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RESEARCH ARTICLE

Assessment of the Economic Efficiency of Using Pulp and Paper Industry Waste in Crop Production in Northern Regions of Russia

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ABSTRACT

Currently, issues related to waste recycling and the secondary use of various types of industrial waste are discussed worldwide, and various measures are developed and adopted at the state and corporate levels. In the northern regions of Russia, the issue of recycling pulp and paper industry waste is acute, exacerbated by low recoverability and the high vulnerability of ecosystems, which also affects soil fertility. With increasing sanctions, greater attention has been directed toward the country's food independence, which is harder to achieve in regions with harsh climatic conditions. One potential way to address these issues in northern regions is through the industrial symbiosis of pulp and paper and agricultural enterprises. This article proposes a methodological approach to assessing the economic efficiency of using pulp and paper industry waste in crop production in northern regions of Russia. The main research methods include comparative and statistical analysis, correlation-regression analysis, and forecasting. The study reveals a strong influence of vegetable crop yields on their gross production and vegetable self-sufficiency in the Republic of Karelia and Arkhangelsk region. Given the positive impact of using activated sludge on soil fertility and vegetable yields, predictive models were built to forecast changes in self-sufficiency levels in the northern regions under other constant parameters.

1. INTRODUCTION

Currently, environmental protection issues related to industrial and consumer waste management are frequently raised globally, and circular economy strategies are being developed (Circular Economy, n.d.). The international community has noted that the minimum acceptable level of paper and cardboard waste recycling should be no less than 60% (European Parliament and Council Directive 94/62/EC, 1994). In the Russian Federation, the "Circular Economy" project was approved at the federal level in 2022, aiming for the index of secondary resource and waste utilization in economic sectors to grow more than fivefold by 2030 compared to 2022 (Passport of the Federal Project, n.d.).

In Russia, paper and cardboard waste amounts to approximately 15 million tons, which is 2.5 times higher than the country's pulp production (Nikolaevskaya, 2011; Semenova et al., 2023). The regions of northern Russia make a significant contribution to the development of the pulp and paper industry. A quarter of the country's large pulp and paper enterprises are located in three regions fully classified as the Far North: in the Republic of Karelia (Segezha Pulp and Paper Mill, Kondopoga Pulp and Paper Mill), the Komi Republic (Syktyvkar Forest Industrial Complex), and the Arkhangelsk region (Arkhangelsk Pulp and Paper Mill, Kotlas Pulp and Paper Mill, Solombala Pulp and Paper Mill – production currently halted) (Malevskaya-Malevich and Kudryashov, 2023). In these regions, the

share of shipped products in economic activities such as "paper and paper product manufacturing, printing and information media copying" was over 35% in 2022 (Regions of Russia, n.d.). The issue of pulp and paper waste disposal in northern regions is intensified by the high sensitivity and low recoverability of ecosystems, requiring a specialized approach (Presidential Decree No. 645, 2020).

Additionally, ensuring food security is a significant concern for Russia's socio-economic development overall, with the sanctions regimes affecting this aspect (Bartenev, 2022 ; Garnov et al., 2024). To enhance food independence, the federal government approved a strategy for the development of the agro-industrial and fishery sectors through 2030, with one of the main state policy priorities being to increase vegetable crop yields and bring new land into agricultural use. The national self-sufficiency ratio for vegetables is inadequate but shows a positive growth trend (Figure 1). In Russia's northern regions, however, this ratio has declined by over five times across the macro-region over the past 20 years, specifically by three times in the Republic of Karelia, two times in the Arkhangelsk region, and it has remained nearly unchanged in the Komi Republic. This trend is linked to the reduced share of arable land in northern territories, particularly in the Arkhangelsk region and the Republic of Karelia (Voronina et al., 2023).

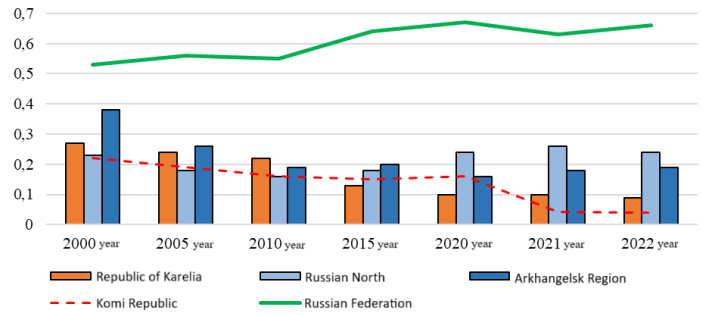

Figure 1: Vegetable Self-Sufficiency Ratio in Northern Regions and in Russia as a Whole (calculated by the authors)

Achieving the set goals in northern territories is hindered by harsh climatic conditions and low soil fertility. In the new realities shaped by crises and global challenges, one method of innovative collaboration—industrial symbiosis, where waste from one enterprise is used as raw material for another—can support the realization of strategic state goals (Preobrazhensky et al., 2020 ; Osintseva and Ishutin, 2023; Safiullin et al., 2023).

