Biomass as Raw Material for the Production of Biofuels and Chemicals

EDITED BY

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Preface

Plant biomass, a common source of valuable raw materials, has been used by humans as food, fodder for farm animals, fuel, building and furniture material, as well as a natural medicine or fertilizer for centuries. With the development of civilization, accompanied by the emergence of more efficient energy sources, new structural materials, fertilizers and other chemicals used in various spheres of life, its importance has still not diminished. It is still the basic food for humans and animals, a popular energy source currently used not only as a solid fuel but also – after appropriate processing – as a liquid or gaseous biofuel used in means of transport, a valuable material employed in various industries, as well as a source of bioactive chemicals for the production of pharmaceuticals, nutraceutics, cosmetics or natural agents that improve soil quality.

Today, in addition to the undeniable application values of biomass, special attention is paid to the key role that biomass plays for the Earth's ecosystem, emphasizing its renewable nature, which ensures the circulation of carbon in the global cycle. The growth of biomass is related to the absorption of carbon from the atmosphere *via* photosynthesis. Naturally, the combustion of biomass releases carbon in the form of CO_2, but it can be assumed that the pool of this element in the atmosphere does not increase because it is built up back into the plant tissues. Although treating biomass as a carbon-neutral fuel is an exaggeration, as fossil fuels are also used during the biofuels production, it should be noted that the energetic use of biomass, especially the waste biomass or the mass of hydrobionts such as cyanobacteria, which pose the threat for water ecosystems, certainly contributes to the reduction of the pollutant emissions and provides many other environmental benefits. Such kinds of biomass are especially valuable as a raw material used in biorefineries. The idea of biorefining is gaining more and more popularity around the world. It is based on multidirectional processing of biomass, as a result of which various products are obtained, while maintaining the lowest possible CO_2 emission rate. Biorefining is closely related to another global mainstream concept – the circular economy, in which attention is paid to the fact that by-products generated at various stages of raw material processing are used as substrates in another production process.

Biomass, as a raw material for industry and energy, has a number of advantages including wide availability, renewable nature, and usually low acquisition cost (especially in the case of waste biomass). However, it also has certain disadvantages. Its biodegradable nature can be a problem during transport and storage. Additionally, the use of special preservation methods, such as drying and ensiling, or protection against external factors is sometimes required. On the other hand, in some types of applications, it is necessary to increase the biodegradability of biomass. The high share of polysaccharides and lignin in lignocellulosic structure limits the efficiency of biomass conversion to the targeted products when the biological processing is realized. Enhancement of biodegradability is achieved through a number of processes based on various mechanisms, ranging from the simple mechanical processing consisting in grinding or crushing to complex and multi-stage chemical or physicochemical methods.

The book shows the exemplary applications of different types of biomass for the production of biofuels and other useful products, such as fertilizers, chemicals, and drugs. Special attention is paid to the practical directions of using the biomass of hydrobionts and microorganisms of activated sludge. Considering different applications of the biomass-derived products, the environmental, economic and energetic aspects were taken into account.

Editors

Waldemar Wójcik was born in Poland in 1949. He is the Director of the Institute of Electronics and Information Technology, former long-time dean of the Faculty of Electrical Engineering and Computer Science at Lublin University of Technology, and Doctor Honoris Causa of five universities in Ukraine and Kazakhstan. He obtained his Ph.D. in 1985 at the Lublin University of Technology, and D.Sc. in 2002 at the National University Lviv Polytechnic, Ukraine. In 2009, he obtained the title of professor granted by the President of Poland. In his research, he mainly deals with process control, optoelectronics, digital data analysis and also heat processes or solid-state physics. He pays particular attention to the use of optoelectronic technology in the monitoring and diagnostics of thermal processes. He is a member of Optoelectronics Section of the Committee of Electronics and Telecommunications of the Polish Academy of Sciences and Metrology Section of the Committee of Metrology and Scientific Equipment of the Polish Academy of Sciences. He is also a member of European Academy of Science and Arts (Austria); Academy of Applied Radioelectronics of Russia, Ukraine and Belarus; the International Informatization Academy of Kazakhstan; and many other scientific organizations of Poland as well as Europe and Asia. In total, he has published 56 books and over 400 papers, and authored several patents. He is also a member of the editorial board of numerous international and national scientific and technical journals.

