the increase of the degree of process development. The exception is the processes of anthropogenic origin, the development of which is fragmentary and not directly confined to soil complexes.

As of 1 January 2023, the land fund of the Russian Federation is 1712.5 million ha. The area of disturbed lands is determined in the amount of 1247.2 thousand ha, which is 0.072.8% of the total land fund of the Russian Federation (Figure 2). According to the results of 2023, the area of disturbed lands will increase (+155.3 thousand ha) compared to 2022.

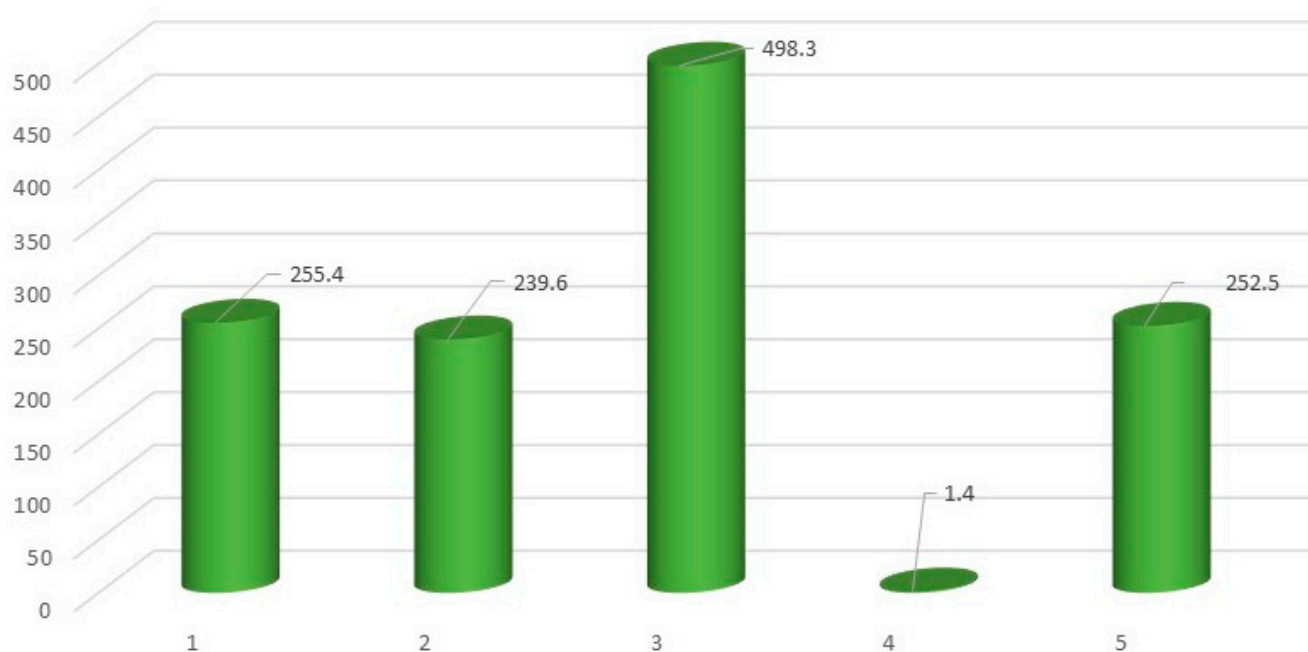


Figure 2. Areas of disturbed lands by categories as of 1 December 2023, thousand ha. (1)—agricultural lands; (2)—lands of the forest fund; (3)—lands of industry and other special purposes; (4)—lands of specially protected territories and facilities; (5)—lands of reserves and settlements.

As of the end of 2023, according to the National Report of the Russian Register, the largest areas of disturbed lands are located in the Yamalo-Nenets Autonomous Region (105.4 thousand ha), Kemerovo Region—Kuzbass (98.0 thousand ha), Magadan (77.7 thousand ha), Sverdlovsk (61.4 thousand ha) Regions, Khanty-Mansiysk (55.7 thousand ha) and Chukotka (47.5 thousand ha) Autonomous Regions, Moscow (34.6 thousand ha), Chelyabinsk (34.5 thousand ha), and Khanty-Mansiysk (55.7 thousand ha) Regions, the Republic of Sakha (Yakutia) (30.9 thousand ha), Irkutsk (26.6 thousand ha), Leningrad (22.9 thousand ha), Vologda (22.2 thousand ha) and Transbaikal Regions (24.2 thousand ha).

The dynamics of changes in the area of disturbed land in the period 2019–2023, is presented in Figure 3.

