Wood Industry Clusters and Their Optimal Location for the Efficient Use of Forest Raw Materials

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World experience in the creating of clusters in different industries has shown their effectiveness. This paper investigated the resource potential for creating a cluster designed for wood processing and to process wood waste from the timber industry of the Krasnoyarsk Territory of Russia. Static indicators were assessed, representing a quantitative characteristic of forest raw material resources: total and operational reserves of wood available in the region. While studying the state and use of forest resources, significant reserves of forest resources and secondary raw materials were revealed. Main indicators of the forest industry of the region over recent years were analyzed. The main systemic issues hindering the development of the timber industry were exposed. It was concluded that the region has raw material potential and industrial infrastructure necessary for the formation and sustainable development of a cluster for processing waste from the timber industry. Analysis of the producers and harvesters of forest products' locations revealed potential wood industry clusters, and areas suitable for cluster economic development were proposed. The average figures of the nearest neighbor were used and analyzed to examine the spatial distribution of raw material harvesters and enterprises that produce finished products with respect to transport infrastructure, staffing, and raw material availability.

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Keywords: Timber industry clusters; Raw material potential; Recycling of wood waste; Hierarchical clustering method; Nearest neighbor cluster analysis

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INTRODUCTION

Forests cover nearly one third of the global land area, which is 4.06 billion hectares. According to the Global Forest Resources Assessment of 2020 carried out by the FAO (Food and Agriculture Organization of the United Nations), more than half (54%) of the world's forests are found in only five countries: the Russian Federation — 20% (815 Mha), Brazil — 12% (497 Mha), Canada — 9% (347 Mha), the United States of America — 8% (310 Mha), and China — 5% (220 Mha). It should be noted that since 1990, it is estimated that 178 million hectares of forest have been lost (FAO 2020).

The majority of Russian forests are located in the Krasnoyarsk Territory, Irkutsk Region (Siberian Federal District), Karelia, Arkhangelsk, and Vologda Regions (North-Western Federal District), Kirov and Perm Regions (Volga Federal District), and the Sverdlovsk Region (Ural Federal District) (Government of the Russian Federation 2021).

The forest industry is strategically important for many countries (Hagadone and Grala 2012; Ratnasingam *et al*. 2017; Griffin *et al*. 2020; Grzegorzewska and Sedliačiková

2021; Ab Latib *et al*. 2022), including Russia (Trofimova *et al*. 2021). Today, new approaches to forestry are in demand. The availability of the resource and raw material base of the region, the amount of forest harvesting, and the number of paper and paperboard and wood processing facilities make it possible to form cluster structures of the timber industry. One of the important factors in clusters is the intraregional location of production facilities, the range of products, the priority of using basic and promising technologies that are associated with the availability of raw materials and the species composition of the region (Woo *et al*. 2020).

Well-built cost-effective logistics of cluster structures will make it possible to develop a comprehensive and rational approach to existing production facilities. Now the most developed countries in Europe, such as Sweden, Finland, and the Baltic states, have been able to improve the economic, environmental, and social aspects of the forest industry (Tayur *et al*. 1999; Shapiro 2006; Zhang *et al*. 2011). Furthermore, the raw material base will allow expanding the range of products by increasing the rate of processing and the extent of using wood raw materials and industrial waste (Fedorov and Ryazanova 2021; Mamaeva and Isaeva 2021). The issue of wood waste processing remains an urgent and unsolved task in the Krasnoyarsk Territory. The required minimum capacity for processing waste from the forest complex of the Krasnoyarsk Territory without crown waste is 8.63 million m^3/year. The potential of secondary raw materials is mainly formed by waste from logging production, including crown waste – 4.29 million m^3 and waste from stem wood - 5.29 million m^3. At the same time, unused sawmill waste amounts to 3.35 million m^3 (Hartanovich and Zelenskaya 2020).

As shown by global and local experience, the application of the cluster approach to stimulating the development of economic systems in different industry sectors contributes to their competitiveness. Therefore, the comprehensive use and waste-free processing of wood raw materials is the fundamental principle of the development of the timber industry cluster (Kiseleva 2014; Sember and Mayevka 2016; Fitchin 2017; Kozhukhov *et al*. 2017; Starikov *et al*. 2017; Melman 2021).

The Cluster Map of Russia, designed and developed by the Russian Cluster Observatory based at the Higher School of Economics, Institute for Statistical Studies and Economics of Knowledge, shows six Russian clusters specializing in Forestry and Wood Processing, as well as Paper and Paperboard Production. These clusters include the cluster of wooden house construction and wood processing of the Vologda Region, the innovative territorial wood industry cluster of the Arkhangelsk Region called PomorInnovaLes, the cluster of furniture manufacturers, wood processing, and related sectors (the Republic of Sakha (Yakutia), the wood industry cluster of the Komi Republic, the non-profit organization Wood Industry Cluster of the Khanty-Mansiysk Autonomous District Yugra, and the industrial cluster of the Pestovsky Municipal District of the Novgorod Region. Except for the PomorInnovaLes cluster, all clusters are at the initial stage of development (Russian Cluster Observatory 2019).

The innovative territorial wood industry cluster of the Arkhangelsk Region PomorInnovaLes specializes in forestry, wood processing, paper and paperboard production, industrial biotechnologies, environmental protection, and waste treatment. Today the cluster consists of 23 companies and organizations that by 2025 intend to increase the volume of produced goods worth up to 111.5 billion rubles per year (Russian Cluster Observatory 2019). Defining the boundaries of the cluster in the Krasnoyarsk Territory, taking into account the available raw materials and primary wood processing centers, will allow for the correct distribution of capacities for the construction of a full

cycle of processing of forest products and waste processing without increasing the transport shoulder.

Forestry issues require modern approaches to their solution. One of the advantages of forming a cluster is the solution of environmental problems caused by wood waste from the timber industry in Siberia. Cluster structures also allow increased involvement of mechanisms that support sustainable development at different levels of the ecosystem with such social effects as increased employment and improved quality of life in forest villages (Konechnaya *et al*. 2017; Peshkova and Peshkova 2017; Kotelnikov *et al*. 2019).

The creation of a successful wood industry cluster requires a resource and raw material base and a specific wood species composition, the coordination of timber companies (Samarukha and Ivanova 2016), the presence of developing small and medium-sized businesses (Novokshonova 2017), the multipurpose utilization of wood with waste-free production of deep-processed products, as well as investment projects and their introduction into technological processes (Nikitin 2019).

Thus, to ensure sustainable forest management, it is necessary to create appropriate infrastructure on previously acquired forest lands and place timber processing companies nearby. An extremely important factor in forming a cluster is transportation, as it affects the supply of wood and wood waste, as well as the product value. To minimize the costs, it is necessary to search for optimal locations for potential forest industry areas. The optimal location should be determined by considering environmental and socio-economic restrictions that define the number and dimensions of clusters in the region. The use of the cluster approach in the timber industry will also allow for the formation of more competitive organizational and managerial conditions.