Małgorzata Pawłowska, Ph.D., is a researcher and lecturer at the Faculty of Environmental Engineering of Lublin University of Technology. In 2013–2019, she was the Head of the Department of Alternative Fuels Engineering at the Institute of Renewable Energy Sources Engineering. Currently, she heads the Department of Biomass and Waste Conversion into Biofuels. She received her M.Sc. in philosophy of nature and protection of the environment at the Catholic University of Lublin in 1993. In 1999, she received her Ph.D. in Agrophysics at the Institute of Agrophysics of the Polish Academy of Sciences, and in 2010, she obtained a postdoctoral degree in the technical sciences in the field of environmental engineering at the Wrocław University of Technology. In 2018, she was awarded the title of Professor of Technical Sciences. Her scientific interests focus mainly on the issues related to the reduction of the concentrations of greenhouse gases in the atmosphere, energy recovery of organic waste, and the possibility of using the waste from the energy sector in the reclamation of degraded land. A measurable outcomes of her research is the authorship or co-authorship of 105 papers, including 40 articles in scientific journals, 4 monographs, 24 chapters in monographs, co-edition of 5 monographs, co-authorship of 15 patents and dozens of patent applications. She has participated in the implementation of nine research projects concerning, first of all, the prevention of pollutant emissions from landfills and the implementation of sustainable waste management.

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Chapter 3

Assessment of Ecology-Economic Efficiency in Providing Thermal Stabilization of Biogas Installations

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CONTENTS

3.1 INTRODUCTION

One of the ways of environmental-friendly and rational use of fuel and energy resources is the investment in the renewable energy sources, such as construction of solar, wind, and bioelectric power plants. In Ukraine, such investments were about 3.7 million euros in 2019. The implementation of bioconversion helps dispose of organic waste in biogas installations, prevents the contamination of the biosphere with harmful substances, and allows obtaining an alternative source of energy – biogas. The process of methane formation requires energy consumption for thermal stabilization of anaerobic fermentation in biogas installations (Suresh et al. 2013, Weiland 2003). In terms of scientific research, the energy-saving mechanisms for providing thermal stabilization in biogas energy installations are insufficiently substantiated.

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It is possible to increase the energy efficiency and environment friendliness of bioconversion by rational selection of alternative renewable heat sources for fermentation processes of thermal stabilization. Such alternative sources are solar energy, low-potential thermal energy of soil and water as well as utilization of thermal emissions of bioconversion systems (Zabarnyi & Shurchkov 2002). Ukraine plans to give up the coal energy by 2050. The share of renewable energy sources is predicted to make up 70%.

The analysis of the literature shows that the theoretical and experimental studies of animal waste bioconversion mechanisms and kinetics of the technological process were conducted by G. Ratushnyak, E. Larushkin, S. Yakushko, M. Drukovani, and O. Zuev (Rotshtein 1999, Noyola et al. 2006, Rotshtein et al. 2008). An expert system for an intelligent support of energy-saving management of bioconversion technological process is also considered in the works of E. Larushkin and A. Rotshtein (Rotshtein 1999, Rotshtein et al. 2008). There are no examples in the literature of the calculations related to the ecological and economic efficiency of bioconversion (Drukovani et al. 2006, Noyola et al. 2006, Rotshtein et al. 2008). The purpose of the research was to create a theoretical background and develop a scientifically proven system of making effective decisions for choosing an innovative bioconversion project.

In order to achieve this goal, the research should solve the following tasks (Geletukha & Martseniuk 1999, Ratushnyak & Anokhina 2013, Zhelikh et al. 2013):

- Develop a classification of factors affecting ecological and economic indicators of the mechanisms for ensuring thermal stabilization in biogas plants (Zadeh 1975, Zuev 2009).
- Develop a hierarchical system of mathematical models related to multifactor analysis regarding the ecological economic efficiency of the mechanism ensuring the process of thermal stabilization based on fuzzy logic, which takes into account the influence of quantity and quality factors (Redko et al. 2016, Kukharchuk et al. 2017).

3.2 METHODOLOGY

The classification of the factors affecting ecological and economic indicators of mechanisms ensuring thermal stabilization in biogas plants was developed. The inference tree (Figure 3.1) is based on classified factors; it defines a system of nested statements and establishes hierarchical links between them. It characterizes the impact of a set of influencing factors. It can be represented as a fixed ratio:

$$Y = f(X, Z), \tag{3.1}$$

where

X is a linguistic variable which describes environmental factors;
Y is a linguistic variable which describes economic factors.

