Economic-mathematical model of obtaining commodity products of the green construction department of the Krasnoyarsk city

N Haydenok\textsuperscript{1}, V Chumakov\textsuperscript{1} and N Yakovenko\textsuperscript{2}

\textsuperscript{1}Department of machinery and technology of environmental engineering, Forest Technology Institute, Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarsky Rabochy Avenue, 660037, Krasnoyarsk, Russian Federation
\textsuperscript{2}Division's Directorate of the Research Institute of Innovative Technologies and the Forestry Complex, Voronezh State University of Forestry and Technologies named after G F Morozov, 8 Timiryazev Street, 394087, Voronezh, Russian Federation

E-mail: vglta@vglta.vrn.ru

Abstract. The article deals with the possibility of obtaining marketable products from plant raw materials obtained as a result of urban landscaping and gardening in Krasnoyarsk. The aim of this scientific research is to create an effective system of recycling environmentally friendly organic waste, and thus to reduce the negative impact on the environment and ensure environmental safety. The material of the research is organic waste from pruning of trees, bushes and lawn mowing, as well as means of production for their processing. A linear programming method was used in the work. Solving the posed optimization problem according to the chosen criteria and established systems of restrictions, we will receive either the maximum income, or the minimum costs, or the maximum productivity. It is realistic to formulate the optimization problem seasonally. Economic effect is achieved by reducing the cost of landfill disposal and obtaining a profit from the sale of commercial products made from green organic waste. The project is planned to be implemented on the basis of Krasnoyarsk municipal enterprise "Green Building Department". The prospect of this research is to reduce the amount of waste by maximising recycling and incorporating it into the economy.

1. Introduction

In addition to climate change, which dictates a global economic transformation, the current global financial and energy crises also necessitate a search for new economic growth patterns oriented towards sustainable development while stabilising wealth consumption and traditional industrial growth [1,2]. Human development (and soon its physical survival) requires an early transition to new principles and economic activities related to the production, distribution and consumption of goods and services that promote human well-being in the long term without exposing future generations to significant environmental risks in an uninhabitable environment [3,4]. As an integral part of urban ecosystems, urban green spaces provide essential ecosystem services for human well-being, such as improving air quality by eliminating pollution and reducing noise levels, conserving water and soil, regulating microclimate, mitigating urban heat island (UHI) impacts, conserving biodiversity and so on. Meanwhile, urban green spaces also provide economic and social benefits, such as saving energy, promoting community integration and outdoor recreation [5-7].
Green construction waste is an integral part of municipal waste and until now has not been identified as a separate category in our country. However, a number of problems accompanying the removal process and a growing public interest are forcing specialists and municipal administrations to look for new approaches to solving them. Until now, the main practice of disposal of green construction waste has been its disposal in landfills and sanitary landfills [8].

This option has been shown to be unacceptable under current conditions. Firstly, because of their low density, transporting them over long distances is unprofitable. Secondly, smouldering piles of leaves and branches of woody plants in autumn and spring cause great resentment among the population [9,10]. Soil deprived of organic matter as a result of rubbish collection is depleted, which leads to deterioration of growth conditions for trees, shrubs and herbaceous vegetation in urban areas. As a result, there is a need to organise the recycling of green building waste into useful products with further use in urban green building. European experience shows that the management of household waste is a complex process involving many parties and includes legal, technical, economic and environmental aspects [11-13].

Effective waste management to achieve its objectives should be carried out in accordance with the theory of management. According to this theory, management is a system of different forms and methods of influence of the subject of management on the object of management in order to achieve the goals set. In the waste management system, all the waste management processes defined above are the object of management. The subjects of management (i.e. management system) are the authorized state, regional and municipal bodies that provide the management process.

A waste management system can be defined as a process of interaction between the management entity and the management system that leads to the achievement of the management objective. The priority objective of waste management is to minimise the negative impact of waste on the environment and human health. However, the household waste management system also includes important economic issues: costs and return on investment for investors, costs and tariffs for authorities and population.

Cost minimisation is therefore another important task. Standard economic modelling allows a least-cost solution, neglecting other important tasks such as environmental aspects (e.g. a landfill is often the most cost-effective solution, but usually the least desirable from an environmental point of view). The purpose of this research is to develop an optimisation model to help create an efficient green organic waste management system and, as a result, reduce the negative impact on the environment and ensure environmental safety. The structure of the optimization model consists of the objective function, the area of acceptable solutions and the system of constraints defining this area. The objective function, in its most general form, also consists of three elements: controlled variables; uncontrolled variables; and the form of the function (type of dependence between them). This optimisation model will maintain a balance between the economy and the environment, allowing for the sustainable development of the economic component of the city combined with the conservation of natural resources. They are very important for the present and especially for the future generation.

