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Opportunities and Prospects for the Implementation of Reforestation Climate Projects in the Forest Steppe: An Economic Assessment

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Abstract: New methodologies, rules, modalities, and procedures for the mechanism established under Article 6(4) of the Paris Agreement have led to the need to change the national conditions for the implementation of climate projects, including climate projects in forests. However, the issue of evaluating the effectiveness of such projects and their attractiveness to investors remains controversial, as their place and role in the modern economy remain uncertain. Therefore, the aim of the study was to assess the investment attractiveness and silvicultural feasibility of implementing reforestation climate projects in the central forest steppe of Russia. Thanks to mathematical models (including the developed coefficient of carbon intensity of investment costs) and the calculations carried out, it will be possible to develop a differentiated approach to assessing the investment attractiveness of climate projects' implementation in forests. Reforestation projects including the planting of fast-growing tree species were considered. Maximum carbon sequestration for these projects is expected to occur over a period of 10–30 years. It was found that the coefficient of carbon intensity of investment costs, discounted by the duration of such projects, may become the basis for decision-making on investments in afforestation and reforestation in the central forest steppe.

Keywords: forestry economics; forestry; climate projects; reforestation; low-carbon development

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1. Introduction

Under the modern conditions of climate change, within the framework of market and non-night approaches, many tools and solutions have been created, aimed at adapting to such changes, mitigating climate risks, and encouraging low-carbon economic development. The decision 3/CMA.3, which was adopted within the framework of the 26th Conference of the Parties to the UN Framework Convention on Climate Change in 2021, is indicative of this; at the international level, it has established rules and procedures related to projected activities within the framework of the mechanisms established by paragraph 4 of Article 6 of the Paris Agreement [1].

However, the inclusion of forests in international climate agreements has been difficult, often viewed as a secondary mitigation option. In general, international recognition of the leading role of forests in reducing emissions and greenhouse gases has only been achieved within the framework of the Paris Agreement [2].

Countries under the Paris Agreement should provide Nationally Determined Contributions ((I)NDCs) to relevant international bodies [3], which should include mitigation goals. Thus, forests have become a key element in the implementation of the Paris Agreement. A global transition from the total greenhouse gas emissions of 1990–2010 (1.3 ± 1.1 Gt CO_2-eq. year^{-1}) to a much lower total carbon absorption in 2030 (up to

-1.1 ± 0.5 Gt CO_2-eq. year^{-1}) has begun; this should account for 25% of the planned reduction of greenhouse gas emissions [4].

The previously mentioned decision 3/CMA.3 contains separate provisions for the implementation of climate projects (i.e., the implementation of project activities). Thus, project activities, in particular, should provide additional carbon absorption within the framework of low-carbon socio-economic development, and should not lead to an increase in greenhouse gas emissions; they should aim to reduce greenhouse gas emissions according to the Paris Agreement; they should bring benefits in terms of climate change; they should minimize the risk of waste greenhouse gas emissions outside the boundaries of the project activity's implementation; and finally, they should minimize the negative environmental and social consequences of economic activity.

One of the key aspects of decision 3/CMA.3 is its designation of certain periods of credit for project activities. For projects related to A6.4ER, such a period is a maximum of 5 years, taking into account extensions no more than twice, or a maximum of 10 years without extension. For projects related to the absorption of greenhouse gases, such a period is a maximum of 15 years, with an extension of up to two times. Climate projects in forests are also included in the projects related to the absorption of greenhouse gases.

The most important result of project activities are carbon units (or carbon credits). As a result of the study [5], it was found that forest management improvement projects in the USA account for 96% of all loans from forestry projects, and 58% of all loans, and cover various practices, with different potential for carbon storage.

Forest ecosystems reduce greenhouse gas emissions by depositing carbon (SEQU model) directly, as well as indirectly; this may be, for example, if wood is used as biofuel in the energy system in power plants with CCS (the WBCCS model). The analysis carried out in the study [6] shows that both options for reducing greenhouse gas emissions within the framework of forestry are effective, but the combination of these options becomes the most effective. Activities under the WBCCS + SEQU models account for 23%–28% of all mitigation measures. SEQU is effective in the initial stages in conditions of low carbon unit prices, while WBCCS is more important in the long term in conditions of high carbon unit prices. Mitigation of climate change increases the attractiveness of forest management, as well as forest conservation. Thus, the SEQU model leads to an increase in forest areas and the formation of natural woodlands, and the WBCCS model allows for effective forestry and an increase in the area of managed forests.

However, opportunities for trading carbon units or credits do not exist in all countries. Moreover, often, the carbon effect from the implementation of climate projects or other investment projects is not calculated. This effect is dictated by national conditions, which are established individually in each state. In this regard, there are no specific guarantees of low-carbon development in individual countries.

Some researchers, using the example of Brazil [7], indicate the need to assess economic activity in relation to the level of greenhouse gas emissions.