METHODOLOGY

Amount and Main Uses of Forest Resources of the Krasnoyarsk Territory

The Krasnoyarsk Territory is located in Eastern Siberia. It is the geographical center of Russia and covers 13.86% of its territory. It borders Yakutia and Irkutsk Region to the east, Tyva and Khakassia to the south, Kemerovo and Tomsk Regions, and the Khanty-Mansiysk and Yamalo-Nenets Autonomous Districts to the west. The Krasnoyarsk Territory is located in the Yenisey River basin. Maritime transportation is especially important in the logistics of the Angara-Yenisey region. It is the only means for transporting goods within the territories of the Far North and settlements near small rivers where the system of roads and railways is not developed (Dmitrieva and Epauletov 2020). Being in a favorable geographical position, the region has a great economic potential, is rich in natural resources, and has developed industrial, energy, and transport infrastructure (Resolution of the Government of the Krasnoyarsk Territory 2018).

The total forest area of the Krasnoyarsk Territory is estimated to be 168.1 million hectares (20.62% of Russia's forest reserves or 6% of global reserves) (Decree of the Governor of the Krasnoyarsk Territory 2018). According to the information in the National Forest Register as of January 01, 2020, the total reserves of wood in the Krasnoyarsk Territory is 11.4 billion m^3, which is 18% of Russia's wood resources, including 9.5 billion m^3 of conifer species (83.4%), 6.7 billion m^3 of which are mature and over-mature stands (Decree of the Governor of the Krasnoyarsk Territory 2018). Conifer species account for 88% of the forests in the region (more than 50% is larch, 17% is spruce and fir, 12% is

pine, and more than 9% is cedar). The majority of valuable forests grow in the central part of the region (Krasnoyarsk Territory. The official portal 2022).

Despite the substantial amount of reserves of forest resources in the Krasnoyarsk Territory, its share in the production of forest products in Russia is rather small and amounts to 2.48% (Kurkudinova 2013). This is because companies having well established timber processing and paper and paperboard production are not sufficiently developed. For example, while harvesting 7.45 million m^3 of wood, only 230 thousand tons of paper and paperboard products are produced per year. More than 5 million m^3 of round timber is exported from the Krasnoyarsk Territory and Russia.

Most of the timber industry products of the Krasnoyarsk Territory are exported: commercial wood (53.1%), sawn timber (46.7%), newsprint paper (17.06%), corrugated cardboard (13.1%), chip boards (31.6%), wood fiber boards (11.4%), and wood pellets (100%). The main importing countries of round timber are China and Japan, which account for more than 90% of total exports. Sawn timber is exported to Japan, China, Egypt, Austria, Great Britain, Germany, Spain, Turkey, Tunisia, Lebanon, Greece, *etc.* Cellulose is exported mainly to China, Ireland, Italy, Korea, Poland, and Slovakia (Chelpanova 2008).

See Table 1 for the main figures of timber harvesting and production of forest products in the Krasnoyarsk Territory for the period from 1990 to 2020.

Table 1. Production of Forest Products in the Krasnoyarsk Territory from 1990 to 2020

Forest Products of the Krasnoyarsk Territory	1990 to 1995	1996 to 2000	2001 to 2005	2006 to 2010	2011 to 2015	2016 to 2020
Total timber harvesting (thousand solid m^3)*	91440	32646	32287	52936	61947	69103
Commercial timber (thousand solid m^3)	71841	25436	24766	35392	46044*	51364*
Sawn timber (thousand m^3)	23719	9011	9030	10896	11460	19528
Wood fiber boards (thousand conventional m^2)	171601	207077	269940	285501	226567	170114
Chip boards (conventional m^3)	613041	180300	353852	323735	197540	-
Newsprint paper (tonnes)	165055	132004	158703	144670	-	-
Containerboard (tonnes)	461802	204882	298306	414788	-	-
Furniture (conventional units)	2113474	649176	357186	812322	1031346	813717
Estimate Indicators (%)						
Commercial timber / Timber harvesting	78.57	77.91	76.71	66.86	74.33	74.33
Sawn timber / Commercial timber	33.02	35.43	36.46	30.79	24.89	29.08

Note: (-) means that data is not published
*The permissible error in the calculations of the commercial timber indicator was determined according to the average value of the specific weight in the wood removal indicator for the previous decade (0.743)

The figures presented in Table 1 show a noticeable decrease in the production of timber industry products in the period from 1990 to 2020 in terms of: harvesting, export, and production of commercial and sawn timber. This is due to the collapse of the USSR in 1991 and the transition to a market economy. Most of the enterprises, including the management staff, were not ready for the new realities. The protracted period of the crisis lasted until 1998, but it made positive changes in the work of the timber industry by increasing a significant share of export products. Since 1998, there has been an increase, albeit insignificant, but it has not been possible to reach the level of 1990 by any indicator.

This data indicates that the figures of 2020 are remarkably lower than those of 1990, which is also shown in Figs. 1 through 4 (Krasnoyarsk State Statistics Service 2022).

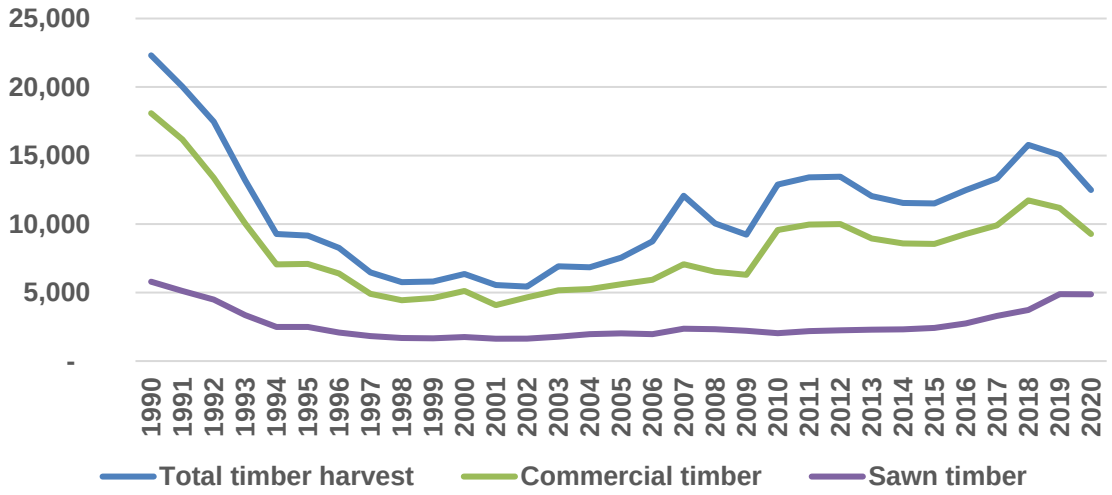

Fig. 1. Timber harvesting and production of commercial timber and sawn timber in the Krasnoyarsk Territory for the period from 1990 to 2020 (thousands m^3)

Figure 1 shows a dramatic drop that continues until 1994 in the figures of wood harvesting and processing in the region. After a long break, the production volumes increased, but they did not reach the level of 1990.