One characteristic of a region's economy is its food security, ensuring food independence, population access to food products, and quality drinking water (Sutina and Zhigalova, 2020; Plotnikov et al., 2024 ; Bartenev, 2022).Therefore, the absence of a need for certain food resources is significant for the region.

The economic efficiency of using pulp and paper industry waste in the agricultural crop production sector is indirectly assessed through vegetable production development. Of particular interest is the extent to which open-field vegetable yields affect gross vegetable production and the overall self-sufficiency of a region in vegetable crops.

According to the Ministry of Agriculture's methodology for calculating the level of self-sufficiency in agricultural products, raw materials, and food, the recommended consumption rate of vegetables is 140 kg per person (Order of the Ministry of Health of Russia No. 614, 2016). It is considered that a region can be self-sufficient in vegetables if it meets this rate by 90% (Order of the Ministry of Agriculture of Russia No. 582, 2020).

1 DEGREE OF STUDY OF THE PROBLEM

Issues of utilization and recycling of unused pulp and paper industry waste are increasingly raised by both government authorities and the scientific community. For instance, S.Yu. Sarkisov, N.P. Gorlenko, S.V. Samchenko, and M.G. Bruyako propose using corrugated cardboard waste in the

development of thermal insulation materials (Sarkisov et al., 2024). The recycling of this industry's waste into biofuel is explored by Yu.O. Vinogradov, E.A. Vorontsova (2019), and others.

Research and development are also underway regarding the recycling of pulp and paper industry waste as soil fertilizers. For example, A.S. Shatrova, A.V. Bogdanov, A.I. Shkrabo, and O.V. Alexeeva propose solving the problem of lignin-containing waste accumulation from the Baikalsk Pulp and Paper Mill (OJSC) by using it as soil or fertilizer, supplemented with ash from thermal power plants or sewage treatment sludge, based on a low-energy, environmentally safe, and import-independent technology developed by the authors (Shatrova et al., 2022). Similar solutions were previously proposed by O.D. Sidorenko (2003) and E.V. Klimova (2005) for paper sludge. In the northern regions, representatives of the Karelian Research Center of the Russian Academy of Sciences actively conduct studies on using pulp and paper waste, particularly sodium lignosulfonate and activated sludge, to enhance soil fertility and crop yields (Dorogaya et al., 2023; Suraganov et al., 2024; Ansabayeva and Akhmetbekova, 2024)

The above indicates the search for various solutions to reduce the environmental burden in areas where the pulp and paper industry is developed. With findings on possible recycling methods for pulp and paper waste, there is a need to assess the effectiveness of their use at different levels: individual, corporate, sectoral, and territorial.

Currently, various methodological approaches exist to evaluate the effectiveness or efficiency of different types of waste recycling. For instance, V.V. Glukhov and K.S. Movchan (2019) propose a comprehensive methodology for assessing the environmental hazard of waste from recycling industries using a hierarchical group of indicators. Representatives from the Murmansk region calculate the economic efficiency of waste disposal and the preparation of a backup raw material base at Kovdorsky GOK (OJSC) (Melik-Gaikazov et al., 2012). V.N. Krasnoshchekov and G.G. Lunev developed a methodological approach to assess the comprehensive efficiency of recycling secondary construction resources (Krasnoshchekov and Lunev, 2022). The study by A.N. Nikulin and S.V. Kovshov focuses on evaluating the environmental and economic efficiency of processing low-liquid solid combustible waste (Kovshov and Nikulin, 2016), among others. A comparative analysis of scientific research showed the lack of a methodological approach to assess the economic efficiency of using pulp and paper industry waste in crop production in northern Russia at the regional level, highlighting the relevance of this study.

The aim of the study is to assess the economic efficiency of using pulp and paper industry waste for developing the crop production sector in agriculture in northern Russia.

2 RESEARCH METHODOLOGY

The study focuses on northern regions of Russia, all of which are classified as the Far North or areas equivalent to it. The subject of the study is pulp and paper mill (PPM) waste. Thus, the study's geographical scope is limited to northern regions where the pulp and paper industry is developed: Republic of Karelia, Komi Republic, and Arkhangelsk region.

The information base of the study comprises statistical data from the Federal State Statistics Service (Rosstat), the Unified Interdepartmental Statistical Information System (EMISS), as well as data from government authorities found in legal information systems such as "Consultant Plus," "TechExpert," and "Garant."

The study covers the period from 2010 to 2022.