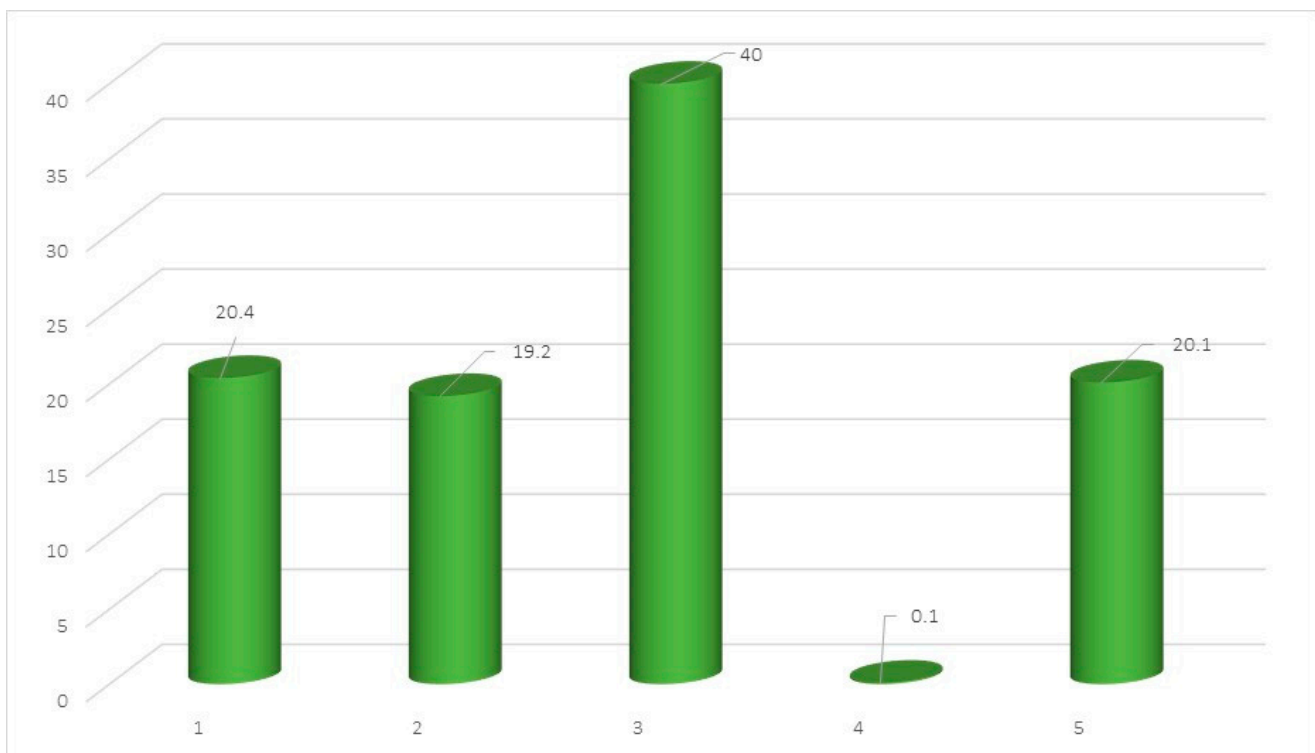


Figure 3. Dynamics of disturbed land area for 2019–2023 (thousand ha). (1)—agricultural lands; (2)—lands of the forest fund; (3)—lands of industry and other special purposes; (4)—lands of specially protected territories and facilities; (5)—lands of reserves and settlements.

In the period from 2019–2023, the cumulative growth rate of disturbed lands was 116.1%. The highest value was recorded in the category of reserve lands and settlements (132.1%). In the category of agricultural land, the growth rate was 124.0%. On the lands of industry and other special purpose, the growth rate was 113.9%; on the lands of specially protected territories and objects—107.6%; on the lands of the forest fund—100.5%.

Based on the objectives set, the study analyzed the categories of disturbed lands (agricultural lands; forestry lands; industrial and other special purpose lands; lands of specially protected territories and objects; reserve lands and settlements) for each Region of the Russian Federation in order to determine the land potential for the implementation of climate projects.

The category of disturbed lands—‘lands of the water fund’—was not included in the data of the analysis of disturbed lands, as it is impossible to implement forest-climatic projects in this category. In the course of the analysis, the category of disturbed lands—‘reserve lands and settlements’—also included data on lands within administrative boundaries.

The largest share in the structure of disturbed lands in the Central Federal District belongs to the lands of industry and other special purpose—30.3%; the share of agricultural lands—26.6%; forest lands—24.8%; reserve lands and settlements occupy—17.3%; the share of lands of specially protected territories and objects is 0.82%. The leaders in terms of the area of disturbed lands out of 15 Regions of the Russian Federation in the Central Federal District are the Moscow Region—35.2 thousand ha, the Tver Region—20.3 thousand ha, the Smolensk Region—18.6 thousand ha.

There is no area of disturbed lands in the city of Moscow. The largest area of disturbed land in the category of land for agricultural purposes is located in the Tver Region (9.1 thousand ha). The largest area of disturbed land in the category of forest land is located in the Moscow Region (14.3 thousand ha), as well as in the category of industrial and other special purpose land (6.6 thousand ha).

Also, the Moscow Region ranks first in the Central Federal District in terms of the area of disturbed lands in the category of lands of specially protected territories and objects (1.3 thousand ha) and lands of reserves and settlements (10.0 thousand ha).

The Urals Federal District is the leader in terms of disturbed land area in the Russian Federation (293.4 thousand ha), followed by the Far Eastern Federal District (237.4 thousand ha), with the Siberian Federal District in third place (217.4 thousand ha). The largest area of disturbed lands in seven federal districts is formed on the lands of industry and other special purpose (Central Federal District, Southern Federal District, Volga Federal District, Urals Federal District, Siberian Federal District, North-Western Federal District, Far Eastern Federal District). The leading federal districts in this category are Siberian Federal District (124 thousand ha), Far Eastern Federal District (97.1 thousand ha), and North-Western Federal District (91.7 thousand ha).