To assess the ability of forestry measures to reduce greenhouse gas emissions in Turkey, Asif Raihan and Almagul Tuspekova [8] used the DOLS co-integration approach proposed by Pesaran et al. [9]. As part of the analysis, it was found that an increase of 1% in the area of intact forests in Turkey led to a reduction of 3.17% in greenhouse gas emissions. This is why the authors proposed an increase in the area of intact forest territories as a promising direction for low-carbon development in Turkey.

Another paper [10] by Asif Raihan provides a cost–benefit analysis (CBA) of potential mitigation measures within the framework of forest management activities in Malaysia, taking into account three main analysis periods—25, 50, and 75 years—as well as two scenarios, taking into account discount rates of 0% and 3%.

The results of the study indicate the high economic efficiency of forestry measures in mitigating climate change, these measures being associated with reforestation, improved forest management, and forest conservation. In addition, other functions of forestry are also indicated, including the preservation of biodiversity, the preservation of ecosystems, and the provision of ecosystem services.

Among the measures for adaptation to climate change and the mitigation of such changes, the authors note the intensification of forest reproduction and the adaptation of logging in ensuring the sustainability of forest ecosystems.

All of the above has led to the need to implement project activities in forests that are aimed at reducing emissions and increasing the absorption of greenhouse gases. One of the first mechanisms for such activities was the global initiative to reduce emissions from deforestation and forest degradation (Reducing Emissions from Deforestation and forest Degradation (REDD+)) [11]. It is important to note that this mechanism was aimed, among other things, at the formation of a unified forest management system at different levels, including at the international level.

The REDD+ mechanism itself provides an opportunity for developing countries to participate in the mitigation of global climate change through the sale of government loans for the implementation of project activities for reforestation, the prevention of deforestation, and forest conservation [12]. Funding for REDD+ projects has increased in recent years, and the number of REDD+ projects has increased, but so far, a relatively small number of studies have studied their implementation.

Using the experience of community forest management (CFM) remains one of the options for implementing project activities under the REDD+ mechanism. According to the results of individual studies [13] (for example, in Nepal) most REDD+ pilot projects have been implemented in public forests, especially in forests with a high carbon content. In Tanzania, the REDD+ mechanism was used to expand the area of forests under local management. Researchers, among other things, point to tools that can improve the effectiveness of CFM practice within the framework of REDD+ projects. These tools include improving the coordination of national and international institutions, equitable allocation of resources and results of project activities, community development within the framework of project activities, the modernization of project monitoring, and reporting processes.

Voluntary markets give businesses, organizations and individuals that are not regulated by greenhouse gas emissions the opportunity to purchase carbon offsets to reduce their carbon footprint. Carbon offsets (also known as carbon credits and carbon units), in essence, represent the amount of emissions prevented or reduced, or sequestered carbon. Voluntary carbon markets appeared after the adoption of the Kyoto Protocol, and have become an important mechanism for the turnover of carbon units. In such markets, carbon units of the so-called voluntary standards are being circulated.

It should be noted that, for example, several new forest carbon voluntary market programs have been launched in the USA, and additional programs are being developed; these are aimed at expanding the access of small landowners to carbon units [14]. Many of these programs are based on enabling a few landowners to combine their land to save on scale:

- The NCX forest carbon lease market, which is open to landowners. The first market auction was held in March 2021.
- The American Carbon Registry, which launched the IFM protocol in 2021 for the registration of land with an area of 40 to 50,000 acres.
- The Family Forest Carbon Program [15], developed by The Nature Conservancy, The American Forests Foundation, and TerraCarbon, involves the implementation of climate projects in forests on areas from 20 to 1000 acres, and was supposed to begin in the summer of 2021. The program protocol was verified and approved within the framework of the voluntary Verra standard.

Many carbon markets accept forest carbon compensation and have developed carbon project standards and protocols for three main categories of forest management activities. The owners of forest lands can receive compensation through the implementation of the following types of projects:

- Afforestation and Reforestation (A/R) projects include the creation of tree cover on previously unforested lands (afforestation) or the restoration of tree cover on previously forested lands that have recently lost tree cover (reforestation).
- Avoided Conversion (AC) projects include the prevention of the conversion of forest lands into non-forest lands (for example, the prevention of deforestation).
- Improved Forest Management (IFM) projects include land management activities that increase or maintain the baseline level of carbon storage. In other words, these are projects that increase the average carbon content in forests per acre on the project territory at various time scales [16].

The issues and concerns related to carbon markets in forestry are similar to those related to compensation of carbon emissions in agriculture and carbon markets in general, and are related to how each specific project will comply with the methodologies for implementing climate projects in forests.

There are also concerns related to carbon offsetting for plantation forestry, and general concerns about the extent to which the provision of carbon offsetting by forests can replace a more reliable reduction of greenhouse gas emissions through the implementation of other measures [17].

There are other problems related to the economic aspects of the implementation of climate projects in forests, including problems related to the profitability, scalability, and feasibility of projects on carbon emissions in forests.