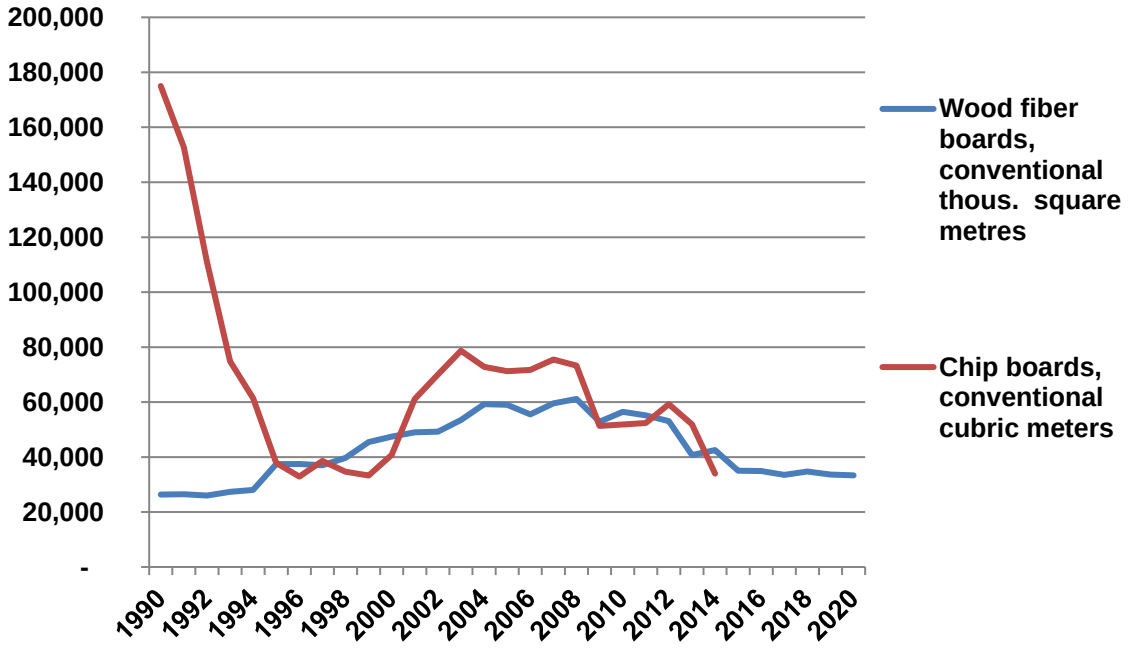

Fig. 2. Production of wood fiber boards and chip boards*
*Note: The 2017 through 2020 figures are given with an error. Forecast, based on data from the previous period.

According to Fig. 2, by 2008 there was an increase in the production of wood fiber boards and then a drop to a level below that of 1990. The production of chip boards also indicates a gradual decrease in the production volumes almost throughout the entire period, with the exception of some growth in 2001 through 2008. During this period there was a decline in the production indicators of the production of fiberboard. For example, in the first half of 2009, the impact of the economic crisis became more noticeable: the production of chipboard compared to the same period in 2008 decreased by 31%, and fiberboard – by 35%. The crisis has had a serious impact on the domestic furniture industry, which, along with the construction industry, consumes a significant amount of wood slabs.

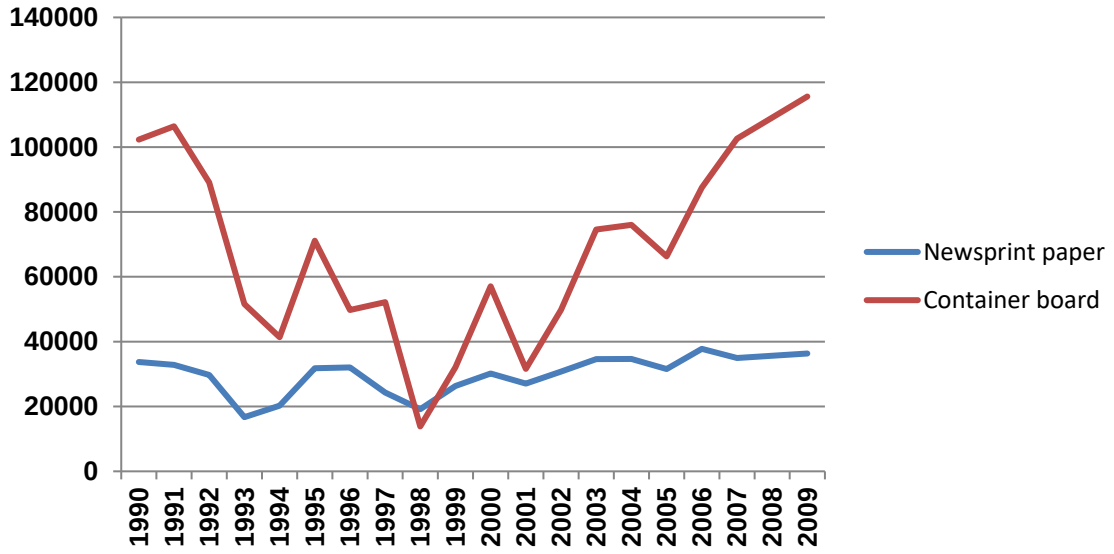

Fig. 3. Production of newsprint paper and paperboard

The production of newsprint paper (see Fig. 3) is characterized by dramatic drops and increases, but in general the trend line shows an increase, and in 2006, paper production volumes exceeded the production level of 1990. Despite rapid changes during the review period, the production of containerboard reached the level of 1990 by 2007 and exceeded it in 2008–2009.

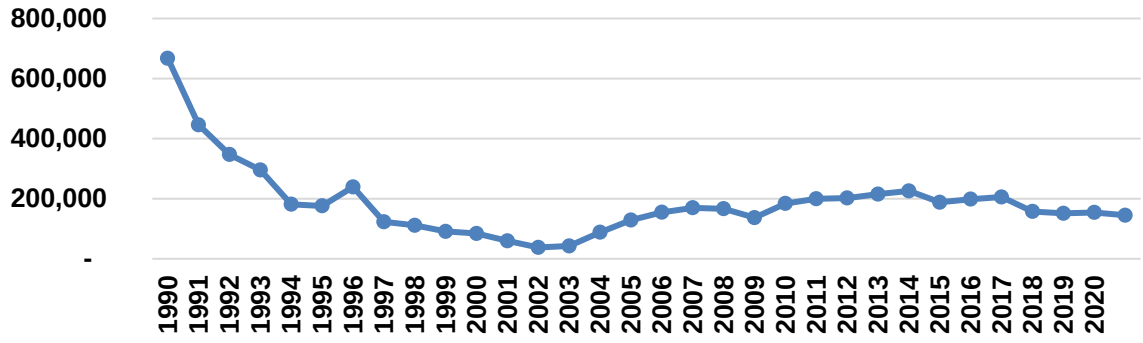

Fig. 4. Production of furniture, units

After a noticeable decline, the production of furniture from solid wood and composite materials (see Fig. 4) in the region has not reached the level of 1990.