2. Methods and materials
The objectives of the work included several steps. Firstly, a theoretical study of the feasibility of processing urban forestry residues into compost. Secondly, a study the volume and composition of wood and vegetation residues of Krasnoyarsk city forestry.

Thirdly, a study the existing systems for recycling wood and plant residues. Fourthly, a study and choose technology of wood and plant residue processing in Krasnoyarsk forest park economy. Fifthly, a study on the justification of the technological parameters of composting wood and plant residues. These parameters include the composition of wood and plant residues, the composition and amount of additives in the woodchips during composting, moisture and temperature of the compost mass, aeration at different seasons of the year. The article uses programming methods, which is the field of mathematical programming. It includes methods for solving extreme problems, which are characterised by a linear relationship between variables and a linear criterion.
3. Results and discussion

The composition and volume of waste generated may vary considerably depending on the size of the locality, the prevailing industries, etc. However, organic waste makes up the bulk of it. Disposal methods can be divided into chemical, mechanical, thermal and biological, with varying degrees of combination. The biological or biochemical methods of organic waste treatment include composting. In recent years, most developed countries have paid special attention to the recycling of the organic fraction of municipal waste.

Food waste makes up a significant proportion of the organic material (about 40%) contained in municipal waste. They are generated by the residential and other sectors (catering, trade, hospitals, educational and pre-school institutions, etc.). In the industrial disposal of food and municipal wood and vegetal waste, a combination of three main technologies is widely used: composting in barks (passive or active), composting in closed reactors and anaerobic digestion. The determining factors in the selection of organic waste collection, treatment and disposal methods in the developed organic waste management system are factors such as the target indicators for the volume of biodegradable organics in total municipal waste, the necessary level of accessibility of the considered methods to system participants, location and size of the required land for treatment and recycling and waste disposal, environmental and economic indicators.

The analysis of these factors helps to determine which technologies are most suitable (composting system, anaerobic digester system or combined system), and the possible impact of the technologies under consideration on existing waste management systems at local and regional level is also assessed. Once waste collection, recycling and disposal methods and technologies have been selected, their integration into the existing waste management system needs to be considered, in particular management (staffing and reassignment opportunities), economics (capital, operating and running costs, taking into account sales of the resulting products) and sources of finance.

The main objectives of the territorial scheme of waste management are to develop measures aimed at creating the necessary facilities for waste utilisation, neutralisation and disposal, introducing new technologies, ensuring economic efficiency of this type of activity, reducing the negative impact on the environment and improving environmental safety. The main principles of economic regulation in the field of waste management are:

- reducing the amount of waste and involving it in economic turnover;
- payment for waste disposal;
- economic stimulation of activity in the field of waste management [14].

According to the data of the Krasnoyarsk Municipal Green Construction Department, the annual volume of plant material resulting from landscaping and beautification, sanitary pruning of tree plantings and lawn treatment is about 240,000 cubic metres. To extract the maximum profit from this raw material, it is necessary to solve the optimisation problem, taking into account the fractional composition of the raw material and the resulting marketable product.

Let's show this with the example of organic waste from the forest-park economy of the city of Krasnoyarsk (table 1). However, we do not only work with waste from the park, but also with the pruning of all trees in the city. Savings are obtained by transferring the costs from putting green waste in the landfill into the company's income by obtaining marketable products from this green waste.
Table 1. Nomenclature of raw materials and products.

| Fractional composition of raw materials | Costs, ths. Rub. |
|----------------------------------------|------------------|
|                                        | L   | L+G | B   | T₁  | R   | Launchers | Production |
| compost                                | +   | +   | +   | +   | +   | 136 000   | 23 998     |
| bio-soil                               | +   | +   | +   | +   | +   | +         |            |
| pilots                                 | 0   | 0   | +   | +   | +   | C<sub>ij</sub> | C<sub>ij</sub> |
| firewood                               | 0   | 0   | 0   | +   | 0   | C<sub>ij</sub> | C<sub>ij</sub> |
| wood decorative chips                  | 0   | 0   | +   | +   | +   | C<sub>ij</sub> | C<sub>ij</sub> |
| cellulose                              | +   | +   | +   | +   | +   | C<sub>ij</sub> | C<sub>ij</sub> |
| metals                                 | +   | +   | +   | +   | +   | C<sub>ij</sub> | C<sub>ij</sub> |
| chemical materials                     | +   | +   | +   | +   | +   | C<sub>ij</sub> | C<sub>ij</sub> |
|                                        |     |     |     |     |     | ...       | ...        |

where L – leaves, G – grass, B – branches, T₁ – tree trunks, R – roots, “+” – suitable for production and industry, 0 – unsuitable for production and industry.