For example, in the USA, current market conditions often do not make coal mining projects in the forest profitable or feasible for small forest owners. As a rule, the costs per acre of a climate project in forests can be high compared to the potential price of carbon units in voluntary and mandatory carbon markets. In order to obtain financial returns, most participants in the forest carbon markets increase the boundaries of project implementation or participate in large projects. Most often, the implementation of climate projects in the forests of the USA is carried out by corporate landowners, who account for 20% of the forest lands of the USA.

Nearly 40% of U.S. forest land is owned by approximately 10.6 million families, individuals, trusts, and estates, many of whom own less than 100 acres of land. The rest of the USA's forest lands are in state ownership [14]. Expanding access to forest carbon markets for these landowners will potentially increase the scale of the cumulative benefits of carbon offsetting.

Thus, the following factors should be noted, which made it possible to determine the aim of this study:

1. The regional nature of research on emissions and absorption of greenhouse gases by forests;
2. The lack of comprehensive economic studies considering investment costs for the implementation of climate projects in forests, taking into account the modeling of their implementation;
3. The concerns of the performers of climate projects in forests regarding the possibility of obtaining carbon units within the framework of the implementation of such projects;
4. The lack of forecast estimates of profitability and scalability of climate projects in forests;
5. The withdrawal of voluntary carbon markets from national regulations (i.e., institutional environments).

Therefore, the aim of this study was to assess the investment attractiveness and silvicultural feasibility of climate reforestation projects in the central forest steppe of Russia. This study will increase the investment attractiveness of reforestation projects in Russia and determine directions for increasing carbon sequestration in forests, taking into account the existing natural and climatic conditions of forest steppe regions.

As a result of the study, the methodological feasibility and availability of data for the evaluation (in physical and cost indicators) of forest climate projects were confirmed, and the main methods and problems of implementing the ESG approach to the evaluation and planning of such projects were identified, with an emphasis on the benefits of interested parties.

2. Materials and Methods

2.1. Methodology for Predictive Assessment of Carbon Sequestration by Reforestation

Calculations were carried out on the basis of the methodology developed at the Center for Forest Ecology and Productivity of Russian Academy of Sciences (CEPF RAS) for the informational and analytical assessment of the carbon budget of afforestation/reforestation at the local level [18]. Carbon absorption and stock were assessed for pool of live phytomass. Pools of dead wood, litter, and soil were not conservatively taken into account in the calculations.

The conversion approach recommended by the Intergovernmental Panel on Climate Change is the basis for determining the amount of C stock used by plantings [19]. The assessment of carbon stock by the phytomass pool is based on the method of stock difference. The basis for these calculations are data on the dynamics of the volume stock from regional yield tables, taking into account the peculiarities of technological approaches to the creation of forest crops. Before calculations, the dynamics of the taxation indicators were reduced to a step of 1 year. Linear interpolation was used for ages of plantings exceeding the starting age of the yield table. For ages less than the starting age of the yield table, linear extrapolation from the starting value to 0 was used for the height, diameter, and density of plantings.

The volumetric conversion method was used to calculate the carbon content of phytomass. For non-closed forest cultures, an allometric method for determining the carbon stock of phytomass was used [20].

The calculation of the carbon in the phytomass of a tree species k is carried out according to the following equation:

$$\mathrm{CPh_k} = 0.5 \cdot \mathrm{M_k} \cdot \mathrm{D_k} \cdot \mathrm{BEF_k} \cdot (1 + \mathrm{R_k}), \quad (1)$$

where $\mathrm{CPh_k}$ is the carbon in the phytomass of tree species k, t C ha^{-1}; $\mathrm{M_k}$ is the volume stock of wood of tree species k, m^3 ha^{-1}; $\mathrm{D_k}$ is the conversion factor of volume stock of wood of tree species k into the phytomass of the trunk, t m^{-3}; $\mathrm{BEF_k}$ is the biomass expansion factor for tree species k, dimensionless; $\mathrm{R_k}$ is the ratio of underground to aboveground biomass for tree species k, dimensionless; and 0.5 is the conversion factor from biomass to carbon.

In the absence of data on the stock of wood for non-closed forest cultures, the carbon stock of phytomass (without fractionation) was calculated using the following equation:

$$\mathrm{CPh_k} = \mathrm{N_k} \frac{\mathrm{a_k} \cdot \mathrm{h_k}^{\mathrm{b_k}}}{1000} \quad (2)$$

where $\mathrm{CPh_k}$ is the carbon stock of the phytomass of tree species k, t C ha^{-1}; $\mathrm{N_k}$ is the density of tree species k, ha; $\mathrm{h_k}$ is the average height of the tree species k, m; $\mathrm{a_k}$ is the parameter «a» of the equation for calculating the carbon of the phytomass of non-closed forest cultures of tree species k (Table 1); $\mathrm{b_k}$ is the parameter «b» of the equation for calculating the carbon of the phytomass of non-closed forest cultures of tree species k (Table 1); and 1000 is the conversion factor from kg to t of carbon.

Table 1. The parameters of Equation (2) for calculating the carbon stock of the phytomass of non-closed forest cultures (kg C per 1 plant). Adapted with permission from Ref. [20]. 1996, Utkin A.I.