After analyzing the above, a dynamic decrease was observed in almost all figures, which indicates a remarkable drop in the efficiency of using forest resources of the Krasnoyarsk Territory (Krasnoyarsk State Statistics Service 2022).

RESULTS AND DISCUSSION

One of the main conditions for increasing the efficiency of using forest resources and increasing the output of timber products in the regions is the grouping of companies into clusters (Kurkudinova 2013), this has the potential to significantly reduce the transportation costs of both raw materials and waste. Understanding the geographical location of the waste obtained during logging and wood processing, it is possible to plan the territorial location of production facilities more constructively.

M. Porter (Porter 1993, 2000), the author of this concept, defines clusters as a geographically proximate group of interconnected companies and associated organizations that operate in a particular field, complement each other, and are linked by their common activity. A regional cluster is a geographical agglomeration of firms and organizations that engage in one or more related kinds of economic activities (Enright 2000).

These are the main reasons for stimulating the development of clusters: clusters contribute to the rise in labor productivity and increase production efficiency; they stimulate innovation and the invention of new developments, and they foster the commercialization of technical developments.

The cluster structure is the most promising form of organizing timber industry companies in Russia, including those in the Krasnoyarsk Territory. One of the important factors in the market environment is the creation of reliable relationships with suppliers, buyers, various institutions that have a significant impact on the efficiency of production, as well as its acceleration and improvement (Medvedev 2017; Step *et al.* 2018).

Grouping companies into a cluster will allow the potential of each individual enterprise to be achieved more efficiently than when a company operates outside the cluster. When resources are limited, this factor can be considered as a key factor. The fact that forest areas are decreasing, along with reduced production, indicates the need to increase efficiency, increase the production of products with a higher added value, increase the production with advanced and comprehensive wood processing, and reduce the plain use of resources.

It is proposed that timber industry clusters shall include companies that harvest timber, produce sawn timber and wooden containers, paper and paperboard, other paper and cardboard products; as well as forest chemical industry companies, service enterprises, infrastructure, and scientific and educational organizations and centers.

As previously stated, the Krasnoyarsk Territory ranks first in Russia in terms of wood reserves. The exceptionally rich forest reserves in the Krasnoyarsk Territory are the main prerequisite for the formation of a cluster. The administrative structure of the Krasnoyarsk Territory consists of 54 districts and 19 cities with the city of Krasnoyarsk being the administrative center. About 400 companies are involved in forest harvesting and wood processing. Among the largest of them are: Lesosibirsky LDK No. 1, Open Joint-Stock Company, Novoyeniseysky LHK, Joint-Stock Company, Kraslesinvest, LLC, and DOK Yenisey, LLC, *etc.* (Chelpanova 2008). High indicators for the availability of wood

resources and low production of products, including products of deep processing of wood, indicate that the timber industry of the Krasnoyarsk Territory, having significant potential, does not use it in full.

One of the most important matters in the formation of a cluster is the definition of its boundaries. It seems not entirely correct to define the entire Krasnoyarsk Territory as a single cluster, because its area is rather large and amounts to 2,366,797 km. The Krasnoyarsk Territory extends for about 1,250 km from north to east, and for nearly 3,000 km from south to north. To determine the boundaries of a cluster, it is important to understand the most important connections between cluster members, as well as to identify the most expensive processes, the cost of which is affected by the distance. The boundaries of a cluster may change over time not only due to new members, but also due to the introduction of new technologies that compensate for long distances (State Report (2022).

Based on the specifics of the timber industry, the authors conclude that the most important aspect in the formation of a cluster is the location of forest harvesting enterprises, which is their distance from the primary enterprises of the cluster where raw materials are processed.

The boundaries of a cluster were determined using economic and mathematical methods, namely the method of hierarchical cluster analysis. According to this method, objects combined into one group are called clusters. However, this is not the same as grouping companies into clusters with regards to this research topic; therefore, when describing the method, we will use the term group (cluster).

At the first stage of applying this method, objects for the cluster analysis must be determined. The analysis objects are forestry enterprises that are the sources of raw materials (wood), the total number of which is 20 units. Further in the text we will use numerical designations of settlements in which logging enterprises are located: 1 – the village of Yartsevo, 2 – the village of Nazimovo, 3 – the city of Yeniseisk, 4 – the village of Ust-Tasey, 5 – the village of Motygino, 6 – the village of Ordzhonikidze, 7 – the village of Nizhne-Teryansk, 8 – the village of Manzia, 9 – the village of Artyugino, 10 – the village of Angarsky, 11 – the village of Boguchany, 12 – the village of Gremuchy, 13 – the village of Shiversky, 14 – the village of Nevonka, 15 – the village of Pashutino, 16 – the village of Ridge, 17 – the village of Govorkovo, 18 – the village of Chadobets, 19 – the village of Tagara, 20 – the city of Kodinsk.

Figure 5 shows the map, where the forest areas of the Krasnoyarsk Territory (61 units) and logging enterprises (numbers) located in these forest areas are indicated in different colors. The map (the callout at the top left) also shows which part of Russia the Krasnoyarsk Territory occupies. At the second stage, a set of variables must be defined. The variables will be points of destination (industrial hubs) (2 units) and delivery methods (3 units). The city of Lesosibirsk and the village of Boguchany are selected as possible destination points. The main enterprises for the processing of wood raw materials are currently located there.

Three methods of delivery of wood raw materials available in the Krasnoyarsk Territory were selected: by timber rafts (only down the river), by barges, and by trucks. It should be noted that delivery by truck is possible only along the Yenisey River and the left bank of the Angara River (there are no roads or bridges on the right bank meeting the requirements, and this situation would make the delivery of raw materials unprofitable). Table 2 gives the data on the distance between the main points of harvesting and processing raw materials, as well as on the possibility of delivering raw materials by different means of transport.