Based on table 1, we will compose mathematical matrices:

Cost: C

\[
C = \begin{pmatrix}
    c_{11} & c_{12} & \ldots & c_{1n} \\
    c_{21} & c_{22} & \ldots & c_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    c_{m1} & c_{m2} & \ldots & c_{mn}
\end{pmatrix}
\]

Profit: P

\[
P = \begin{pmatrix}
P_{11} & P_{12} & \ldots & P \ \\
P_{21} & P_{22} & \ldots & P_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
P_{m1} & P_{m2} & \ldots & P_{mn}
\end{pmatrix}
\]

Factory load: X

\[
X = \begin{pmatrix}
x_{11} & x_{12} & \ldots & x_{1n} \\
x_{21} & x_{22} & \ldots & x_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
x_{m1} & x_{m2} & \ldots & x_{mn}
\end{pmatrix}
\]

Then the target function for income will have the form:

\[
Z = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}(P_{ij} - C_{ij}) \rightarrow \text{max}
\]

(4)

At a minimum cost, if there is such a need:

\[
Z = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}C_{ij} \rightarrow \text{min}
\]

(5)

Maximum profit:

\[
Z = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}P_{ij} \rightarrow \text{max}
\]

(6)

To obtain a practical solution, it is necessary to impose a number of restrictions on the system. Let us denote the total stock of raw materials of the j-th type S<sub>j</sub>. Then the total stock of all types of raw materials is determined by the vector S:

\[
S = (S_1, S_2, \ldots, S_n)
\]

(7)

Moreover, in specific production conditions, the presence of the j-th type of S<sub>j</sub> raw material, as a rule, is in the range:

\[
S_j \in [S_{0j}, S_{1j}]
\]

(8)
This, of course, determines the restriction on the output of all possible types of products from it:

$$\sum_{i=1}^{m_i} X_{ij} \in [S_{i0}, S_{i1}]$$

(9)

If the stock of the j-th type $S_j$ of raw materials is known exactly: $S_j = S^*_j$, then expression (9) generally turns into inequality (10):

$$\sum_{i=1}^{m_i} X_{ij} \leq S^*_j$$

(10)

Similarly, the restriction on the total output of products of the i-th type $R_i$ will be written as (11):

$$\sum_{i=1}^{m_i} X_{ij} \geq R^*_j$$

(11)

In addition, the system is subject to limitations in terms of technical equipment, staffing, logistical constraints, etc. [2]. The economic essence of the waste problem is that technologically they are not needed by the process in which they were generated and are of interest only from the point of view of the whole production, industry or related industries. The economic effect of waste use should be determined taking into account the possible effect of reducing the loss of raw materials, as well as the costs of creating and operating the dumps. At the same time, the effect of the use of waste in relation to the reduction of damage to society and the environment must be taken into account. By solving the applied optimisation problem according to the chosen criteria and the set systems of constraints, we will obtain either the maximum income, the minimum costs or the maximum productivity.

It is realistic to formulate a seasonally appropriate optimisation task. In addition, the results of this work can be used in the sanitary purification of large forest plantations, products of plant processing on the territories of nurseries and greenhouse enterprises. The obtained mathematical model allows increasing the efficiency of the green organic waste management system, and therefore reducing the negative impact on the environment and ensuring environmental safety. Knowing the fractional composition of green organic waste, using the author's developed economic-mathematical model, it is possible to determine the optimal assortment of commercial products in terms of obtaining the maximum economic effect.

Foreign experience [6] considers the processing of this type of raw material only to obtain compost, but, as practice shows, wood decomposes very long, and the composting process takes years. The authors suggest sorting this green organic waste into fractions and from each fraction obtaining the best commercial product in terms of economic efficiency.

4. Conclusion

The mathematical apparatus we propose is a classical economic-mathematical model, which has been widely tested in both domestic and global economies. This model makes it possible to maximise profits in each situation. Extensive use of the developed model at a real site will achieve significant economic benefits, develop practical measures for managing the internal processes of green organic waste processing, and accelerate and improve the methods of in-situ research.