Tree Species	a	b
Scots pine *Pinus sylvestris*	0.0727	2.3937
Pedunculate oak *Quercus robur*	0.0979	2.3988
Poplar *Populus* var. "E.s.-38"	0.0099	3.1463

The calculation of the phytomass carbon stock in the tree stand is carried out according to the following equation:

$$CPhS = \sum_k \frac{P_k \cdot CPh_k}{10} \quad (3)$$

where CPhS is the carbon stock of the phytomass of the tree stand, t C ha^{-1}; P_k is the proportion by composition (number of units less than 10) of tree species k; and CPh_k is the carbon stock of the phytomass of tree species k, t C ha^{-1}.

The carbon budget for the phytomass pool is estimated as follows:

$$BCPhS_i = CPhS_i - CPhS_{i-1} \quad (4)$$

where $BCPhS_i$ is the carbon budget for the phytomass pool of the plantation for year i, t C ha^{-1} $year^{-1}$; $CPhS_i$ is the carbon stock of the phytomass in year I, t C ha^{-1}; and $CPhS_{i-1}$ is the carbon stock of the phytomass in the previous year (i − 1), t ha^{-1}.

For the first year of the plant's existence, the previous carbon stocks of the phytomass are considered to be zero.

To determine the CO_2 removal from the atmosphere, $BCPhS_i$ values were converted using the following equation:

$$Va = BCPhS_i \times 44/12 \quad (5)$$

where Va is the CO_2 removal from the atmosphere in the baseline or project scenario, t CO_2 ha^{-1} $year^{-1}$; $BCPhS_i$ is the carbon budget for the phytomass pool of the plantation for year i, t C ha^{-1} $year^{-1}$; and 44/12 is the conversion factor from carbon to carbon dioxide.

2.2. Investment Analysis

The investment attractiveness of forest climate projects can be assessed by comparing the investment costs related to project implementation and the potential income (benefits) from the issuance of carbon units.

Investment analysis and assessment of the attractiveness of implementing forest climate projects aimed at increasing carbon absorption in forests involves a number of analytical procedures:

1. Determination of the duration and conditions for the organization and implementation of forest climate projects aimed at reforestation;
2. Determination of one-time and current costs for the organization and implementation of reforestation projects (operational costs);
3. Determination of income and net income from the implementation of forest climate reforestation projects;
4. Analysis of calculated criteria of investment efficiency in the implementation of climate projects aimed at increasing carbon absorption in forests (discounted profit, internal rate of return, investment return index, investment payback period).

The investment costs necessary for the implementation of forestry activities include the following:

1. Labor costs of the project staff;
2. Maintenance and operation costs of the equipment;
3. The costs of growing seedlings of woody plants;
4. Fuel and energy costs used for production purposes.

The duration of the reforestation was assumed to be 15, 30, or 45 years. Initial data for investment analysis were data on the planting technology used, the composition of tree species, methods of soil preparation, and seedlings used. Calculation of income and investment costs in the implementation of forest climate reforestation projects was carried out on 1 hectare of forest area.

The investments required to implement the forest climate project were determined by considering the direct costs of the project implementation, including one-time and current expenses. All costs were calculated in Russian rubles, using national cost standards [21], and converted to USD ($) using the exchange rate of 26 July 2023.

The one-time costs for the implementation of forest climate projects included the following:

- design of reforestation measures;
- validation and verification of the project;
- preparation of soil in areas planned for reforestation;
- planting of forest seedlings. The planting of seedlings with a closed root system was accepted as a project line.

One-time investments of USD 488.77 per 1 hectare are required for the implementation of reforestation projects in the regions of the central forest steppe of Russia (Table 2).

Table 2. One-time costs for the implementation of reforestation projects per 1 ha.

One-Time Costs	Amount, USD
Projecting of reforestation measures	10.99
Validation	1.67
Verification	4.44
Soil treatment	160.56
Planting seedlings	311.12
Total one-time costs	488.77

The current costs were directed at the agrotechnical care of the created plantings. Agrotechnical care is aimed at loosening the soil, destroying herbaceous vegetation, watering and fertilizing plants, and supplementing seedlings to the initial planting density in case of their death (in a quantity not exceeding 5% of the total number).

The total number under agrotechnical care for the first five years of growing forest crops in the forest steppe zone was taken in the amount of ten.

The current costs of reforestation in the sparsely wooded regions of the central forest steppe of Russia in an area of 1 ha amounted to USD 1129.95 (Table 3).

Table 3. Current costs for the implementation of reforestation projects per 1 ha.

Current Costs	Amount, USD
1 year of project implementation	
Agrotechnical care	126.78
Addition of seedlings to the initial planting density	135.62
Application of fertilizers	148.26
Watering of seedlings	80.66
Total current costs	491.32
2 and 3 years of project implementation (annually)	
Agrotechnical care	120.25
Watering seedlings	80.66
Total current costs	200.92
4 and 5 years of project implementation (annually)	
Agrotechnical care of seedlings of woody plants by loosening the soil	118.4
Total current costs	118.4
Total costs	1129.95

Depending on the species composition of the plantings, the cultivation techniques used and the soil types of the location wherein the climate project is implemented, direct costs can be reduced or increased by 10%–12%.