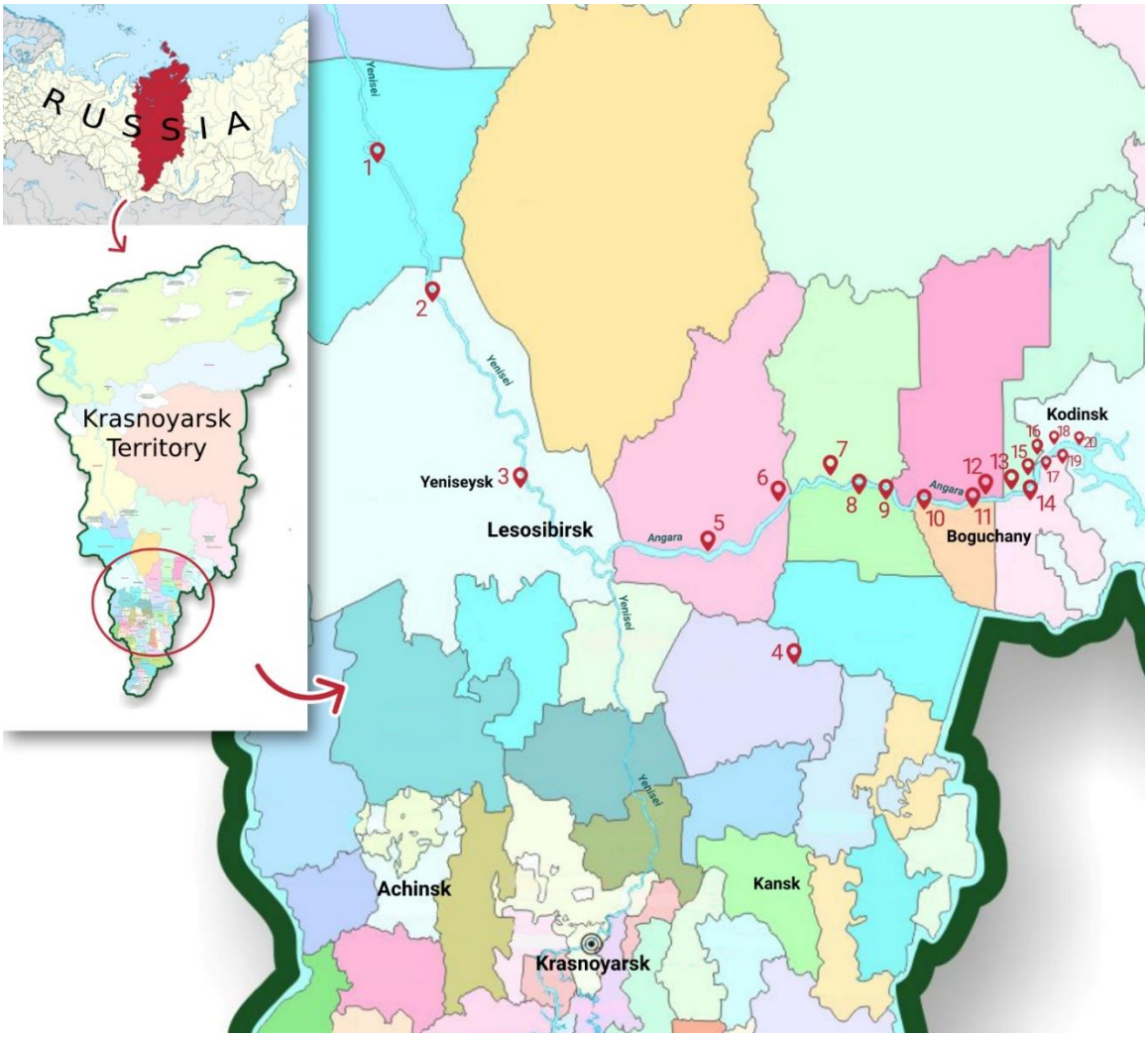

Fig. 5. Map of the forest districts of the Krasnoyarsk Territory with the display of logging enterprises located on the Angara, Yenisei and Tasei rivers

Table 2. The Distance of Delivery from the Logging Enterprise (1,2,3,...20) to the Selected Nodes (the City of Lesosibirsk or the Village of Boguchany) and the Possibility of Delivering Raw Materials by Various Modes of Transport (Notes are on the following page.)

Reference Point	Localities									
	1	2	3	4	5	6	7	8	9	10
Lesosibirsk	322	222	54	109	144	208	256	265	294	328
Boguchany village	667	567	399	236	201	137	89	80	51	17
Road transport	+	+	+	+	-	-	-	+	-	-
Barge	+	+	+	+	+	+	+	+	+	+
The plot	-	-	-	+	+	+	+	+	+	+
Reference Point	Localities									
	11	12	13	14	15	16	17	18	19	20
Lesosibirsk	345	346	370	400	418	435	438	450	459	471
Boguchany village	-	1	25	55	73	90	93	105	114	126
Road transport	+	-	-	+	-	-	+	-	-	+
Barge	+	+	+	+	+	+	+	+	+	+
The plot	+	+	+	+	+	+	+	+	+	+

Note: The value on the first line indicates the distance from the forestry enterprise to the city, for example, 322 km. This is the distance from Yartsevo (point 1) to the city of Lesosibirsk
The value on the second line indicates the distance from the forestry to the village. Boguchany. 667 km is the distance from Yartsevo (point 1) to the village of Boguchany
The sign (+) or (–) indicates the presence (+) or absence (-) of the possibility of delivering raw materials between designated points by this type of transport.
For example, the transportation of a sawmill from Yartsevo (point 1) to Lesosibirsk is possible by motor transport (+), on a barge (+), but it is impossible on rafts (-) (due to geographical components: the village of Yartsevo is located upstream from the city of Lesosibirsk).

The third stage of applying the hierarchical clustering method is to define a disparity measure, which is the cost of delivery depending on the distance between the destination points and the delivery method. Figure 6 shows a preliminary classification of typological groups.

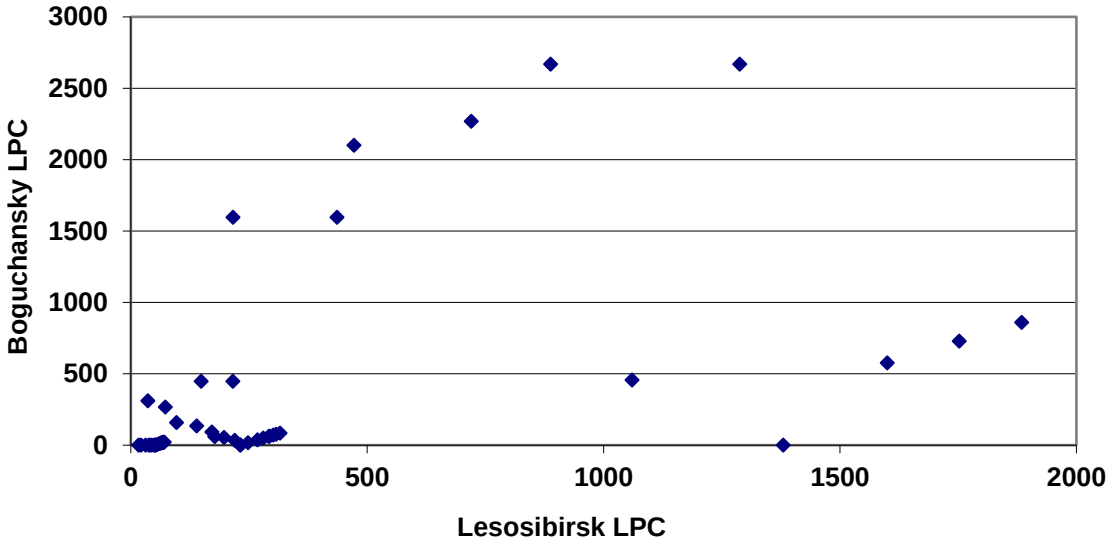

Fig. 6. Two-dimensional scatter diagram of variables by destination point and delivery method (including delivery by truck)

Figure 6 shows three groups (clusters) of values. The upper group is delivery to the village of Boguchany from remote forestry enterprises by truck, the lower right group is delivery to the city of Lesosibirsk. The lower left group is cost-effective (preliminarily) delivery by all means of transport.

