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A new Model for Calculating the Impact of Forests and Wood Use on the Balance of C-CO_2 in the Earth's Atmosphere

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According to the FAO (Global Forest Resources… 2020), the world's forests store 662 billion tons of carbon, of which 44.5% is biomass, 10.3% is dead wood and litter, and 45.2% is in the soil. Forests have an essential carbon function, removing each year about 20% of global anthropogenic CO_2 emissions (Bellassen, et al, 2021).

In the Paris Climate Agreement, forests play major role in reducing CO_2 levels in the atmosphere. The generally accepted calculation of CO_2 fluxes in forests leads to the conclusion that with an increase in planting area and their productivity, the runoff of carbon dioxide from the atmosphere increases sharply.

The objective results of assessing the impact of tree plantations on CO_2 fluxes in the atmosphere largely depend on the duration of the analysis of natural and anthropogenic transformations of wood.

To calculate the CO_2 balance in the atmosphere during forest cultivation, we used the results of a model experiment on the creation of forest plantations based on aspen (*Populus tremula* L.), its natural and modified forms (Komarov, et al., 2015). The model experiment was carried out by the authors on the example of the soil and climatic conditions of the north-west of the Leningrad Oblast (Russia). The growth of plantations with a short turnover of felling (30 years), established on the site of cut down spruce forests, was modeled. Nitrogen mineral fertilizers were applied in the experiment at a dose of 150 kg of active substance per 1 ha at planting, 10 years after planting and 5 years before the main felling.

According to the results of a model experiment on the creation of forest plantations of aspen, its natural and genetically modified forms (Komarov, et al., 2015 *), we revealed a large net sink of C-CO2 from the atmosphere both in the first rotation of the plantation (Table 1) and in the second (Table 2).

Table 1. *C*-CO_2 balance in plantations of natural and genetically modified forms of aspen *Populus tremula* L. (1-st rotation of the plantation).

Unit of measurement	Aspen shapes		
	natural	**natural with N fertilizers**	**genetically modified with N fertilizers**
стволовая древесина			
biomass, t/ha*	94,8	99,6	116,9
technical energy costs in wood production			
GJ/ha	9,4	55,2	55,2
C-CO_2 emissions from wood production			
t/ha from technical energy	0,22	1,2	1,2
t/ha from loss of soil humus	9,0	9,0	10,0
C-CO_2 sink in stem biomass			
t/ha	47,7	50,1	,62,5
thinning wood			
biomass, t/ha*	17,4	18,2	25,8
C-CO_2 runoff in the wood of thinnings			
t/ha	8,7	9,1	12,9
total C-CO_2 emissions from wood production			
t/ha	9,22	10,2	11,2
total C-CO_2 sink in woody biomass			
t/ha	56,4	59,2	73,4

In experiments, a large biomass of tree wood was obtained, especially when nitrogen fertilizers were applied. The runoff of C-CO_2 in stem biomass was 37.9 - 45.5 t/ha. The total runoff of C-CO_2 in woody biomass was 44.1-55.2 t/ha.

Table 2 . *C*-CO_2 balance in plantations of natural and genetically modified forms of aspen *Populus tremula* L. (2-nd rotation of the plantation)

Unit of measurement	Aspen shapes		
	natural	**natural with N fertilizers**	**genetically modified with N fertilizers**
стволовая древесина			
biomass, t/ha*	75,7	89,4	91,0
technical energy costs in wood production			
GJ/ha	9,4	55,2	55,2
C-CO_2 emissions from wood production			
t/ha from technical energy	0,22	1,2	1,2
t/ha from loss of soil humus	9,0	9,0	10,0
C-CO_2 sink in stem biomass			
t/ha	37,9	44,7	45,5
thinning wood			
biomass, t/ha*	12,3	14,4	19,3
C-CO_2 runoff in the wood of thinnings			
t/ha	6,2	7,2	9,7
total C-CO_2 emissions from wood production			
t/ha	9,22	10,2	11,2
total C-CO_2 sink in woody biomass			
t/ha	44,1	51,9	55,2

The total emission of $C\text{-}CO_2$ into the atmosphere during cultivation amounted to no more than 11.2 t/ha or 3.2% of the carbon content in wood. Thus, forest plantations do appear to be an important sink of carbon dioxide from the atmosphere.