The discounting method was used to estimate economic indicators in a comparable manner:

$$Fc = \frac{Co + S}{(1 + i)^n}, \quad (6)$$

where Fc is the one-time and current costs of climate project implementation, discounted to the n-th year, USD ha^{-1}; Co is the one-time costs of climate project implementation in forests, discounted to the n-th year, USD ha^{-1}; S is the current costs of forest management activities of the project line of the forest climate project implementation, discounted to the n-th year; C is the current costs of the forest management activities of the project line of the forest climate projects' implementation; i is the discount factor, in hundredths of a unit (assumed to be 3%); and n is the number of periods in the future, during which the planned activities will be implemented.

In the study, the following assumptions were made to evaluate reforestation climate projects:

- baseline represents a business-as-usual (BAU) situation in the absence of project activity. Generally, BAU is the absorption of CO_2 during the artificial forest regeneration of burned areas, according to forestry legislation requirements, with the widespread practice of planting monocultures of Scots pine (*Pinus sylvestris*). Natural regeneration in a forest steppe environment is challenging because of environmental limitations (insufficient moisture, droughts, etc.);
- the project scenario assumed artificial regeneration with a mixed-tree species composition, including the planting of seedlings of Scots pine (*Pinus sylvestris*), highly productive poplar (*Populus* varieties), and pedunculate oak (*Quercus robur*) with a closed root system, with a density of 3500 plants per hectare. Firstly, these tree species are native to the central forest steppe, and project activities are not involved in establishment of plantations of introduced and invasive species that would threaten the local biodiversity. Secondly, the range of tree species includes both fast-growing species (poplar), trees with a moderate growth rate (pine), and slow-growing but long-living species (oak). Thus, on the one hand, this will provide sustainable production of timber in the future; on the other hand, it will provide a high level of CO_2 absorption and long-term carbon storage in the phytomass.

The biomass stock per hectare of forest plantations created by seedlings of pine, poplar, and oak were calculated with an interval of 5 years.

The total cost of the additional annual volume of CO_2 absorption (Icarbon) was calculated using the following equation:

$$Icarbon = Pc \cdot \Delta Va, \quad (7)$$

where Pc is the current unit price of the carbon stock in the base period, USD t^{-1}; and ΔVa is the additional volume of absorbed greenhouse gases in CO_2 through project activities.

The cost of one ton of CO_2 was assumed to be equal to USD 11. Revenues in the project line were determined by the difference of greenhouse gas absorption between the baseline and the project scenario, taking into account the price per 1 ton of CO_2 eq., which is the carbon unit.

For an economic assessment of the effectiveness of the implementation of individual reforestation and afforestation climate projects, we used indicators of the effectiveness of investments such as the return on investment (PI) index, which is determined as follows:

$$PI = CFt/Fc, \quad (8)$$

where CFt is the net income received during the implementation of the forest climate project, taking into account the n-th year, $, and Fc is the one-time and current costs of climate project implementation, discounted to the n-th year, $ ha^{-1}.

The net present value of income (NPV) was defined as follows:

$$NPV = -IC + CFt, \quad (9)$$

where IC is the initial investment costs for reforestation, given by the n-th year, thous. $; CFt is the net income received during the implementation of the forest climate project, taking into account the n-th year, thous. $.

If NPV > 0, revenues exceed the investment costs of the project. If NPV < 0, costs exceed revenues, which makes the project unattractive to investors.

For the economic assessment of the possibility of implementing forest climate projects, the carbon intensity coefficient of investment costs was used. The coefficient characterizes the costs of the investor for the implementation of a set of forestry measures necessary to increase the absorption of CO_2 by 1 ton, created by plantings on 1 hectare of a forest climate project. This coefficient allows an investor to determine the land area required for a carbon offset project, as well as the carbon unit value of a reforestation project.

The coefficient of carbon intensity of investment costs (Cci) was determined according to following equation:

$$Cci = Fc/\Delta Va, \quad (10)$$

where Fc is the one-time and ongoing costs for the implementation of the climate project, discounted by the n-th year, $ ha^{-1}; ΔVa is additional CO_2 removal from the atmosphere (difference between project scenario and baseline), t CO_2 ha^{-1}.

The carbon intensity coefficient allows differentiating climate projects from the perspective of investment costs necessary to create plantings capable of absorbing 1 ton of greenhouse gases.

3. Results

For reforestation climate projects, the predicted absorption values in the baseline scenario and as a result of project activities are presented in Table 4. At the same time, the project implementation period is determined on the basis of the previously mentioned decision 3/CMA.3 of the 26th UNFCCC Conference of the Parties.

Table 4. CO_2 absorption during the reforestation project in the central forest steppe of the Russian plain (t $CO_2 \cdot ha^{-1} \cdot year^{-1}$).