Separately, we would like to mention disturbed lands in the Luhansk and Donetsk Republics, Zaporozh'ye, and Kherson Regions, which are subject to special types of disturbances due to military operations. At this stage, there are no statistics on the areas, but it should be noted that the emergence of new types of such landscapes will require completely different approaches to the development of measures to involve these lands in the turnover.

As practice shows, the functioning and development of industrial production does not always contribute to the organization of rational land use. This primarily concerns industrial and civil construction, mining, operation of pipeline transport, organization of landfills, reconstruction and repair of engineering structures, and survey works.

The increase in the area of disturbed lands in the category of reserve lands and settlements in 2023 compared to 2019 amounted to (+61.2 thousand ha). This also confirms the connection of the majority of disturbed areas and industrial facilities, both in the territorial zones of industrial character of cities and inter-settlement area.

Certain negative changes are taking place on both agricultural and forestry lands (Figures 4 and 5).

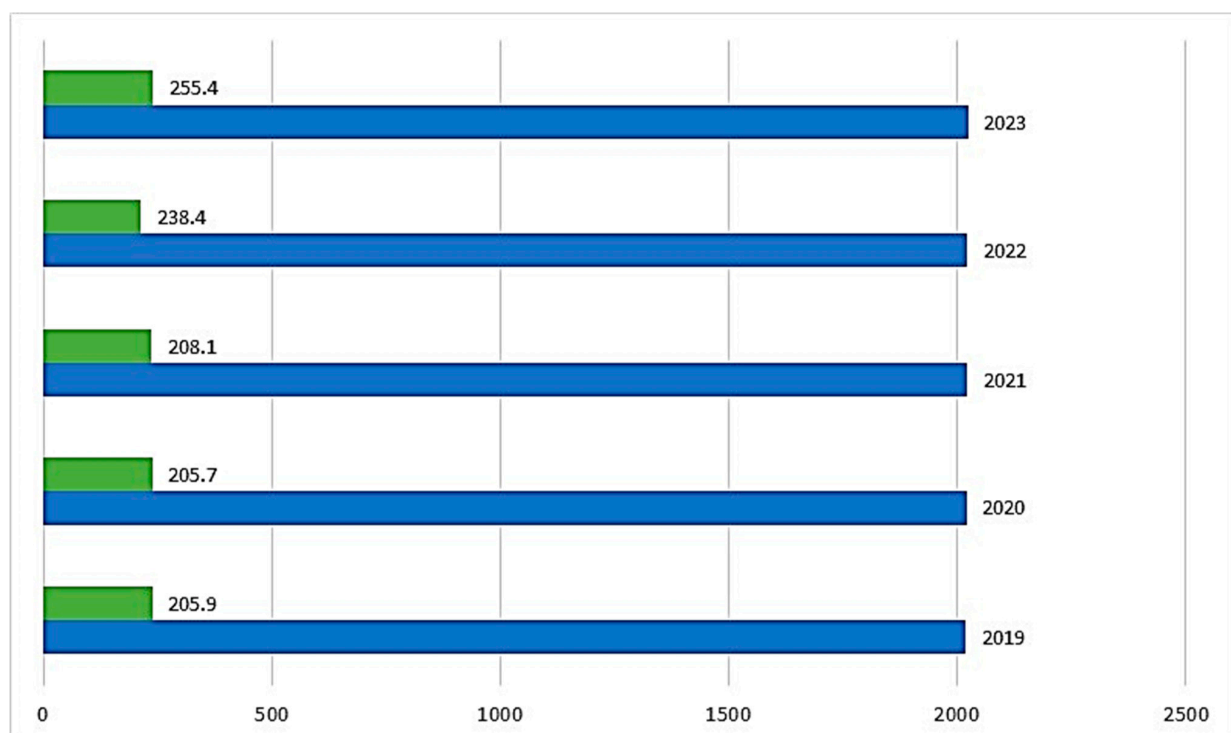


Figure 4. Growth dynamics of disturbed lands area on agricultural lands for the period 2019–2023, thousand ha.