According to preliminary conclusions, the delivery of raw materials by truck is not economically efficient. Therefore, the classification of typological groups does not include delivery by truck. The cheaper out of two transport means was selected, a table compiled (see Table 3), and a two-dimensional scatter diagram constructed of variables by destination point and delivery method (see Fig. 7).

Figure 7 also shows three groups (clusters). The upper right group includes forestry enterprises, the delivery from which is the most expensive and inefficient. The second cluster (at the top left) includes forestry enterprises located near Lesosibirsk. The delivery to Lesosibirsk is cost-effective and the delivery to Boguchany is not. The third cluster (at the bottom) includes forestry enterprises, the delivery from which is cost-effective to both destination points.

Table 3. Initial Data for Cluster Analysis

Cluster Location	Localities									
	1	2	3	4	5	6	7	8	9	10
X_1 – Lesosibirsk	215.7	148.7	36.18	16.35	21.6	31.2	38.4	39.75	44.1	49.2
X_2 – Boguchany	446.9	446.9	310.2	267.3	158.1	134.7	91.79	59.63	53.6	34.2
Cluster Location	11	12	13	14	15	16	17	18	19	20
X_1 – Lesosibirsk	51.75	51.9	55.5	60	62.7	65.25	65.7	67.5	68.85	70.65
X_2 – Boguchany	0	0.15	3.75	10.8	13.5	16.05	16.5	18.3	19.65	21.45

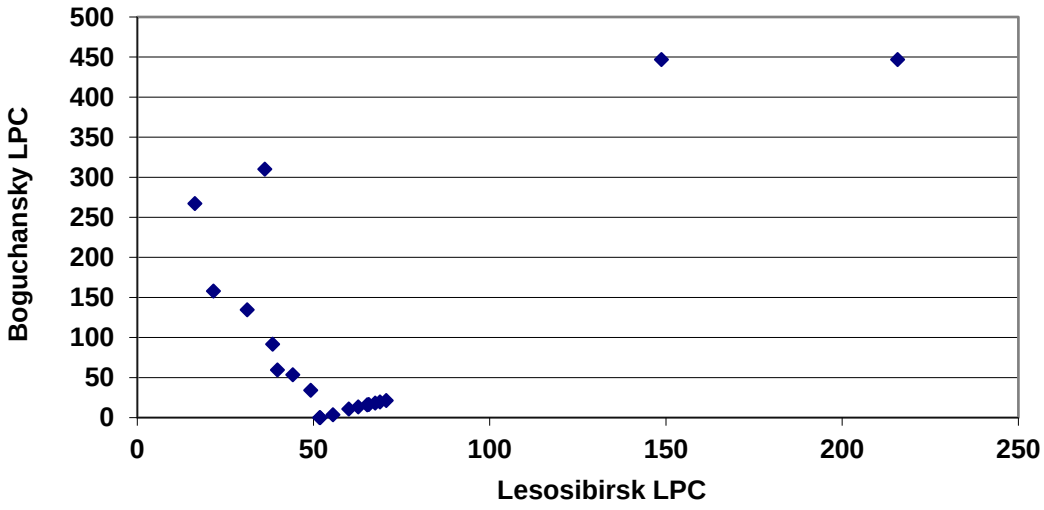

Fig. 7. Two-dimensional scatter diagram of variables by destination point and delivery method (excluding delivery by truck)

At the fourth stage, using the single-linkage or the nearest neighbor method, calculations were performed using Eq. 1. According to the standard Euclidean metric, the distance between observations 1 and 2 was calculated by the following formula (Duran and Odell 1977),

$$p_{1,2} = \sqrt{\sum_{j=1}^{p} \left(x_1^{(j)} - x_2^{(j)}\right)^2} \quad (1)$$

where x_1 is the cost of transportation to Lesosibirsk, and x_2 is the cost of transportation to Boguchany.

It is clear that $\rho_{1,1} = 0$. Likewise, the distances were determined between all observations and the distance matrix 1 were constructed. The distance matrix 1 shows that objects 11 and 12 are closest to $\rho_{11,12} = 0.21$, so they should be combined into one group (cluster). An excerpt (clipping) from matrix 1 is shown in Figure 8.

After merging them into a single cluster, we have one cluster less. The distance between clusters is calculated according to the nearest neighbor method using the conversion formula (Duran and Odell 1977). The distance is given by Eq. 2:

$$\rho_{1,(n,m)} = \rho(S_1, S_{(n,m)}) = \frac{1}{2}\rho_{1,n} + \frac{1}{2}\rho_{1,m} - \frac{1}{2}\left|\frac{1}{2}\rho_{1,n} - \frac{1}{2}\rho_{1,m}\right| \quad (2)$$

The distance ρ_1, (11, 12) is equal to the distance from object 1 to the neighbor object, which is part of cluster S (11, 12), *i.e.*, ρ1, (11, 12) = ρ1.12. In the course of similar

calculations, we construct distance matrix 2, where clusters 16 and 17 are closest to each other, then matrix 3, where clusters 18 and 19 are closest to each other, and so on until the final matrix 19 is constructed.