Year of Project Implementation	Baseline, $Va_{baseline}$	Project Scenario, $Va_{project}$	Additional Volume (Difference between Project Scenario and the Baseline), ΔVa
1–5	2.6	3.7	1.1
6–10	4.8	10.3	5.5
11–15	6.6	15.9	9.3
16–20	8.5	21.5	13.0
21–25	5.0	15.7	10.7
26–30	4.8	15.5	10.7
31–35	4.1	8.3	4.2
36–45	4.0	8.2	4.2
Average for the 45-year project implementation period	5.1	12.4	7.3

The rules of reforestation [22] provide different options for the implementation of measures, with the common practice of planting coniferous monocultures. Therefore, the widespread practice of planting monocultures of Scots pine in the central forest steppe region was assumed to be the baseline scenario. Such approaches to artificial reforestation lead to decrease in biodiversity and soil fertility, an increase in the risk of new wildfires, and damage to forests by pathogens. According to our calculations, CO_2 absorption does not exceed 8.5 tons of $CO_2 \cdot ha^{-1} \cdot year^{-1}$, with an average value of 5.1 tons of $CO_2 \cdot ha^{-1} \cdot year^{-1}$ over the 45-year period of the existence of such plantations, assuming their complete survival.

Carbon sequestration via mixed planting is predicted in the project line, where 50% of coniferous trees are replaced by deciduous ones, both fast–growing (poplar, 40%) and slow-growing (oak, 10%). It should be noted that for the prediction of poplar carbon sequestration, data on the growth of a highly productive intersectional hybrid of the poplar variety "E.s.-38" ("Voronezh giant") were used. Its annual growth is three times higher than that of aspen under similar growing conditions, and varies from 17 to 20 $m^3 \cdot ha^{-1} \cdot year^{-1}$ [23].

The maximum amount of carbon sequestration predicted for the 10–30-year period of mixed plantings' growth varies from 15.5 to 21.5 tons of $CO_2 \cdot ha^{-1}$ per $year^{-1}$. It is obvious that during this period, the maximum additional absorption compared to the baseline scenario is achieved, exceeding it by 1.5–2 times. However, on average, over the 40-year project period, the annual sequestration will be about 12.4 tons of $CO_2 \cdot ha^{-1} \cdot year^{-1}$, which is 7.3 tons of $CO_2 \cdot ha^{-1} \cdot year^{-1}$ higher than the baseline.

The dynamics of carbon sequestration in the baseline scenario and resulting from project activities are shown in Figure 1.

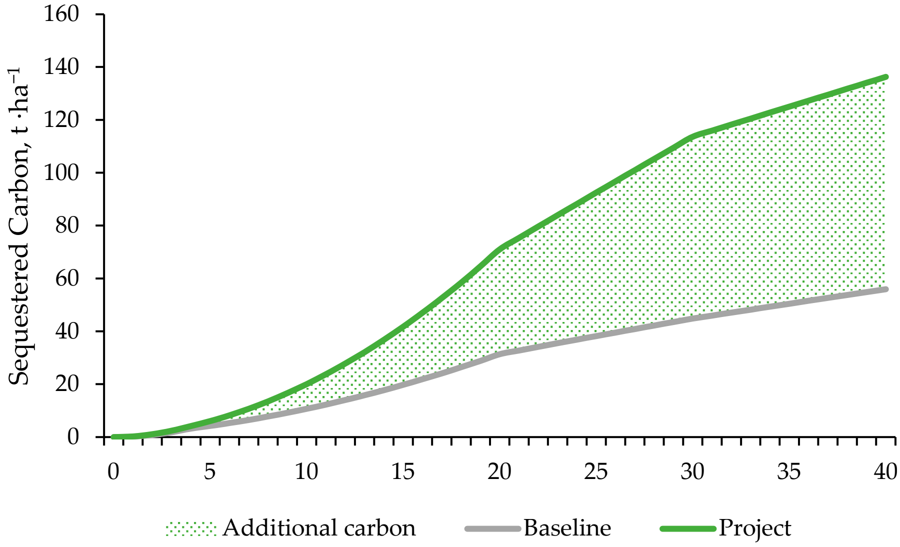

Figure 1. Dynamics of carbon sequestration during the reforestation project in the central forest steppe of the Russian plain.

Obviously, the option of artificial reforestation presented in the project activity significantly increases carbon sequestration by forest stands. Thus, thanks to the project, the total sequestered carbon will increase by at least 80 $t\ C \cdot ha^{-1}$, and reach about 136.3 $t\ C \cdot ha^{-1}$. In addition, it is necessary to take into account a number of other benefits associated with increasing the sustainability and ecological potential and environmental functions of forests in the low-forested region of the central forest steppe.

In accordance with the obtained values of absorption/emissions of CO_2, the cost indicators of the investment attractiveness and efficiency of the implementation of forest climate projects are calculated.

The revenues and expected current investment costs for the climate reforestation project in the central forest steppe are shown in Figure 2.

