Ecological and economic balance modeling for regional multifunctional sustainable forest management

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Abstract. Balance as a principle of long-term sustainable development is considered in the context of forest management results in Russian regions (forest industry production) in comparison with results of carbon storage of forest ecosystems. These results reflect two main functions of forest potential: socio-economic (consumer) and socio-natural (carbon depositing). Considering various quantitative and qualitative aspects of their relevance, the latter should be recognized as an emphasis. Five concepts characterize effects of forests ecosystem function. To determine the value of carbon stocks used, two variants of income function in the regional ecological and economic system are considered. The models were approved using regions typology adapted for state forest management purposes according to the criteria of forest cover and development. In each group, representing a separate type of regions (multi-forest, medium-forest, low-forest and underdeveloped), new spatial configurations were formed, which indicated fundamental differences in carbon cost by Russian regions. Calculations make it possible to justify charges introduction for carbon stocks consumption in the region and differentiation of fee rates. Modelling allows to substantiate imperative of compliance with ecological and economic balance between deforestation (timber harvesting) and carbon storage. The study results provide a basis for differentiated state policy of forest management based on regional characteristics.

1. Introduction
Modeling multifunctional sustainable forest management is based on the principle of maintaining a balance between economic and environmental performance, which includes forest management as a component of the national economy, as well as results of natural and quasi-natural forest ecosystems. Balance is seen as a principle of long-term sustainable development of countries as macro-systems. Its implementation requires taking into account regional diversity and stability features of a particular region territory [1] as meso-level subsystems.

To harmonize the development of Russian regions and regional forest management, it is advisable to compare results of economic and environmental "production" as forest potential effects. The proposed indicators of economic and environmental effects are as follows: the volume of timber production and carbon pools in forest ecosystems. These indicators reflect the results of two main forest potential functions – socio-economic (through timber production) and socio-natural (through carbon storage). Obviously, forest potential carbon depositing function should be recognized as a priority in the long term, as it provides basic ecosystem goods and services for economic development, including absorption of greenhouse gases, carbon accumulation in various structural components of
forest ecosystems, production of primary biological products; biodiversity conservation; climate control, impact on human health, productivity, and life expectancy. We characterize the effectiveness of forest ecosystem function at the present level of environmental and economic science development as "factor five". Firstly, the country (region) receives compensation for the absorption of "foreign" carbon dioxide emissions. Secondly, at the same time, there is an accumulation of carbon in the biomass of woody plants and its transformation into other forms, which generally increases the carbon potential of the territory for the long term. This carbon potential can be seen as an energy platform for future development. Thirdly, biocenotic potential of the territory increases due to conservation of biodiversity, which, fourthly, allows for developing such ecological and economic activities as hunting, recreation, agroforestry, etc. Fifthly, preservation of natural living conditions for the population in areas with a low rate of biological circulation (metabolism) should be considered as a factor of ensuring human health, condition of increasing life expectancy and, consequently, preservation of human potential. Thus, payment for forest ecosystems conservation by other members of the world community, as well as deferred opportunities for future generations to use forest potential, considering a new level of knowledge and technology can compensate refusal of modern economic use of forest potential in the country. It should be emphasized that economic and environmental results are achieved due to the multifunctionality of forest and cyclical nature of its reproduction.

Modern foreign studies present an analysis of empirical data on regions with different scale and location, as well as in various aspects. Forest management of the Miyun watershed as a protective screen and provider of ecosystem services in Beijing city [2] is considered in terms of related economic value. From the standpoint of American researchers concerning Wisconsin State, there is a focus on an understanding of organic carbon spatial distribution in the soil and the forecast of its future state, which is crucial for future estimates of carbon dioxide emissions and carbon storage management options [3]. Digital maps generated in this study allow taking decisions on both farm management and state-level environmental policy. Finnish scientists present a process approach to carbon balance with a strong empirical component based on forest inventory. This model is linked to the global forest sector model to ensure consistency between woodcutting and demand [4]. For Canada as a whole, modelling of carbon fluxes, depending on tree species, growing conditions and forest management practices in Canadian forests, was performed [5]. This study is aimed to improve accounting of biogenic carbon in forest phase of coniferous products life cycle.