It quantifies the material, energy, economic and environmental parameters for a given waste management scenario. The output parameters of the model are the amount of obtained secondary material resources, secondary fuel or compost, total costs, revenues, the amount of consumed and received energy, total air emissions, wastewater discharges and the amount of residual waste sent for disposal. Thus, urban and industrial organic waste represents a huge resource potential for use as components in the production of non-conventional organic fertilisers.

However, significant amounts of organic matter, mineral nutrients and nitrogen are disposed of annually in landfills. The economic effect is achieved by reducing the cost of landfill disposal and making a profit from the sale of marketable products produced from green organic waste. Reducing the negative impact on the environment and human health is provided by the balanced development of communal infrastructure systems in accordance with the needs and improving the quality of services for processing, recycling and disposal of green organic waste.

The perspective of these studies is to reduce the amount of waste through maximum recycling and involvement in economic turnover. The project is to be implemented at the Krasnoyarsk Municipal Enterprise “Green Construction Department”. The improvement of the ecological situation on the
territory of the urban district is possible taking into account the achievement of the standards of permissible environmental impact by the organizations of the communal infrastructure systems.

References

[1] Arnold J, Kleemann J and Furst C 2018 A Differentiated spatial assessment of urban ecosystem services based on land use data in Halle Germany. *Land.* 7 101 doi: 10.3390/land7030101

[2] Kabisch N 2015 Ecosystem service implementation and governance challenges in urban green space planning. *Land Use Policy* 42 557 doi: 10.1016/j.landusepol.2014.09.005

[3] Kim G, Miller PA and Nowak DJ 2015 Assessing urban vacant land ecosystem services: Urban vacant land as green infrastructure in the City of Roanoke. *Urban Forestry & Urban Greening* 14(3) 519 doi: 10.1016/j.ufug.2015.05.003

[4] Kopecka M, Szatmari D and Rosina K 2017 Analysis of urban green spaces based on Sentinel-2A Case Studies from Slovakia. *Land.* 6(2) 25 doi: 10.3390/land6020025

[5] Park J, Kim JH, Lee DK, Park CY and Jeong SG 2017 The influence of small green space type and structure at the street level on urban heat island mitigation Urban For. *Urban Green.* 21 203 doi: 10.1016/j.ufug.2016.12.005

[6] McPherson E G, Nowak D, Heisler G, Grimmond S, Souch C, Grant R and Rowntree R 1997 Quantifying urban forest structure, function, and value: *The Chicago Urban Forest Climate Project. Urban Ecosyst.* 1 49 doi: 10.1023/A:1014350822458

[7] Votsis A 2017 Planning for green infrastructure: The spatial effects of parks, forests, and fields on Helsinki’s apartment prices. *Ecological Economics* 132 279 doi: 10.1016/j.ecolecon.2016.09.029

[8] Kohda C , Ando T and NakaY 1997 Isolation and characterization of anaerobic indole- and skatole-degrading bacteria from composting animal wastes. *Gen. Appl. Microbiol.* 43(5) 249 doi: 10.2323/jgam.43.249

[9] MacHugh D E, Larson G and Orlando L 2017 Taming the Past: Ancient DNA and the Study of animal domestication. *Annu Rev Anim Biosci.* 8(5) 329 doi: 10.1146/annurev-animal-022516-022747

[10] Nowak D J, Hirabayashi S , Doyle M, McGovern M and Pasher J 2018 Air pollution removal by urban forests in Canada and its effect on air quality and human health Urban For. *Urban Green.* 29 40 doi: 10.1016/j.ufug.2017.10.019

[11] Wu Z J and Zhang Y X 2018 Spatial Variation of Urban Thermal Environment and Its Relation to Green Space Patterns: Implication to Sustainable Landscape. *Planning Sustainability* 10(7) 2249 doi: 10.3390/su10072249

[12] Xue F, Gou Z H and Lau S Y 2017 Green open space in high-dense Asian cities: Site configurations, microclimates and users’ perceptions Sustain. *Sustainable Cities and Society* 34 114 doi: 10.1016/S0169-2046(08)00045-0

[13] Jianguo W Urban ecology and sustainability: The state-of-the-science and future directions. *Landscape and Urban Planning.* 125(2014) 209 doi: org/10.1016/j.landurbplan.2014.01.018

[14] Hritonenko N and Yatsenko Yu 2014 *Mathematical Modeling in Economics, Ecology and the Environment* (Springer Publishing Company: Incorporated) p 332