In the first years of the project's implementation, the project costs associated with reforestation significantly exceed the expected revenues.

This is due to the fact that the achieved level of greenhouse gas absorption during this period is relatively small, and despite exceeding the baseline, the expected income is lower than the project costs. The regions of the central forest steppe of Russia are characterized by difficulties with reforestation in a natural way, and the overgrowth of forests with woody plants occurs after 8–10 years. The income from 20 years of implementation of the forest climate reforestation project will amount to $7770.

The accumulated profit for this period will be $5300. NPV value > 0; therefore, the income from the release of carbon units exceeds the investment costs.

The internal rate of return (IRR) of the reforestation project in the central forest steppe equals 15%. The discounted payback period of such a forest climate project is 10.4 years.

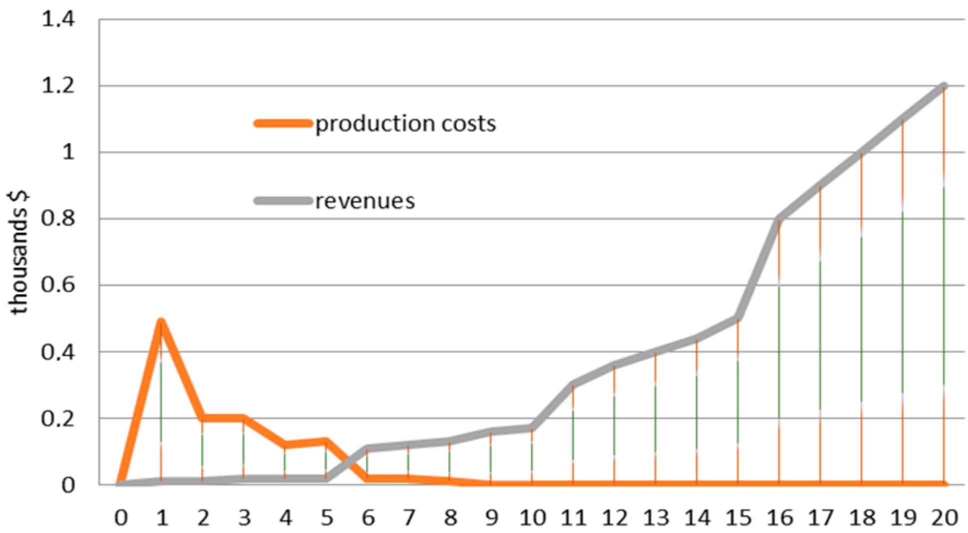

Figure 2. Dynamics of production costs and revenues of the reforestation climate project in the central forest steppe of the Russian plain, shown in thousands of USD.

To assess the investment attractiveness of forest climate projects implemented in the central forest-steppe, the coefficients of the coal intensity of investment costs were calculated.

Based on the results of economic calculations, the possibility of implementing forest climate projects for reforestation in the conditions of the central forest steppe was confirmed.

The carbon intensity coefficients of investment costs were calculated for forest climate projects in the central forest steppe of the Russian plain, with implementation periods of 15, 30, and 45 years. Despite the fact that the costs of forestry activities of the reforestation climate project are concentrated at the beginning of the period of its implementation, the effectiveness of investments will be different (Table 4).

The highest investment efficiency indicators are demonstrated by reforestation climate projects with a 45-year implementation period (the deadlines are set on the basis of decision 3/CMA.3 26 of the UNFCCC Conference of the Parties). The long duration of the project ensures maximum absorption of CO_2-eq., and is minimally correlated with investment costs (Table 5). At the same time, reforestation climate projects with an implementation period of 30 years demonstrate good performance indicators, as shown earlier. Thus, an investment of $1000 in a reforestation project (for one hectare of land) can be expected to sequester from 117.9 to 158.3 tons of CO_2 eq., with a carbon unit cost of $6 to $8 per ton.

Table 5. Assessment of the potential for the implementation of climate projects in the forests of Russia.

Expected CO_2 Absorption, t CO_2 ha^{-1} Per Year	Direct Project Costs, Thous. USD ha^{-1}	Project Implementation Period	Carbon Intensity Coefficient of Investment Costs, t CO_2 Per USD ha^{-1}	Carbon Unit Cost, USD
up to 9.5	up to 160	15 years	79.2	12.6
up to 9.5	up to 160	30 years	158.3	6.3
up to 9.5	up to 160	45 years	237.5	4.2
up to 7.5	up to 140	15 years	70.3	14.2
up to 7.5	up to 140	30 years	140.6	7.1
up to 7.5	up to 140	45 years	210.9	4.7
up to 5.5	up to 130	15 years	58.9	16.9
up to 5.5	up to 130	30 years	117.9	8.5
up to 5.5	up to 130	45 years	176.8	5.6

Forest climate projects with short-term implementation (up to 15 years) are characterized by high investment costs and low expected revenue from carbon units. The use of the carbon intensity coefficient of investment costs makes it possible to compare investment projects and identify the most economically feasible ones for implementation, taking into account the investor's current expectations.