It should be noted that, based on domestic [6-11] and foreign experience to ensure forest potential development in the context of long-term socio-economic development of Russia and its regions, it is necessary to support dual implementation of forest potential, i.e. simultaneous achievement of economic and environmental results, which should be either interchangeable or complementary. In fact, the main functions, socio-natural and socio-economic, compete with each other, i.e. are partially or completely mutually exclusive. However, in terms of spatial organization, they can be complementary in different spatial dimensions or interchangeable in one space level. Therefore, in the relationship of these functions, the principle of balance has to work. In this regard, we should talk about the ecological and economic efficiency of regional forest potential implementation.

2. Models and methods

In terms of functions interaction mentioned above, we consider the case of their interchangeability in regional space [12], forming a ratio where, on the one hand, total area of regional forest fund corresponds to total carbon stock in different pools, and, on the other hand, the maximum possible economic result (in particular, timber production), which can be produced from forest, as a source of raw materials and services obtained from the same total area of regional forest fund at this level of productive forces development (taking into account existing skills and production technologies). Results (indicators) of economic and environmental production comparison allow us to obtain a regional carbon equivalent of produced timber product in the region. We can calculate in value terms current possibilities of using carbon reserves of forest ecosystems in Russia based on prices for forest
products. In addition, carbon losses from forest management (primarily timber harvesting) can be estimated on this basis. Finding a balance between forest production and carbon production (accumulation) requires determining the value of carbon stocks used.

In economic terms, two options of income function in the ecological and economic system are considered. Under the first option, benefit from the use of forest resources can be seen as the difference between the value of output and the value of total carbon used.

\[ R = Q(S) - p(S)C(S) \rightarrow \text{max}, \]  

where \( R \) is income from forest potential use (in particular, forest resources); \( Q \) – the volume of regional timber production (billion rubles), on which previously accumulated carbon stock is spent; \( C \) – total carbon reserves (million tons) in the lands of regional forest fund (in wood, wood residues, soil); \( S \) – total area of regional forest land (thousand hectares); \( p \) – the cost of carbon consumed during timber production.

With the implementation of the second option of benefit function measurement, it takes a relative character and the form of a ratio of timber production value and value of total carbon reserves (pools):

\[ (2) R = \frac{Q(S)}{p(S)C(S)} \rightarrow \text{max}. \]

Based on the first option of calculating income (absolute), the cost of carbon is defined as \( p = \frac{\Delta Q}{\Delta C} \).

When calculating income according to the second option, which can be characterized as relative, incremental cost will be as follows:

\[ \frac{\Delta p}{p} = \frac{\Delta Q}{Q} - \frac{\Delta C}{C}. \]  

3. Results and discussion

For practical application of considered models, we used the typology of regions based on forest cover and forests development indicators. About it means four types of regions: multi-forest industrial, medium-forest developed, low-forest, and underdeveloped [13]. In each group, new spatial regional configurations have an ascending order of total area of forest fund lands. Selected regional typology indicates a fundamental difference in the cost of carbon for regions, depending on the level of forest cover and the development of timber production (table 1). However, interpretation of results implies further research and use of additional characteristics.