1	2	3	4	5	6	7	8	9	10	11	12	13
0	67	225,66	268,32	347,96	362,68	396,92	425,37	429,11	445,05	476,03	475,84	471
67	0	177,06	223,09	315,52	333,61	371,85	402,3	406,97	424,55	457,29	457,12	452
225,66	177,06	0	47,24	152,79	175,61	218,43	250,61	256,73	276,35	310,6	310,46	307
268,32	223,09	47,24	0	109,34	133,49	176,92	209,01	215,52	235,46	269,66	269,53	266
347,96	315,52	152,79	109,34	0	25,34	68,42	100,15	106,91	126,99	160,97	160,85	158
362,68	333,61	175,61	133,49	25,34	0	43,48	75,53	82,09	102,1	136,23	136,1	133
396,92	371,85	218,43	176,92	68,42	43,48	0	32,19	38,61	58,62	92,76	92,63	89
425,37	402,3	250,61	209,01	100,15	75,53	32,19	0	7,44	27,16	60,83	60,71	58
429,11	406,97	256,73	215,52	106,91	82,09	38,61	7,44	0	20,09	54,14	54,02	51
445,05	424,55	276,35	235,46	126,99	102,1	58,62	27,16	20,09	0	34,27	34,13	31
476,03	457,29	310,6	269,66	160,97	136,23	92,76	60,83	54,14	34,27	0	**0,21**	
475,84	457,12	310,46	269,53	160,85	136,1	92,63	60,71	54,02	34,13	0,21	0	5
471,22	452,84	307,07	266,47	158,05	133,16	89,69	58,06	51,14	31,07	5,3	5,09	
463,07	445,03	300,36	260,22	152,24	127,17	83,82	52,86	45,66	25,74	13,59	13,38	8

Fig. 8. Excerpt (clipping) from matrix 1

Calculations are carried out in the Excel program. Matrix 1 contains 20 graphs and 20 rows. Matrix 2 contains 19 graphs and 19 rows, *etc*. By iterating and combining forest enterprises (using the nearest neighbor method) into one group, we consistently come to matrix 18, which already contains 3 graphs and 3 rows, and to the last, matrix 19, which contains 2 graphs and 2 rows. These calculations result in a dendrogram (see Fig. 8), which is a tree-based representation of a group of objects that changes at different levels of the hierarchy (Duran and Odell 1977).

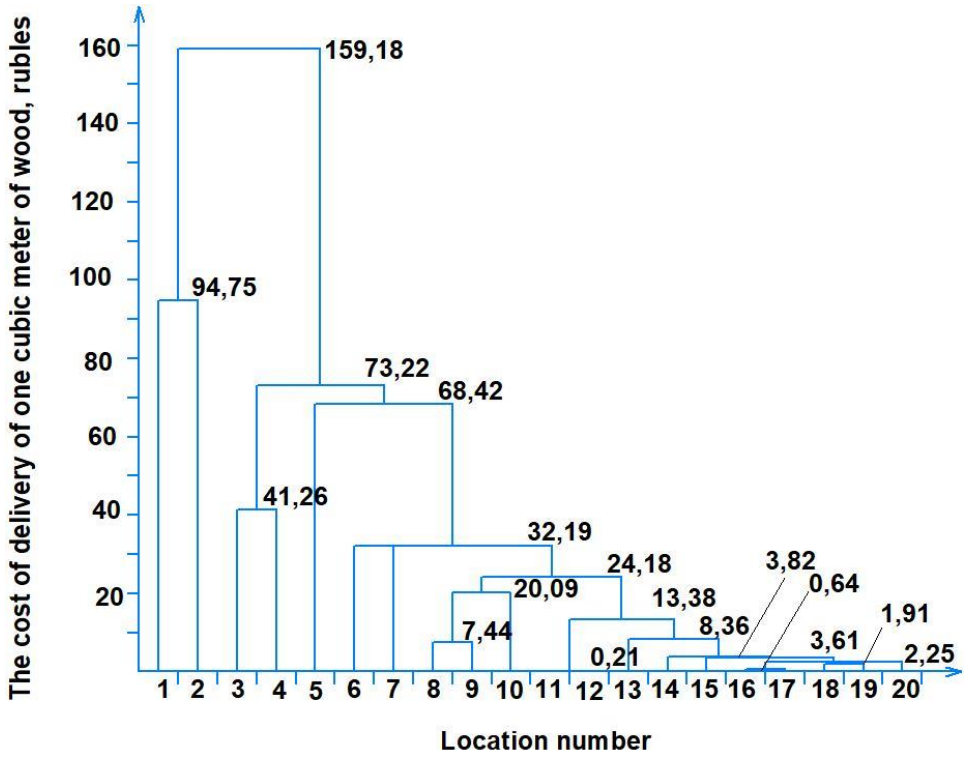

Fig. 9. Dendrogram based on the nearest neighbor cluster analysis

The object numbers are listed horizontally on the dendrogram, the distances (in conventional units) at which the objects are grouped (in clusters) and listed horizontally. At the first steps, the following groups (clusters) are formed: (11, 12), then (16, 17), then (18, 19), *etc.* At the first steps (the lowest horizontal line/step is located just above the abscissa line), groups (clusters) are formed: (11, 12) next, (horizontal line just above) (16, 17), then (18, 19), then (18-19) - 20; then (16-17)-(18-20), then 15-(16-20), then 14-(15-20): then 8-9, then 13-(14-20); then (11-12) – (13-20), then (8-9) – 10, then (8-10) – (11-20); then 7-(8-20); next 6-(7-20); then 3-4, then 5-(6-20); then (3-4) – (5-20) and last 1-2. *etc*.

Based on the dendrogram (see Fig. 9), we can make an overall conclusion that three groups of forestry enterprises can be identified in the Krasnoyarsk Territory: the first group (points 8 through 20) includes enterprises that are focused on the delivery of raw materials to Boguchany *via* waterways; the second group (points 3 through 7) includes enterprises that can deliver raw materials in two directions: both to Lesosibirsk and Boguchany; the third group (points 1 and 2) are enterprises that are located noticeably far from both Lesosibirsk and Boguchany. As a result, shipping costs increase dramatically. However, Lesosibirsk is located somewhat closer to them (points 1 and 2), so this city will be their delivery direction.

Apart from forestry enterprises, forest industry clusters should be formed by considering the location of forest industry hubs where raw materials are processed. They include the city of Lesosibirsk, the village of Boguchany, as well as the city of Krasnoyarsk, where the recycling of raw materials usually takes place. The enterprises located there can act as the cluster core, *i.e.*, the primary enterprises of the cluster involved in the main production activity — processing of wood raw materials. A cluster includes forestry, timber harvesting industry, wood-processing industry, paper and paperboard industry, forest chemical industry, production of machinery and equipment, automated systems, and furniture production. The primary forest industry enterprises are key leading companies that are responsible for the main production processes. The economic success of a cluster will be ensured primarily by the primary enterprises. The primary enterprises supply the main products of the forest industry: sawn timber, paper pulp, paper, cardboard, *etc.*

A cluster sector (subcluster) is an agglomeration of enterprises located close to each other within one or two cities (determined on an actual basis).

Thus, it is suggested that the main timber industry enterprises of the Krasnoyarsk Territory are represented as three main areas: the northern area is the city of Lesosibirsk, the central area is the city of Krasnoyarsk (the distance between Lesosibirsk and Krasnoyarsk is 300 km), and the north-eastern area is the village of Boguchany. In other words, the forest industry cluster of the Krasnoyarsk Territory can be represented as three subclusters (sectors): Northern, North-Eastern, and Central. In this regard, it is worth noting that because of the geographical aspect, there is no direct transport connection between the northern and the northeastern subclusters. This is a significant problem. The road is possible only through the city of Krasnoyarsk. If on the Angara River, then only during high water, numerous shoals, shivers and especially rapids interfere with navigation. Therefore, enterprises of greater deep processing of wood should be placed in the central subcluster, where there is access from all links.