The implementation of reforestation climate projects in the central forest steppe of the Russian plain is most favorable when invested in for terms of 20 years or more.

4. Discussion

Maximum carbon deposition by newly created forest stands can be ensured by growing the most highly productive tree species, corresponding to the natural and climatic conditions of each specific region. The most important environmental limitation is the condition for the conservation of biological diversity and, above all, the species diversity of forest-forming species in each region and latitudinal zone.

One of the most important ways to solve this problem is reforestation in forest steppes, steppes, and semi-desert regions, where natural and artificial reforestation is extremely difficult due to the aridity of the territories. The sites of these territories are identified by researchers of this problem as the most promising for solving the problems of carbon deposition and increasing the absorption of greenhouse gases in general.

This study shows that the greatest positive values of carbon balances in forests have been recorded in the European territory of Russia, especially in its central and southern parts. Areas with large positive greenhouse gas balances are suitable for forest climate projects that can accomplish a stable long-term carbon storage scenario (e.g., afforestation projects). Some studies [24] indicate that this method of forest management is more cost-effective than a number of alternatives. Implementation of forest climate projects with a duration of 20 years or more is feasible in Russia in suitable areas. For example, fast-growing native tree species should be used for planting to increase the sequestration capacity of forest stands.

The costs of carbon sequestration in forest climate projects are highly variable and depend on the location and conditions of the project and can be quite significant [25]. These differences in investment costs are due to the influence of plantation establishment technology, which also affects the additionality of the project [26]. C.S. Galik [27] highlights other factors that influence costs, such as the rotation period and future use of timber. Other studies suggest that reforestation projects are not effective in the early years because young trees absorb less CO_2 in the first ten years after planting than in the following decades [28,29]. Our results are similar and demonstrate the importance of increasing the rotation period of plantations in the central forest steppe of Russia.

Both opportunity costs and prices in voluntary carbon markets have a significant impact on the investment attractiveness of forest climate projects [30–33]. As part of the Ecosystem Marketplace report for 2021, the largest share of carbon units obtained during the implementation of forestry and land use projects within the VERRA standards was noted (about 10 Mt CO_2-eq. of the studied 36.7 Mt CO_2-eq.) [34]. The ACR standard (about 2.5 Mt CO_2-eq.) is the second in terms of the output of carbon units in the implementation of climate projects of "Forestry and other land use" (about 36.7 Mt CO_2-eq.).

At the same time, the average price of carbon units under VERRA standards was USD 1.74 in 2019, and USD 3.76 in 2020; by August 2021, it had increased to USD 4.17. For the ACR standard, the price was USD 5.36 in 2019; USD 8.44 in 2020; and in August 2021, USD 11.37. Regarding the CDM standard, the average price in 2019 was USD 2.02; in 2020, USD 2.19; and by August 2021, already USD 1.13 [35].

However, the average prices for "Forestry and land use" projects differed slightly from the average prices for all climate projects (for the VERRA standard in 2019, this was $3.77, and for the ACR standard, $6.86 [36]). Thus, the average price for such units under the VERRA standard for "Forestry and land use" projects was twice the average price for carbon units for other types of projects, and under the ACR standard, the price was greater by more than a third.

This difference was primarily caused by free pricing and subjective ideas about higher-quality carbon units obtained during the implementation of climate projects in the "Forestry and land use" sector. It is precisely due to the voluntary nature of part of the carbon markets (the actual lack of institutional regulation by states and their withdrawal from the national legal field) [37] that stakeholders in the implementation of climate projects in forests have some concerns related to the implementation of such projects.

Our data on the possible value of carbon units in reforestation projects in the central forest steppe do not contradict the average carbon unit prices reported in several studies [38,39], and range from USD 4 to 17 per ton. The implementation of reforestation climate projects in the central forest steppe of Russia may not only be attractive for investment, but given the challenge of increasing carbon sequestration, such projects will be essential for achieving current global climate change mitigation goals.

5. Conclusions

The present study identified a mechanism for assessing the investment attractiveness of climate reforestation projects in the central forest steppe. The developed models for the implementation of forest climate projects can be further applied in practice as promising methodologies for such projects in some regions of Russia with similar forest and vegetation conditions.

Reforestation projects with planting of fast-growing tree species were considered, and it was found that for these projects, maximum carbon sequestration by plantations is predicted to take 10–30 years. The coefficient of carbon intensity of investment costs, discounted taking into account the conditions of the implementation of such projects, may be the basis for decision-making on investments in afforestation and reforestation in the central forest steppe of Russia.

The obtained results show that artificially established forests may be a cost-effective way to offset greenhouse gas emissions, and the implementation of afforestation projects in the central forest steppe has great potential at the national level.

The proposed methodological approach for assessing the investment attractiveness of climate projects in forests, based on understanding the difference between the total value of carbon sequestration in reforestation projects and their investment costs, is useful for determining strategies and political decision-making on climate change mitigation in arid steppe regions, including the central and southern regions of Russia.

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