**Table 1.** Cost of consumable carbon stocks by types of regions in the Russian Federation.

| Type of regions – subjects of the Russian Federation | 1st calculation option: carbon optimal cost, RUB/t | 2nd calculation option: range of relative carbon incremental costs |
|-----------------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|
| multi-forest industrial                             | 68.82                                         | [-0.89; 49.36]                                                |
| medium-forest developed                             | 43.00                                         | [-0.86; 12.63]                                                |
| low-forest                                          | -8.32                                         | [-0.87; 39.29]                                                |
| Underdeveloped                                      | 0.33                                          | [-0.88; 6.96]                                                 |

Experimental calculations provide an opportunity to draw some conclusions about factors determining carbon cost, a policy of balanced forest management for different types of regions, consideration of charges for carbon stocks consumption as a financial lever in the region, as well as identification of factors for differentiating payment rates for its consumption.
The expected maximum value of carbon consumption is observed in multi-forest industrial regions (68.82 RUB/t). For this type of regions, where wood processing is poorly developed, negative values are typical: the Republic of Altai and Primorsky Krai. The maximum values were in Yaroslavl (150.24 RUB/t), Arkhangelsk (143.13 RUB/t) and Vladimir (119.18 RUB/t) regions, i.e. regions of the Russian Federation with a high level of timber industry complex (TIC) development. Medium-sized developed regions, as well as multi-forest regions, are characterized by significant differentiation within the group at an average cost of 43.00 RUB/t of consumable carbon. Low-forest regions are characterized by an average negative value of consumed carbon cost (-8.32 RUB/t). At the same time, maximum values are observed in regions with a significant level of woodworking development (Rostov region (22.80 RUB/t)) and significant carbon reserves (Tula region (16.43 RUB/t)). In underdeveloped regions, there are very low values of consumed carbon cost (0.03 RUB/t) with insignificant differentiation within the group.

Option II model analysis revealed the following. The maximum value of relative increments (incremental cost) of consumed carbon in multi-forest industrial and medium-forest developed regions is much higher than in low-forest and underdeveloped regions. For low-forest regions, the widest range of relative growth should be noted, and in underdeveloped regions, the minimum and maximum values of relative growth are characterized by the smallest range.

Among the multi-forest industrial regions, the maximum values of consumed carbon incremental cost indicator are observed where the most developed branches of timber industry are located: the Irkutsk region (49.36), the Republic of Komi (38.99) and the Republic of Karelia (37.19). Negative values of growth index in this type of regions considered as underestimation of forest lands potential by forest users characterize the Kostroma, Smolensk, Vladimir, Tver regions (found in a small number of areas of this type). A similar pattern is observed in medium-forest developed regions. Among low-forest and underdeveloped regions, the maximum values of consumed carbon incremental cost are typical for regions with the most developed woodworking industries.

4. Conclusion
Experimental calculations allow us to draw the following conclusions:

1) estimated cost of carbon varies significantly, depending on the types of regions (according to the level of forest cover and forest development); 2) imperative of compliance with ecological and economic balance in modern society is determined by the fact that forest cutting reduces the possibility of carbon absorption, thus, introduction of a fee rate (which serves as a fine) for the use of carbon stocks suggests a policy of balanced (equilibrium) forest management; 3) funds received for the used carbon stocks can be accumulated in extra-budgetary fund of the region and directed in a targeted way to reforestation activities and research of forest potential (including forest science); 4) rates of payment for the use of carbon stocks should be differentiated based on regional characteristics: forest cover and forest development (primarily this applies to multi-forest industrial and medium-forest regions); for low forest cover regions forest policy is related to other life-supporting economic activities (in particular, agriculture and water management; production of forest products in this type of regions, obviously, should not be related to carbon stocks in their territories).

Modeling multifunctional-sustainable regional forest management can be supplemented by a forest-carbon "uptake" model, which implies cost comparison of carbon-absorbing capacity in forests with a volume of woodcutting. This idea is based on a hypothetical comparison of the cost of greenhouse gas absorption volume for the period (annual cycle), as well as the cost of annual harvesting (cutting) of wood in the region, based on the current level of productive forces development. At the same time, we proceed from the premise that in our country (in most regions) the main problems of the current period are not related to forest reserves but to their use since in terms of indicators associated with forest protection and biodiversity conservation, Russia is raked quite prosperous and occupies a leading position in the world.
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