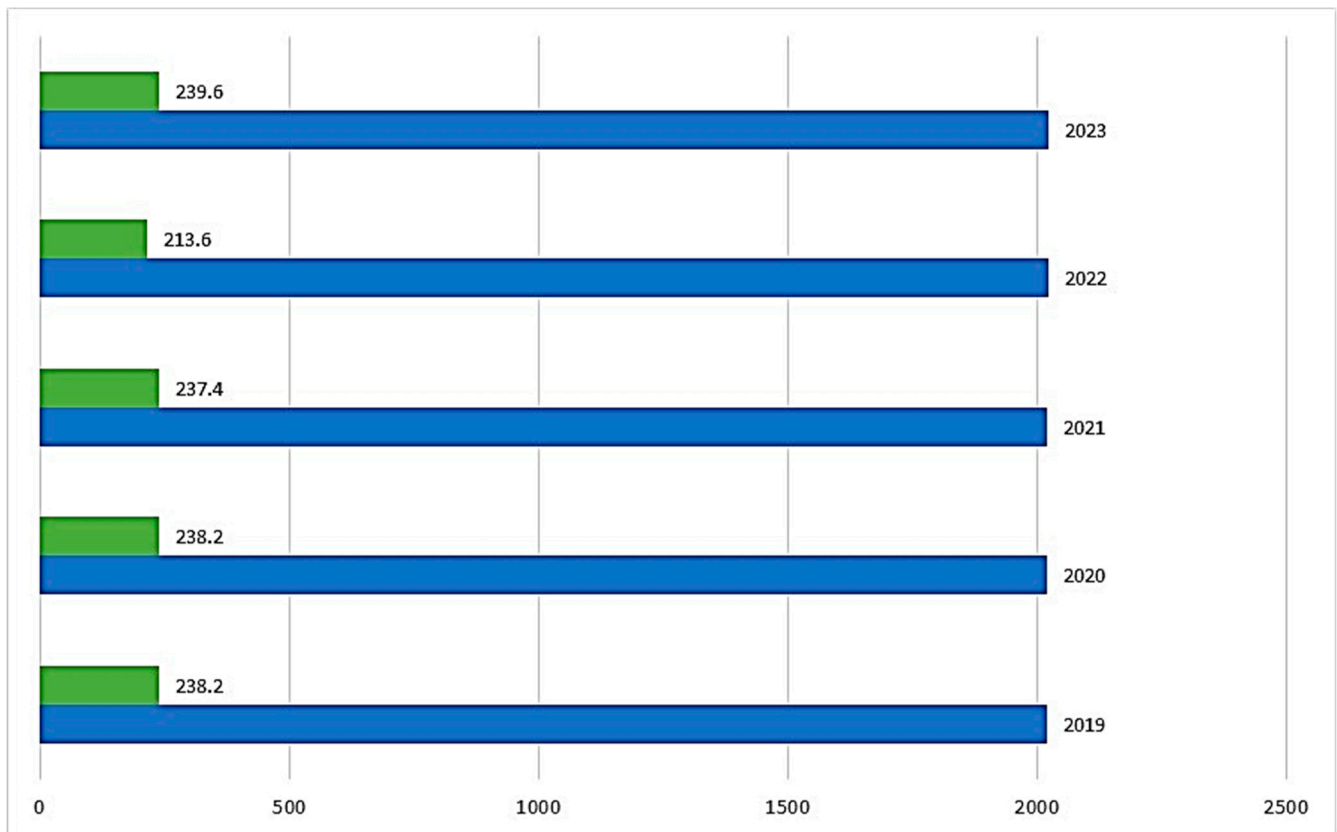


Figure 5. Growth dynamics of disturbed land area on the forest fund lands, for the period 2019–2023, thousand ha.

In the category of agricultural land, the area of disturbed lands increased from 205, 9 thousand ha in 2019 to 255.4 thousand ha in 2023. In the category of forest fund lands, the area growth in the period 2019–2023 amounted to 1.4 thousand ha.

3.2. The Land Potential of Project Activities for the Regions of the Russian Federation and Category of Disturbed Lands

The land potential of project activities for each constituent entity of the Russian Federation and category of disturbed land is presented in Tables 2–10.

Table 2. Potential of project activities in Central Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Belgorod Region	5860	-	160	-	-	-	3289	3
Bryansk Region	662	-	18	-	-	-	188	42
Vladimir Region	3588	-	33	-	-	-	86	29
Voronezh Region	1105	-	18	-	-	-	122	243
Ivanovo Region	774	-	653	-	1063	-	166	8
Kaluga Region	1340	-	29	-	84	-	67	76
Kostroma Region	737	-	518	-	1711	1	78	6
Kursk Region	7552	-	137	-	-	-	-	-
Lipetsk Region	1769	-	66	-	-	-	263	18
Moscow Region	2914	-	313	-	16	-	464	285
Oryol Region	357	-	36	-	-	-	168	-
Ryazan Region	2172	-	53	-	-	-	424	-
Smolensk Region	1162	-	301	-	5621	-	191	16

Table 2. *Cont.*

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Tambov Region	316	-	416	-	-	-	117	41
Tver Region	2113	-	35	-	46	-	51	105
Tula Region	1339	-	155	70	-	-	609	123
Yaroslavl Region	1193	-	38	-	-	-	271	27

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 3. Potential of project activities in Southern Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Astrakhan Region	2474	-	210	-	-	-	4134	12
Volgograd Region	3244	-	601	841	-	-	227	606
Krasnodar Region	102	-	10	-	-	-	-	181
Republic of Adygea	706	-	19	-	-	-	-	-
Republic of Kalmykia	15	-	8	-	-	-	3	2
Republic of Crimea	2474	-	210	-	-	-	4134	12
Rostov Region	3244	-	601	841	-	-	227	606