To achieve the goal, the following sequential steps are required:

Comparative analysis of scientific literature to identify research results on using pulp and paper industry waste to improve soil fertility and crop yields;

Compilation of a database for each studied region characterizing changes in population size, vegetable yield, gross vegetable production, and northern regions' need for vegetable crops to calculate their level of self-sufficiency;

Conducting econometric (correlation-regression) analysis to determine the impact of vegetable yield on regional self-sufficiency by building regression models using the method of simple regression. The yield of open-field vegetables, measured in centners per hectare (X1), is chosen as the factor, as its impact has been confirmed through the use of activated sludge as fertilizer.

The resulting indicators are:

Y1: Gross vegetable production, thousand tons

Y2: Region's vegetable self-sufficiency, thousand tons

The Chaddock scale was used to determine the influence level of each factor in the studied impact, with the degree of connection normalized by the approximation reliability coefficient (R^2) as high (0.71-1.0), moderate or noticeable (0.31-0.7), weak (0.1-0.3), and absent (less than 0.1). Statistical significance was tested using p-value (≤0.05), F-statistic (≤0.05), and reliability level (≥95%).

Building predictive models to assess changes in gross vegetable production and regional self-sufficiency depending on the influence of vegetable crop yield in the territory using formula 1:

$$y = \alpha' + \beta_1' x_1 \quad (1)$$

Interpretation of results and formulation of conclusions.

3 RESULTS

The econometric analysis revealed a dependence between gross vegetable production volume and vegetable self-sufficiency on yield levels in northern regions of Russia (Table 1).

Table 1. Impact of Vegetable Yield on Food Security in Northern Regions of Russia

Region Model	**Gross Vegetable Production in Region (Y1)**	**Vegetable Self-Sufficiency in Region (Y2)**
	R^2	**R^2**
Republic of Karelia	0.74	0.76
Komi Republic	0.31	0.14
Arkhangelsk Region	0.88	0.81

According to the Chaddock scale, a high influence of vegetable yield on gross vegetable production is observed in the Republic of Karelia and Arkhangelsk region, while in the Komi Republic, it is moderate due to harsher climatic conditions that complicate crop production activities.

Based on the regression analysis, models are constructed to forecast gross vegetable production and self-sufficiency in the Republic of Karelia and Arkhangelsk region under the following conditions:

Open-field vegetable yield increases 1.6 times each year compared to the previous year (base year – 2022). Researchers from the Karelian Research Center found that using activated sludge as a supplement for various crops increases their yield by 1.3 to 1.9 times, so the average of 1.6 is chosen (Russian Science Foundation, n.d.).

The population in the region remains unchanged.

Conditions are set as in the experiment on using activated sludge to improve soil fertility.

Vegetable planting areas increase proportionally with the growth in vegetable yield in the region.

Thus, with these conditions, an annual increase in open-field vegetable yield by 1.6 times with the application of activated sludge will increase gross vegetable production in the Republic of Karelia and Arkhangelsk region approximately 6.6 times, as well as vegetable self-sufficiency in these northern regions (Figure 2).

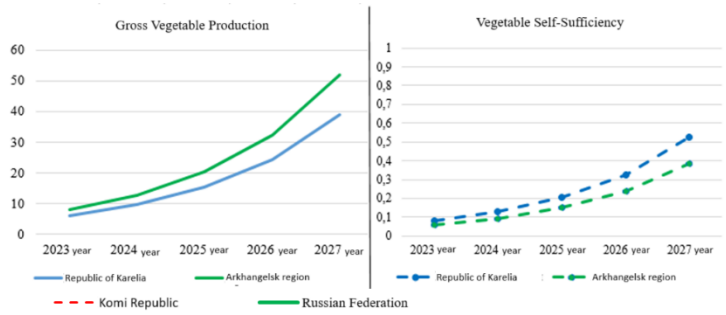

Figure 2: Projected Change in Gross Vegetable Production and Self-Sufficiency Level with the Use of Activated Sludge to Improve Soil Fertility and Vegetable Crop Yield in the Republic of Karelia and Arkhangelsk Region, thousand tons

The study determined that with the consistent use of activated sludge as an organic soil fertilizer, the self-sufficiency level in vegetable crops can be increased over five years to 52% in the Republic of Karelia and 38% in the Arkhangelsk region by 2027.

4 CONCLUSION

The results of this study suggest the need to apply pulp and paper industry waste in crop production to enhance soil fertility and crop yield in the Republic of Karelia and Arkhangelsk region. This approach will not only improve food security in these northern regions but also reduce the environmental burden on vulnerable ecosystems.

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6 AUTHOR CONTRIBUTIONS

LV conceived the idea, designed the project and wrote the manuscript. MJ participated in the design of the study and helped in writing the manuscript. All authors read and approved the final manuscript

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