The linguistic variable X that describes environmental factors can be represented by the expression:

$$X = f(x_1, x_2, x_3) \tag{3.2}$$

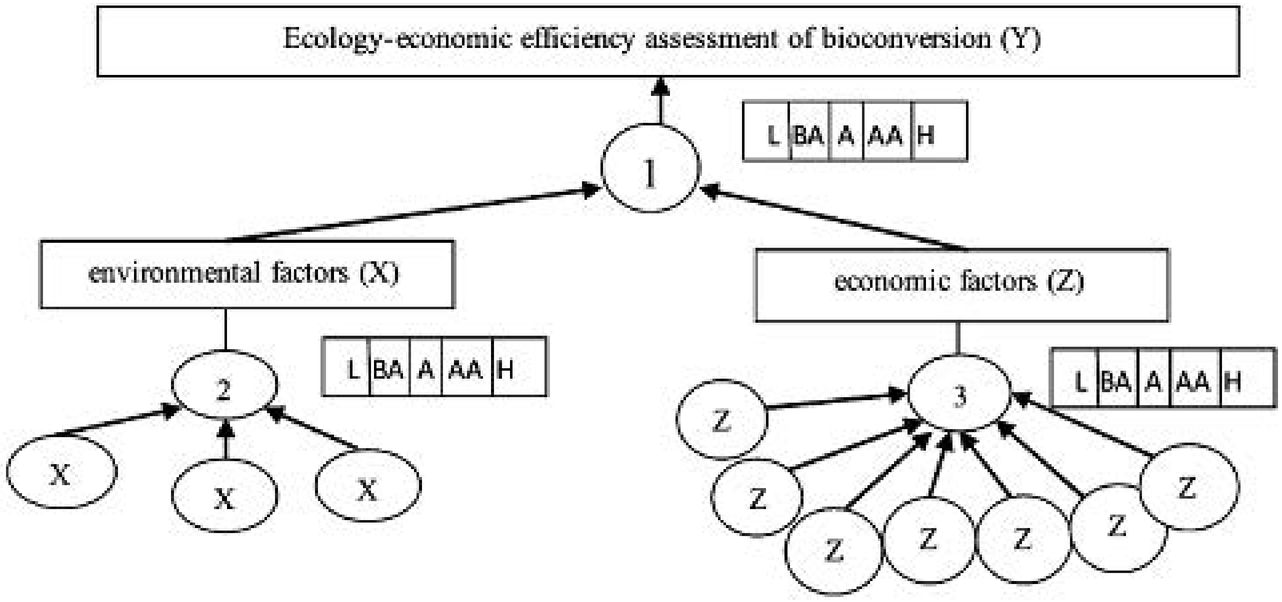

Figure 3.1 The tree of inference which concerns hierarchical relationships of factors that influence environmental and economic assessments of a bioconversion project.

where

x_1 is the linguistic variable "CO_2 emissions",
x_2 is the linguistic variable "organic waste disposal",
x_3 is the linguistic variable "environmental pollution".

The linguistic variable Z, which describes environmental factors, can be represented by the expression:

$$Z = f(z_1, z_2, z_3, z_4, z_5, z_6, z_7), \qquad (3.3)$$

where

z_1 – the linguistic variable "term of recoupment";
z_2 – the linguistic variable "Net Present Value";
z_3 – the linguistic variable "Internal Rate of Return";
z_4 – the linguistic variable "Profitability Index",
z_5 – the linguistic variable "duration of operation";
z_6 – the linguistic variable "profit";
z_7 – the linguistic variable "operating costs".

Simulation of the system-level intellectual support of project variant selection can be done by using the following terms:

$$T(Y) = \langle \text{Low, Below Average, Average, Above Average, High} \rangle$$
$$T(X) = \langle \text{Low, Below Average, Average, Above Average, High} \rangle$$
$$T(Z) = \langle \text{Low, Below Average, Average, Above Average, High} \rangle$$

The fuzzy inference technique helps calculate the predicted number by means of a fuzzy set using the "IF - THAT" linguistic expression system. It combines the fuzzy terms of output and input variables by using operations I and OR, which correspond to operations min and max (Zadeh 1975, Rotshtein et al. 1997, Rotshtein 1999).