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 4. Potential of project activities in North Caucasian Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Kabardino-Balkarian Republic	329	-	-	-	-	4	28	-
Karachay-Cherkess Republic	572	-	1	-	-	1	112	2
Republic of Dagestan	494	-	144	-	-	-	-	-
Republic of Ingushetia	9	-	-	-	-	-	-	1
Republic of North Ossetia–Alania	157	-	-	-	-	-	5	-
Stavropol Region	1326	31	591	-	-	-	311	34
Chechen Republic	19	-	-	-	-	-	2	-

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 5. Potential of project activities in Volga Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Kirov Region	490	-	15	1	1477	-	469	7718
Nizhny Novgorod Region	668	-	1385	-	-	-	315	6
Orenburg Region	9836	2	1835	-	-	1	1406	32
Penza Region	594	-	63	-	-	-	107	-
Perm Region	4647	-	4540	-	88	5	539	765
Republic of Bashkortostan	4034	9	2700	-	-	-	1144	130
Republic of Mari El	266	-	164	-	-	-	130	-

Table 5. Cont.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Republic of Mordovia	704	-	261	6	514	-	118	-
Republic of Tatarstan	1239	-	303	-	-	-	11	16
Samara Region	3192	1	4597	-	-	-	292	126
Saratov Region	1903	1	36,856	-	-	1	216	12
Udmurt Republic	1993	-	162	-	3584	-	334	35
Ulyanovsk Region	920	-	103	-	197	-	10	-
Chuvash Republic	440	-	743	-	-	-	165	1

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 6. Potential of project activities in Urals Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Kurgan Region	386	-	442	-	-	-	57	256
Sverdlovsk Region	18,360	-	2434	-	101	-	10,015	353
Tyumen Region	21,787	5	2089	-	-	-	132	351
Khanty-Mansiysk Autonomous Region	269,779	105	106,770	-	31	120	486	1740
Chelyabinsk Region	16,791	-	1299	3	-	-	2100	337
Yamalo-Nenets Autonomous Region	135,115	91	35,520	-	-	1432	321	739

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 7. Potential of project activities in Siberian Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Altai Region	1571	-	21	3	7663	-	492	3
Irkutsk Region	73,841	-	9761	-	117	150	383	483
Kemerovo Region	86,609	-	3817	2	153	-	3012	713
Krasnoyarsk Region	36,579	-	10,588	11	608	256	1983	754
Novosibirsk Region	8155	-	141	-	-	20	272	557
Omsk Region	106	-	779	-	-	-	977	29
Republic of Altai	357	-	0	-	-	-	48	-
Republic of Tyva	985	-	76	-	-	36	66	5
Republic of Khakassia	10,899	-	414	-	-	18	363	181
Tomsk Region	7688	-	29,595	-	-	5	905	125

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 8. Potential of project activities in North-Western Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Arkhangelsk Region	6180	-	413	2	46	-	1569	37
Vologda Region	1238	-	1035	-	553	-	1994	-
Kaliningrad Region	2203	-	116	-	-	2	15	-
Leningrad Region	8112	-	1035	1	-	-	206	107
Murmansk Region	20,976	-	649	-	28	59	323	65
Nenets Autonomous Region	17,958	-	5431	-	-	10	58	-
Novgorod Region	2297	-	126	-	-	27	129	2
Pskov Region	3085	-	-	24	-	-	99	81
Republic of Karelia	9632	-	3026	3840	438	-	421	371
Komi Republic	30,770	553	14,349	141	321	1668	1498	447

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 9. Potential of project activities in Far Eastern Federal District on disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Amur Region	27,331	-	7733	-	7	100	37	49
The Jewish Autonomous Region	1486	-	859	-	-	4	19	57
Trans-Baikal Region	31,986	6	2456	-	95	130	368	201
Kamchatka Region	2884	-	269	-	5	2210	163	65
Magadan Region	41,504	-	2915	13	-	189	35	1732
Primorsky Region	9011	1	1237	-	1159	85	1994	86
Republic of Sakha (Yakutia)	7905	-	967	-	45	69	1608	111
Sakhalin Region	48,934	-	17,136	-	4495	611	2557	817
Khabarovsk Region	10,680	18	3084	-	-	51	5	30
Chukotka Autonomous Region	11,857	15	3552	-	-	405	172	34

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

Table 10. Potential of disturbed lands as of 1 December 2023, ha.

Regions of the Russian Federation	Category of Disturbed Land							
	1	2	3	4	5	6	7	8
Khanty-Mansiysk Autonomous Region	269,779	105	106,770	-	31	120	486	1740
Kemerovo Region (Kuzbass basin)	86,609	-	3817	2	153	-	3012	713
Chelyabinsk Region	16,791	-	1299	3	-	-	2100	337
Belgorod Region	5860	-	160	-	-	-	3289	3
Moscow Region	2914	-	313	-	16	-	464	285

(1)—during development of mineral deposits; (2)—due to leakage during transit of oil, gas, and oil products; (3)—during construction works; (4)—during land reclamation works; (5)—during logging works; (6)—during survey works; (7)—during disposal of industrial (including construction) and solid domestic waste; (8)—during other operations.

In the process of project activities, when calculating the investment attractiveness of a potential project to be implemented on disturbed land, an important point is to assess the indicators of logistical and economic accessibility of land. The indicators of logistic and economic accessibility of disturbed lands of the Russian Federation Regions are influenced by a number of private parameters that depend on individual conditions and project solutions.