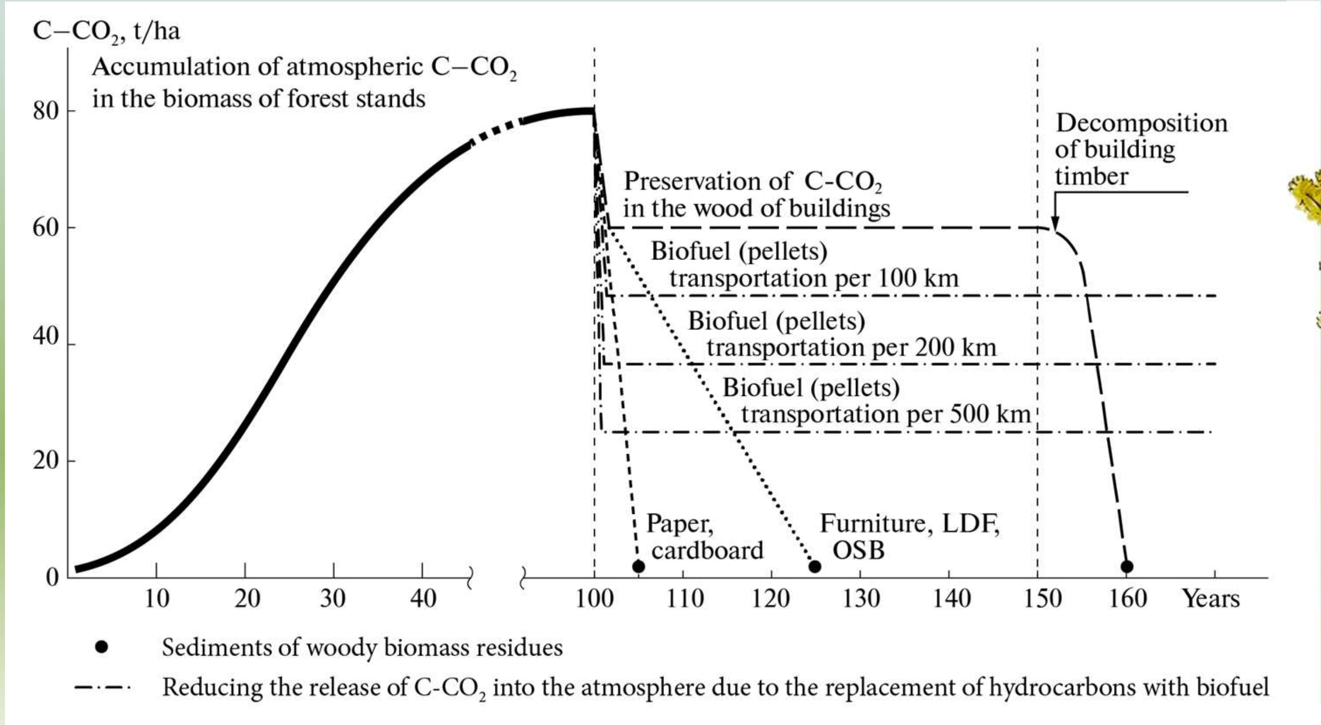
However, a deeper consideration of the fate of wood in time leads to an unexpected conclusion.

The objective results of assessing the impact of tree plantations on the CO_2 balance in the atmosphere largely depend on the duration of the analysis of the natural and anthropogenic transformation of wood.

We have developed a methodology and proposed a new three-stage method for calculating the $C\text{-}CO_2$ balance when growing forests and using wood.

1. Biocenotic balance (for a period of 30–120 years of cultivation, depending on the forest-forming species and the period of felling for the main use),
2. Natural and economic balance (for 170–200 years from the moment of forest renewal to the completion of the service of wooden structures),
3. Biogeochemical $C\text{-}CO_2$ balance (associated with the cultivation of tree plantations and the use of wood and culminating in the entry of residual organic matter into the earth's crust, accumulative landscapes).

Scheme of a three-stage method for calculating the balance of C-CO_2 in the atmosphere when growing forests and using wood



The long-term cycle of C-CO $_2$ the system atmosphere - green plants - industrial wood - man-made buildings and things – dust- the atmosphere ends only with a small positive balance.

It is known that only a small part - 0.8–1.0% of the organic matter synthesized by plants enters the large geological cycle, transforms and is preserved for millions of years (Kovda, 1973 , Alpatiev, 1983).

The bulk of the buried dispersed organic matter is concentrated in the sediments of the continents and the oceanic vector. Concentrated organic reserves of ancient biospheres are found in deposits of coal, hydrocarbon gases and oil. Their intensive extraction and use in the modern period leads to a sharp release of carbon dioxide into the atmosphere.

Table 3. Dead organic matter in the ancient biospheres of the Earth (Bazilevich, 1979)

An object	C, 10^{12} t	%
Continental sediments	10000	66,5
Ocean vector sediments	5000	32,3
Coal	30,0	0,20
Oil	2,5	0,04
Oil shale	10,0	0,08
Hydrocarbon gases	2,0	0,02
The groundwater	2,5	0,04
Dissolved hydrocarbon gases in groundwater	1,4	0,02
Total	15048,4	100

As our studies have shown, the impact of forest cultivation on the neutralization of CO_2 emissions from hydrocarbons is unlikely to be significant. However, there is a highly effective way of using forest plantations to regulate the content of carbon dioxide in the atmosphere, which is currently little *paid attention* – so called substitution effect (Knauf et al., 2015).

1. Intensive use of biomass from thinnings, wood processing residues for the production of heat or electricity.

This path is the use of part of the wood for energy production and the replacement of fossil hydrocarbons used by mankind.