Linguistic statements correspond to a system of fuzzy logical equations, which characterize the surface of belonging to the variables (X, Z) of the corresponding term:

$$\mu_L(Y)=\mu_L(X)\wedge\mu_L(Z)\vee\mu_{BA}(X)\wedge\mu_L(Z)\vee\mu_L(X)\wedge\mu_{BA}(Z) \tag{3.4}$$

$$\mu_{BA}(Y)=\mu_{BA}(X)\wedge\mu_{BA}(Z)\vee\mu_{BA}(X)\wedge\mu_A(Z)\vee\mu_A(X)\wedge\mu_{BA}(Z) \tag{3.5}$$

$$\mu_A(Y)=\mu_A(X)\wedge\mu_A(Z)\vee\mu_L(X)\wedge\mu_{AA}(Z)\vee\mu_{AA}(X)\wedge\mu_L(Z) \tag{3.6}$$

$$\mu_{AA}(Y)=\mu_{AA}(X)\wedge\mu_{AA}(Z)\vee\mu_{AA}(X)\wedge\mu_A(Z)\vee\mu_A(X)\wedge\mu_{AA}(Z) \tag{3.7}$$

$$\mu_H(Y)=\mu_H(X)\wedge\mu_H(Z)\vee\mu_{AA}(X)\wedge\mu_H(Z)\vee\mu_H(X)\wedge\mu_{AA}(Z) \tag{3.8}$$

The assessment of linguistic variables levels related to environmental factors (X) is done by the amount of CO_2 emissions (x_1), the level of organic waste utilization (x_2) and the level of environmental pollution (x_3) using the following system of term sets:

$$\begin{gathered}T(x_1)=\langle\text{Low},\text{Average},\text{High}\rangle\\ T(x_2)=\langle\text{Low},\text{Average},\text{High}\rangle\\ T(x_3)=\langle\text{Low},\text{Average},\text{High}\rangle\end{gathered}$$

The system of fuzzy logical equations which characterizes the surface of belonging to the variables (x_1, x_2, x_3) of the corresponding term can be shown as the linguistic statement:

$$\begin{gathered}\mu_L(X)=\mu_H(x_1)\wedge\mu_L(x_2)\wedge\mu_H(x_3)\vee\mu_H(x_1)\wedge\mu_L(x_2)\wedge\mu_A(x_3)\vee\mu_A(x_1)\\ \mu_L(x_2)\wedge\mu_H(x_3)\end{gathered} \tag{3.9}$$

$$\begin{gathered}\mu_{BA}(X)=\mu_A(x_1)\wedge\mu_H(x_2)\wedge\mu_H(x_3)\vee\mu_A(x_1)\wedge\mu_L(x_2)\wedge\mu_A(x_3)\vee\mu_H(x_1).\\ \mu_L(x_2)\wedge\mu_A(x_3)\end{gathered} \tag{3.10}$$

$$\begin{gathered}\mu_A(X)=\mu_A(x_1)\wedge\mu_A(x_2)\wedge\mu_A(x_3)\vee\mu_H(x_1)\wedge\mu_L(x_2)\wedge\mu_A(x_3)\vee\mu_L(x_1).\\ \mu_H(x_2)\wedge\mu_A(x_3)\end{gathered} \tag{3.11}$$

$$\begin{gathered}\mu_{AA}(X)=\mu_A(x_1)\wedge\mu_A(x_2)\wedge\mu_L(x_3)\vee\mu_A(x_1)\wedge\mu_H(x_2)\wedge\mu_A(x_3)\vee\mu_L(x_1)\\ \mu_H(x_2)\wedge\mu_A(x_3)\end{gathered} \tag{3.12}$$

$$\begin{gathered}\mu_H(X)=\mu_L(x_1)\wedge\mu_H(x_2)\wedge\mu_L(x_3)\vee\mu_L(x_1)\wedge\mu_H(x_2)\wedge\mu_L(x_3)\vee\mu_A(x_1)\\ \mu_H(x_2)\wedge\mu_L(x_3)\end{gathered} \tag{3.13}$$

The assessment of the levels of linguistic variables linking economic factors (Z) with payback period (z_1), with Net Present Value (z_2), with Internal Rate of Return (z_3), with Profitability Index (z_4), with duration (z_5), with profit (z_6), and with operating costs (z_7) is performed by using a system of term sets:

$$T(z_1) = \langle \text{Small(S)},\ \text{Average}, \text{Long(Ln)} \rangle$$
$$T(z_2) = \langle \text{Low}, \text{Average}, \text{High} \rangle$$
$$T(z_3) = \langle \text{Low}, \text{Average}, \text{High} \rangle$$
$$T(z_4) = \langle \text{Low}, \text{Average}, \text{High} \rangle$$
$$T(z_5) = \langle \text{Small(S)}, \text{Average}, \text{Long(Ln)} \rangle$$
$$T(z_6) = \langle \text{Low}, \text{Average}, \text{High} \rangle$$
$$T(z_7) = \langle \text{Low}, \text{Average}, \text{High} \rangle$$