Emphasizing the vector of development of project solutions to meet the objectives of the Strategy for Socio-Economic Development of Russia with low greenhouse gas emissions until 2050, approved by the government (29 October 2021 No. 3052-r), we note that the implementation of the concept of “nature-like” forestry leads to the practice of implementation of climate projects for afforestation, including on disturbed lands.

3.3. Virtual Clustering of Disturbed Lands

From the point of view of the announced initiative, let us highlight the virtual clustering of disturbed lands, taking into account the factors of availability of their areas, the set of forms of exploitation of natural resource potential, as well as logistical and economic accessibility of territories (Table 10 and Figure 6).



Figure 6. Virtual clustering of disturbed land potential suitable for climate-smart afforestation projects.

Based on the analysis of the presented Table 10 and the figure, it can be seen that the leader in terms of the total area of disturbed land is the UFD—399.53 thousand ha, namely: Khanty-Mansiysk Autonomous Region—379.0 thousand ha; Chelyabinsk Region—20.53 thousand ha. The total share of SFD (Kemerovo Region) is 94.3 thousand ha. The Central Federal District is represented on the area of 13.3 thousand ha, of which the potential of Belgorod Region in terms of disturbed lands is 9.31 thousand ha, Moscow Region—3.99 thousand ha.

To date, the possibilities of implementing climate projects on disturbed lands have remained underestimated. The reasons for this are the complex process of reclamation of

disturbed lands, the duration of works, and the significant amount of investment in project implementation.

Table 11 presents information on carbon uptake by tree and shrub species created on disturbed lands and its accumulation in the context of five Regions. Carbon accumulation is determined for the entire project implementation cycle—20 years—and is the largest for the Kuzbass basin.

Table 11. Carbon uptake, $\text{t CO}_2 \text{ year}^{-1}$, carbon storage, t C , carbon uptake, t C year^{-1} , average carbon storage, $\text{t CO}_2 \text{ year}^{-1}$ in the studied regions.

Studied Parameter	Kuzbass Basin	Moscow Basin	Western Siberia	Chelyabinsk Region	Belgorod Region
Carbon sequestration, $\text{t CO}_2 \text{ year}^{-1}$	6.54	6.67	6.56	8.4	3.84
Carbon accumulation, t C year^{-1}	112.42	93.92	102.25	122.64	81.43
Carbon sequestration, t C year^{-1}	1.81	1.82	1.72	2.3	1.01
Average carbon accumulation, $\text{t CO}_2 \text{ year}^{-1}$	9.17	7.7	8.3	9.9	6.64

The average carbon accumulation ranges from $6.64 \text{ t CO}_2 \text{ year}^{-1}$ to $9.9 \text{ t CO}_2 \text{ year}^{-1}$, which does not contradict the amount of carbon accumulation during afforestation on other lands. Changes in the accumulation values in the section of basins are associated with different rock composition and, as a consequence, with the peculiarities of growth and biomass accumulation by plants and their absorption capacity.

3.4. Investment Costs for the Period of Implementation of the Climate Project on Disturbed Lands

Using the proposed methodological approach, we calculated the total costs, both in current prices and taking into account the discount rate, necessary to implement the investment project of afforestation and reforestation. In order to develop the methodology as a model region, the data of the forestry economy of all subjects of the Russian Federation were used. Technical and economic calculations and economic analyses of the costs of forest growing and afforestation were carried out in the form of normative-technological maps.

For five polygons of disturbed lands (Kuzbass Basin, Moscow Basin, Western Siberia Basin, Chelyabinsk, and Belgorod Regions Basins), the aggregated costs of measures aimed at creating carbon-depositing plantations and ground cover were determined. Investment costs for the period of implementation of the climate project on disturbed lands per 1 hectare of area vary from 82.6 thousand rubles to 116.9 thousand rubles (Table 12).

Table 12. Economic assessment of the cost of carbon sequestration (emissions) when implementing forest-climatic projects on disturbed lands.

Regions of the Russian Federation	Costs of Measures, RUB Thousand/ha	Total Carbon Sequestration, tonnes C/ha	Carbon Intensity Ratio of Investment Costs
Kemerovo Region	90.9	183.4	2.01
Khanty-Mansiysk Autonomous Region	92.8	166.0	1.78
Moscow Region	116.9	154.0	1.32
Chelyabinsk Region	104.6	198.0	1.89
Belgorod Region	82.6	132.8	1.60

Analysis of the calculations shows that the carbon intensity of investments in the implementation of climate projects on disturbed lands is high ($C_{cii} > 1.0$).

Climate projects in the Kuzbass basin are characterized by the highest potential for investment, with $C_{cii} = 2.01$.

For the organization and implementation of the climatic project on afforestation on disturbed lands in the Kemerovo Region, investments in the amount of 66.7 thousand rubles/ha

for capital costs and 24.7 thousand rubles/ha for current costs are required. The payback period of the investment project, taking into account the discount rate, will be 13.1 years. For the period under study (20 years), the income of the investment project will cover 228% of its costs.