The production of timber products is associated with the formation of a large amount of waste, from which it is possible to produce products of deep processing of raw materials, thereby increasing the coefficient of its use and the efficiency of the timber industry. It is very important to correctly geographically distribute the locations of

industrial enterprises for the production of products from production waste, taking into account the transport component. So, for example, the transportation of chips for more than 400 km is impractical; therefore, the production of products from technological chips must be located near its receipt. The production of products from waste obtained during logging must also be carried out at logging points, which is practically absent on the territory of the Krasnoyarsk Territory.

According to the forestry regulations of the forest districts of the Krasnoyarsk Territory, the actual volume of timber harvesting is 25.6 million m^3. At the same time, if the useful yield is 48%, about 27.7 million m^3 of waste will be formed. Most of the waste, namely 40% (11.08 million m^3) is not recycled and remains in landfills. If we take into account that in the Krasnoyarsk Territory the actual volume of production is only 21.4% of the possible volume (119.5 million m^3), we have the potential of unused waste of about 107.7 million m^3 (Hartanovich and Zelenskaya2020).

Table 4 shows the types of waste and options for their processing at various sites of the cluster link.

Table 4. Options for Processing Wood Raw Materials and their Distribution by Cluster Links

Cluster Links	Types of Production	Types of Business Wood and Wood Waste	Types of Products	
Forestry enterprises: Northern Podcaster: (1 - 2, 5, 3 - 4, 6 - 7) Northeast Subcluster: (8-20)	Wood harvesting	twigs, branches	1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 18, 21	1 – production of technological chips 2 – production of fuel chips 3 – use as fuel 4 – gasification of wood to produce generator gas and liquid fuels 5 – charcoal production 6 – production of activated carbon 7 – production of biologically active substances (vitamin flour, essential oils) 8 – production of feed 9 – production of compost, organic fertilizers and artificial lands 10 – production of hollow timber 11 – production of glued materials 12 – manufacture of joinery 13 – production of end parquet 14 – hydrolysis industry 15 – timber chemical industry 16 – production of consumer goods 17 – production of slab materials and wood composite materials 18 – production of building materials 19 – furniture production 20 – housing construction 21 – other areas of processing
		stumps, roots	1, 2, 3, 4, 5, 8, 12, 13, 14, 15, 16, 17, 18, 21	
		low-grade and small-sized wood	1, 2, 3, 4, 5, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21	
		woody greens	7, 9, 17	
Centers under cluster links: Lesosibirsk city Boguchany village Krasnoyarsk city	Sawmilling and wood processing	business wood	10, 11, 12, 18, 19, 20, 21	
		bark	3, 4, 7, 8, 9, 14, 15, 17	
		humpback, edges, clippings	1, 2, 3, 4, 5, 8, 12, 13, 14, 15, 16, 17, 18, 20	
		sawdust, shavings	3, 4, 6, 8, 9, 14, 15, 16, 17, 18, 21	

The distribution of production of deep processing products, taking into account the transport component and the place of origin of waste serving as raw materials for

production, makes it possible to increase the efficiency of resource use and increase the coefficient of integrated use of raw materials.

Because of its innovative nature, combining enterprises into a cluster can contribute to the spread of new technologies for advanced processing of wood, the use of state-of-the-art equipment, and the manufacture of high value-added products. The cluster approach will serve as the basis for creating a prototype of a highly efficient forest enterprise with sustainable forest management, committed to improving the species and quality composition of forest resources. The formation of a cluster will allow execution of projects that are beyond the capacity of just one enterprise.

The Development Strategy of the Krasnoyarsk Territory until 2030 prioritizes the improvement of the timber industry of the region (Resolution of the Government of the Krasnoyarsk Territory 2018). Aside from industrial enterprises, the scientific, educational, and professional basis of a forest cluster should include research institutes, universities, and secondary specialized colleges that train future specialists for this branch of science and develop new technologies and innovative products for the comprehensive processing of wood raw materials. Today the following universities and organizations are active in the Krasnoyarsk Territory: the Siberian Federal University, the M. F. Reshetnev Siberian State University of Science and Technology, and the Krasnoyarsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences, which includes the V. N. Sukachev Institute of Forest. These scientific and educational institutions are capable of training highly qualified specialists and developing new technologies in this industry.

CONCLUSIONS

In the course of the study, it was determined that due to the significant size of the Krasnoyarsk Territory and the complexity of the transport movement of raw materials, the boundaries of a potential cluster should be determined not by administrative boundaries, but by the main centers of raw material extraction and processing, depending on the distance from each other. Therefore, it is recommended to use such a concept as cluster links and wood resource processing enterprises to place relative to cluster links in the places of raw material extraction. Consideration will be given to waste processing during logging or in sawmilling nodes, and whether an activity concerns woodworking waste. So in the Krasnoyarsk Territory, three potential cluster links can be distinguished: the Northern one is the wood processing node - the city of Lesosibirsk, the Central one is the wood processing node – the city of Krasnoyarsk, and the north-eastern one is the processing node – the village of Boguchany. Due to the fact that there is no direct transport connection between the northern and north-eastern link, which is a significant problem, enterprises of deeper processing of wood should be located in the central link - the city of Krasnoyarsk, where communication is available from both links. The placement of the waste processing production capacity relative to the places of waste concentration during harvesting and waste during woodworking can significantly increase the efficiency of using raw materials and increase the coefficient of its integrated use.

1. The results of the conducted research show that the potential of the timber industry of the Krasnoyarsk Territory is not being used to the full extent, as evidenced by low wood processing figures.

2. Examples of possible production of deep processing products from available types of wood raw materials and wood waste with the distribution of production capacity depending on the place of origin of waste (raw materials) are given (Table 4).
3. The formation of a wood industry cluster in the Krasnoyarsk Territory will solve some of the main issues hindering the innovation development of the industry and ensure fundamental changes in the structure of wood production by prioritizing the development of advanced wood processing, the rational use of low-value wood and wood waste, the rapid development of the production of timber slabs and fiber semi-finished products, various types of biofuel, and biotechnological products.
4. Under the current conditions, it is necessary to respond more quickly and efficiently to changes in the internal and external market environment of forest products, as well as to make timber companies adapt rapidly to these changes. The functioning of a wood industry cluster makes it possible to consider the demand of timber companies for wood raw materials, organize their horizontal communication with raw material harvesters, better utilize the reserves available in the region, unlock the full potential of the forest sector, and support its investment activities, which will contribute to maintaining the competitive ability of forest products and facilitate the improvement of forest management.
5. The results of the presented study can serve as a theoretical basis for further research into the issues of cluster development of timber industry complexes, as well as into the problems related to ensuring their economic stability and development.

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