The system of fuzzy logical equations which characterizes the surface of belonging to the variables (z_1, z_2, $z_{3,}$ z_4, z_5, $z_{6,}$ z_7) of the corresponding term can be shown as the linguistic statement:

$$\begin{aligned}&\mu_L(Z) = \wedge\mu_{Ln}(z_1) \wedge \mu_L(z_2) \wedge \mu_s(z_3) \wedge \mu_L(z_4) \wedge \mu_L(z_5) \wedge \mu_L(z_6) \wedge \mu_L(z_7) \vee\\ &\mu_A(Z_1) \wedge \mu_L(z_2) \wedge \mu_L(z_3) \wedge \mu_L(z_4) \wedge \mu_S(z_5) \wedge \mu_L(z_6) \wedge \mu_L(z_7) \vee\\ &\mu_{Ln}(z_1) \wedge \mu_A(z_2) \wedge \mu_L(z_3) \wedge \mu_L(z_4) \wedge \mu_S(z_5) \wedge \mu_L(z_6) \wedge \mu_L(z_7)\end{aligned} \tag{3.14}$$

$$\begin{aligned}&\mu_{BA}(Z) = \wedge\mu_{Ln}(z_1) \wedge \mu_A(z_2) \wedge \mu_A(z_3) \wedge \mu_L(z_4) \wedge \mu_S(z_5) \wedge \mu_L(z_6) \wedge \mu_H(z_7) \vee\\ &\mu_{LN}(Z_1) \wedge \mu_L(z_2) \wedge \mu_L(z_3) \wedge \mu_L(z_4) \wedge \mu_S(z_5) \wedge \mu_L(z_6) \wedge \mu_H(z_7) \vee\\ &\mu_A(z_1) \wedge \mu_L(z_2) \wedge \mu_A(z_3) \wedge \mu_L(z_4) \wedge \mu_S(z_5) \wedge \mu_L(z_6) \wedge \mu_H(X_7)\end{aligned} \tag{3.15}$$

$$\begin{aligned}&\mu_A(Z) = \wedge\mu_A(z_1) \wedge \mu_A(z_2) \wedge \mu_A(z_3) \wedge \mu_A(z_4) \wedge \mu_A(z_5) \wedge \mu_A(z_6) \wedge \mu_A(z_7) \vee\\ &\mu_A(Z_1) \wedge \mu_L(z_2) \wedge \mu_A(z_3) \wedge \mu_A(z_4) \wedge \mu_S(z_5) \wedge \mu_L(z_6) \wedge \mu_A(z_7) \vee\\ &\mu_{Ln}(z_1) \wedge \mu_L(z_2) \wedge \mu_A(z_3) \wedge \mu_L(z_4) \wedge \mu_S(z_5) \wedge \mu_L(z_6) \wedge \mu_H(X_7)\end{aligned} \tag{3.16}$$

$$\begin{aligned}&\mu_A(z_1) \wedge \mu_A(z_2) \wedge \mu_A(z_3) \wedge \mu_H(z_4) \wedge \mu_A(z_5) \wedge \mu_A(z_6) \wedge \mu_L(z_7) \vee\\ &\mu_S(Z_1) \wedge \mu_H(z_2) \wedge \mu_A(z_3) \wedge \mu_A(z_4) \wedge \mu_A(z_5) \wedge \mu_A(z_6) \wedge \mu_L(z_7)\end{aligned} \tag{3.17}$$

$$\begin{aligned}&\mu_H(X) = \wedge\mu_S(z_1) \wedge \mu_H(z_2) \wedge \mu_H(z_3) \wedge \mu_H(z_4) \wedge \mu_{Ln}(z_5) \wedge \mu_H(z_6) \wedge \mu_L(z_7) \vee\\ &\mu_S(Z_1) \wedge \mu_A(z_2) \wedge \mu_A(z_3) \wedge \mu_H(z_4) \wedge \mu_{Ln}(z_5) \wedge \mu_H(z_6) \wedge \mu_L(z_7) \vee\\ &\mu_S(z_1) \wedge \mu_H(z_2) \wedge \mu_H(z_3) \wedge \mu_H(z_4) \wedge \mu_{Ln}(z_5) \wedge \mu_A(z_6) \wedge \mu_L(X_7)\end{aligned} \tag{3.18}$$