For the organization and implementation of the climate project on disturbed lands of Khanty-Mansiysk Autonomous Okrug, investments in the amount of 66.4 thousand rubles/ha for capital costs and 26.9 thousand rubles/ha for current costs are required. The payback period of the investment project, taking into account the discount rate, will be 13.4 years. During the study period (20 years), the income of the investment project will cover 225% of its costs.

For the organization and implementation of the climatic project on afforestation on disturbed lands of the Moscow Region, investments in the amount of 85.2 thousand rubles/ha for capital costs and 32.3 thousand rubles/ha for current costs are required. The payback period of the investment project, taking into account the discount rate, will be 15.6 years. During the study period (20 years), the income of the investment project will cover 178% of its costs.

For the organization and implementation of the climate project on disturbed lands of the Chelyabinsk Region, investments in the amount of 77.8 thousand rubles/ha for capital costs and 27.4 thousand rubles/ha for current costs are required. The payback period of the investment project, taking into account the discount rate, will be 12.2 years. The internal rate of return $IRR = 10\%$. For the period under study (20 years), income of the investment project will cover 253% of the costs of the project.

For the organization and implementation of the climatic project on afforestation on disturbed lands of Belgorod Region, investments in the amount of 59.05 thousand rubles/ha for capital costs and 24.1 thousand rubles/ha for current costs are required. The payback period of the investment project, taking into account the discount rate, will be 18 years. The internal rate of return is 5%. For the period under study (20 years), the income of the investment project will cover 143% of its costs.

The obtained data on the effectiveness of investment in the organization of forest-climatic projects on disturbed lands indicate that the investment potential of such project solutions is quite high.

4. Discussion

The issue of investment projects for afforestation on disturbed lands is a topical and complex one, requiring attention both from ecologists and scientists, as well as from the business community and government agencies. In this discussion, we will consider various aspects of research and practical realization of such projects, mentioning the authors whose works have made a significant contribution in this direction.

Studies show that investments in reforestation on disturbed lands can be economically feasible and even profitable in the long term. For example, the work of M. Smith and colleagues [36] demonstrates that, due to the growing interest in sustainable investments, forest restoration projects can attract both financial resources and additional investments from private and public investors.

Afforestation projects have significant social and environmental benefits. The work of M. Mentis [37] emphasizes the importance of considering social aspects in the planning and implementation of such projects, including community participation, job creation, and improved quality of life.

Studies by R. Jones and colleagues [38] indicate a significant potential for scientific and technological innovations in the field of afforestation. The use of genetically modified trees, modern methods of monitoring, and ecosystem management can improve the efficiency of projects and the sustainability of restored forest areas.

The analysis of the work of K. Lee et al. [39] reveals the importance of government support and international cooperation for the successful implementation of investment

projects on afforestation. The implementation of national strategies and harmonization of international standards allow attracting international investment and expertise.

The research by Morkovina S. and co-authors [40] demonstrates how international experience in forestry investments can be adapted to address economic challenges in specific Regions. Experiments with new technologies and management methods can optimize costs and improve project efficiency.

Also, the implementation of forest-climatic projects on disturbed lands is an important component of modern environmental and economic strategy aimed at mitigating climate change and sustainable management of natural resources. V.I. Kosmakov's research [41] shows that reforestation of disturbed lands contributes to a significant reduction of carbon footprint by increasing the carbon stock in biomass and soil sediments. This is especially important under conditions of changing climate and global warming.

The work of Krasnoyarova B.A. et al. [42] investigates the impact of afforestation on biodiversity and ecosystem services. The methodology for assessing ecosystem services of a regional system has been developed, based on theoretical ideas about their essence and generally accepted classifications. The methodology involves the assessment of the main groups of ecosystem services—provisioning, regulating, and information and cultural—based on their identification in a particular Region and taking into account their importance for the regional economy.

The cost-effectiveness analysis of reforestation projects by Wu J. et al. [43] shows that such projects can be profitable for investors and government agencies, especially when long-term environmental and social benefits are taken into account.

In particular, the carbon sink plantation project, which is the core element of carbon sinks in forestry, refers to a project activity that relies on the market circulation of carbon sinks to achieve ecological compensation and measure the value of carbon sinks during the growth period of forest trees. Its comprehensive efficiency is well aligned with the win-win model of economic growth and environmental protection in China.

Studies by A. Karpov, N. R. Pirtskhalava, A. G. Gudina et al. [44] describe the application of new technologies, such as remote sensing and the use of artificial intelligence, to optimize afforestation processes. This allows to significantly improve project efficiency and reduce costs.

The work by Ptichnikov A.V., Shvarts E.A. [45] identifies the importance of state and international support for the successful implementation of forest-climate projects. Inclusion in international climate agreements and cooperation with international organizations contributes to the creation of sustainable financial mechanisms and exchange of best practices.

Current international approaches to the use of natural-climate solutions (NCS) in decarbonization and achieving carbon neutrality are analyzed. It is concluded that the existing or planned state regulation in the field of NCS is clearly insufficient to unlock the potential of NCS in Russia as a possible leader in the promising new market of the next decades.