Indeed, when wood is used for energy, biomass carbon burns out and also enters the atmosphere in the form of CO_2. In this case, carbon dioxide does not replenish the pollutant pool. C-CO_2 simply recirculates in the atmosphere - green plants – wood - atmosphere system. When processing plant biomass into a commercial energy carrier (for example, pellets), about 6.5 kg of CO_2 is emitted into the atmosphere per 1000 MJ of energy contained in the fuel .

When burning oil per 1000 MJ of energy, 73.8 kg of CO_2 enters the atmosphere, or 10 times more compared to biofuels.

Reduction of CO_2 content in the atmosphere through the use of biofuel from wood residues

In Russia every year 9/10 of wood waste remains in the forest and in landfills. Our country can increase the volume of wood biofuel production by 10 times if woodworking waste is included in the trade turnover, as well as logging residues, which are often simply left in the forest and burned at logging sites. Russia annually produces about 3 million tons of wood pellets. About 95% of the production was exported, with 90% to Europe .

On July 9, 2022, EU sanctions came into force prohibiting the import of Russian wood pellets. In Europe, there is already a serious rise in prices. So, if earlier a 15-kilogram bag of pellets in Finland was sold in a store for €2, now it costs €5.

At the same time, the volume of the domestic biofuel market in Russia is only 100–200 thousand tons.

In Russia, there are currently about 70-80 million hectares of unproductive and overgrown agricultural land suitable for forestry.

2. Possibilities of using empty arable land for planting forests in Russia

Areas not occupied by crops make up about one tenth of the total forest area of the country. If even on half of these areas a forest with a short felling rotation (about 30 years) is grown using fast-growing tree species, then with a total bioproductivity (trunks + thinning wood) of about 100 t/ha, 4000 million tons of biomass can be obtained. In terms of 1 year, the productivity will be about 130 million tons. This amount of biomass corresponds to 2340 million GJ per year of renewable energy. Taking into account the costs of growing forests, logging and production of biofuel in the form of pellets, the amount of additional energy will be 1726 million GJ per year, which can replace about 40,4 million tons of hydrocarbon fuel in oil equivalent per year, or about 26% of the annual oil consumption in the Russian Federation. As a result of replacing hydrocarbons with biofuels, CO_2 emissions into the atmosphere will be reduced by 142 million tons per year. The total emission of CO_2 equivalent is currently 1.6 billion tons per year (Strategy for socio-economic development of the Russian… ,2019).

However, in connection with the great tension in food security in the world, the planting of forests on an empty arable land in Russia can hardly be fully implemented.

The most promising and realistic for reducing the content of $C\text{-}CO_2$ in the atmosphere with the help of forests at present is the use of logging residues, wood processing waste, and partially energy forests for the production of biofuels in order to obtain heat and electricity.

2. Reserves for increasing the flow of C-CO_2 from the atmosphere with the help of additional forest plantations in Russia

• Abandoned arable land, mln ha	80
• Area of forest plantations on vacant arable land, mln ha	40
• Forest biomass (with a productivity of 100 t/ha), mln t	
• for 30 years	4000
• on average for 1 year	130
• Renewable energy received, mln GJ/year	2340
• Energy consumption for growing forests	
• and producing pellets, mln GJ/year	414
• Energy costs for the transportation of pellets	
• over a distance of 100 km, mln GJ / year	200
• Amount of additional energy received, mln GJ/year	1726
• Substitution of hydrocarbon fuel, mln tons / year in oil equivalent	40,4
• Reduction of CO_2 emissions of hydrocarbons when using pellets, mln t/year	142

The impact of logistics on the energy and environmental performance of wood biofuels

It is important to take into account that the transportation of biofuel from wood over long distances significantly reduces its efficiency and increases CO_2 emissions into the atmosphere. Thus, the transportation of pellets by road for 200 km reduces the overall energy efficiency from 6 to 3, and carbon dioxide emissions increase by 10.8 kg per 1000 MJ of energy content in biofuels. When transporting 500 km, the energy efficiency drops to 1.7. The release of CO_2 into the atmosphere from transport reaches 17.6 kg per 1000 MJ (Bulatkin, 2018). Thus, from the point of view of ecology, biofuels should be considered as a local source of energy, since transportation over considerable distances almost "none" its effect in the sink of CO_2 from the atmosphere.

Conclusions

1. Influence of forests on the sink of carbon dioxide from the atmosphere in a long time scale, when wood is used only in construction, production of paper, chipboard, fiberboard etc. is not significant.

2. The use of wood from thinnings, wood processing residues and biomass from forests with a short rotation of felling to produce heat and electricity is the main reserve in reducing the concentration of carbon dioxide in the Earth's atmosphere with the help of forests.

Biofuel from wood should be a local source of energy, since transportation over long distances nullifies its energy and environmental efficiency.

3. The energy and environmental efficiency of all renewable energy sources must be assessed taking into account the total cost of technical energy for the construction of installations, the production of equipment, its depreciation, the costs of further disposal and the costs of the logistics of a new energy carrier.

Thank you for your attention!