The fuzzy logic confirmation technique allows observing an indicator predicted as fuzzy sets. Fuzzy sets estimate the environmental and economic performance of a project variant for the fixed vector of influencing factors. In order to move from the obtained fuzzy sets to quantity assessment, a dephasing procedure must be performed. It consists in the transformation of fuzzy information into a distinct form. Among various methods of defuzzification, the most common is finding the "center of gravity" of a flat figure, which is limited by the function of fuzzy set membership and horizontal coordinate. The fuzzy inference model, together with the dephasification procedure, provides an opportunity to monitor the changes in the baseline – the environmental and economic efficiency of the project.

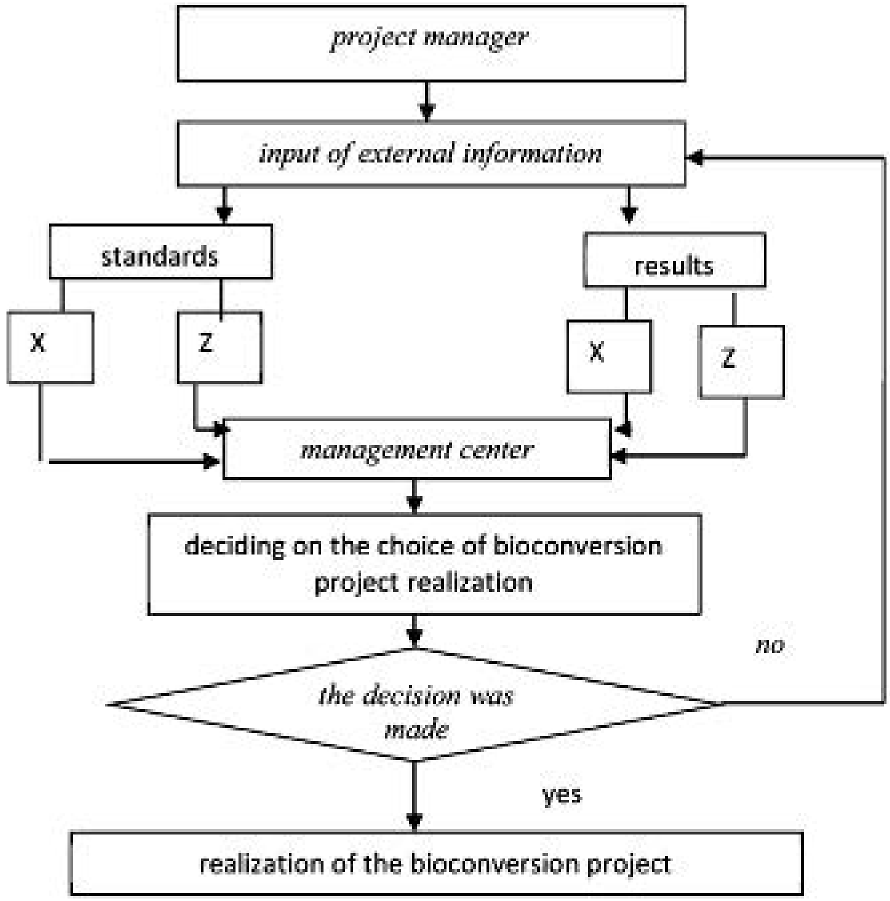

Figure 3.2 Structural and logical model of managing ecological and economic feasibility of an innovative bioconversion project.

In order to assess the economic efficiency of the mechanisms for providing thermal stabilization process in biogas installations at the conceptual phase of the life cycle of an investment project, a structural logical model for minimizing the bioconversion products cost by managing renewable energy sources has been offered (Figure 3.2). This model allows taking into account required variable data about the dynamic parameters of the thermal stabilization process in the production of biogas as ecological energy source.

3.3 CONCLUSIONS

- Formalization and hierarchical classification of the quantity and quality factors were completed, which are important and significantly help determine innovative appeal of a bioconversion project variant.
- Models of managing the assessment of bioconversion ecological-economic efficiency based on fuzzy logic at ecological and economic levels were developed.
- For the first time, a structural and logical model for managing ecological and economic feasibility of an innovative bioconversion project was created.

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