Realizing this potential requires significant targeted work to tune regulations and realign the priorities of public forest management—from extracting wood from forests for processing to integrated forest management, including quantification and monetization of ecosystem services of forest carbon sequestration.

D.E. Ivantsov's work [46] systematizes the best world practices of investment stimulation in the forest sector of the economy to substantiate the feasibility of their application in domestic conditions, taking into account the institutional and natural-climatic features of the development of the forest industry and forestry in Russia.

The study of the investment attractiveness of climate projects on disturbed lands has identified several key limitations that may affect the accuracy of the results and the practical applicability of the recommendations. Let us consider the main ones.

Different regions have unique climatic, soil, and environmental conditions that can significantly affect the investment costs and effectiveness of climate projects. For example,

differences in soil degradation rates, the type of plants used, and climate can lead to significant variations in calculations. Heterogeneous conditions can make it difficult to directly compare results between different regions and limit the applicability of findings to other area.

The cost and revenue figures presented in the study are aggregated and may not take into account all fine details and possible hidden costs. For example, the costs of site preparation, long-term management, and monitoring may be underestimated. In addition, the estimated revenues from carbon credits and other ecosystem services depend on many factors, including changes in policy and market conditions, which may affect their accuracy.

The payback periods for investment projects in this study are calculated based on current economic and environmental data. However, these data are subject to change depending on future policy changes, market conditions, and climatic conditions. Long-term projections may be subject to uncertainty, making it difficult to accurately predict future financial and environmental benefits.

Investment projects in the field of forest-climatic measures may face political and legal risks, such as changes in environmental and forestry legislation. These risks can affect the cost of projects and their financial attractiveness. Lack of stability in the legal environment can make project planning and implementation difficult.

Social and cultural aspects, such as local community perceptions of land use changes and public participation in projects, can also influence the success of climate initiatives. Lack of public support or conflicts with local interests can lead to additional costs and hinder project implementation.

Thus, the discussion on investment projects for reforestation of disturbed lands emphasizes their importance and relevance in the context of current environmental challenges and socio-economic development.

5. Conclusions

The implementation of climate-friendly afforestation projects on disturbed lands in various Regions of Russia represents an important and relevant step towards sustainable development. These projects not only contribute to the restoration of ecological balance in disturbed areas, but also have the potential to significantly reduce the carbon footprint associated with anthropogenic impacts.

It is particularly important to note that in the context of climate change, increasing the area of forests plays a key role in absorbing and neutralizing carbon dioxide from the atmosphere. Forests are natural carbon stores that can effectively store carbon and reduce its concentration in the atmosphere, which in turn helps to mitigate climate change and protect biodiversity.

Due to their scale and potential for creating long-term ecologically sustainable areas, afforestation projects on disturbed lands are of interest not only to environmentalists and public organizations, but also to private investors and government agencies. They contribute to the development of ecotourism, improve the microclimate in the Regions, reduce the risks of natural disasters, and improve the quality of life of the local population.

Thus, the development and support of afforestation projects on disturbed lands in Russia are of strategic importance not only in the context of environmental sustainability, but also for the achievement of global climate goals defined by international agreements such as the Paris Agreement. These projects represent an important element in the global fight against climate change and in creating a sustainable future for all of us.

This study reveals the mechanism for assessing the investment attractiveness of climate afforestation projects on disturbed lands. The coefficient of carbon intensity of investment costs, discounted for the conditions of implementation of such projects, can serve as a basis for decision-making on investments in afforestation and reforestation.

The investment attractiveness of project solutions aimed at absorbing greenhouse gases was assessed for the constituent entities of the Russian Federation. For five polygons of disturbed lands (Kuzbass Basin, Moscow Basin, Western Siberia Basin, Chelyabinsk,

and Belgorod Regions Basins), the aggregated costs of measures aimed at establishing carbon-depositing plantations and ground cover were determined. Investment costs for the period of implementation of the climate project on disturbed lands per 1 hectare of area vary from 82.6 thousand rubles to 116.9 thousand rubles. Climate projects in the Kuzbass basin are characterized by the highest potential for investment, with $C_{cii} = 2.01$. To organize and implement a climatic project on afforestation on disturbed lands in the Kemerovo Region, investments in the amount of 66.7 thousand rubles/ha for capital costs and 24.7 thousand rubles/ha for current costs are required. The payback period of the investment project, taking into account the discount rate, will be 13.1 years. For the period under study (20 years), the income of the investment project will cover 228% of its costs. The obtained data indicate the effectiveness of investment in the organization of forest-climatic projects on disturbed lands, indicating that the investment potential of such project solutions is quite high.

The results show that artificially created forests can be a cost-effective way to offset greenhouse gas emissions, and the implementation of afforestation projects on disturbed lands has great potential at the national level.

The proposed methodological approach to assessing the investment attractiveness of forest climate projects, based on understanding the difference between the total value of carbon sequestration in afforestation projects and their investment costs, is useful for strategizing and making policy decisions on forest climate change mitigation.

Afforestation projects in Russia can be successfully integrated into international initiatives on climate and sustainable development cooperation. This opens up new opportunities for the introduction of innovative forestry methods, including the use of genetically modified trees, the application of modern technologies in forest care, and the creation of sustainable ecosystems.

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