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ECONOMIC AND ENVIRONMENTAL CRITERIA IN MULTI-OBJECTIVE PROGRAMMING PROBLEMS

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Abstract. *Awareness of current and potential conflict of interest between economic growth and environmental preservation has resulted in the concept of sustainable development. Sustainable development is a multidimensional concept that encompasses economic, social, ecological, technological and ethical perspective. From such a definition, it can be concluded that the objectives of sustainable development are characterized by a high degree of conflicting. Furthermore, the terms "development" and "sustainability" in themselves are contradictory terms. In this sense, multi-criteria optimization is the appropriate approach in solving the conflicts in sustainability on both micro and macro level. The aim of this paper is to define some important economic and environmental criteria relevant to the problems of multi-objective programming, as well as their major conflicts.*

Key Words: *multi-objective programming, economic criteria, ecological criteria, environmental protection.*

1. INTRODUCTION

The concept of sustainable development is based on the idea of simultaneous economic prosperity and environmental protection. Development, in terms of economics, means a series of changes in the economic, social, institutional and political structure, which aim is economic prosperity. These changes can be quantitative, such as the growth of gross domestic product, or qualitative, such as the changes in the political scene. Adding the term "sustainable" means a series of changes that give the problem an ethical and environmental dimension. So, basically, the concept of sustainable development is a problem that can be described as follows: it is necessary to project the best development strategy to achieve a higher level of satisfaction of the targeted goals.

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As it is impossible to maximize the number of different, even contradictory objectives simultaneously, the choice of the best strategies for sustainable development corresponds to the definition of the general problems of multi-criteria optimization, and the very best strategy for sustainable development of a compromise solution to a problem that largely meets the set of goals.

One of the key parts of this problem is to determine the relevant criteria in the model, especially when it comes to environmental requirements.

2. THE THEORETICAL BACKGROUND OF MULTI-OBJECTIVE PROGRAMMING

The methods of multi-criteria optimization can be divided into two main groups [17]:

(1) method of multi-criteria programming, where it is necessary to design a solution that mostly satisfies defined criteria and

(2) methods of multi-attribute decision-making or multi-criteria analysis where from the finite number of current, available alternatives, one should be selected, which most contributes to the fulfillment of the objectives defined by the criteria that the decision maker considers relevant.

The problems of multi-criteria programming include two ways of defining the objective function. Under the first method, also known as multi-objective programming, the objective functions are defined so that it is necessary to determine their extreme values and thus optimization is performed. In the second case, the objective functions are defined so that optimization includes the minimum deviation from an already given, preferred value. The second approach is well known in literature as goal programming [5].

As all the categories in the field of environmental protection involve determination of the minimal level of pollution, while the economic criteria usually maximize profit or minimize costs, the first approach will be used in defining a multi-objective programming model which includes both economic and ecological criteria.

Therefore, solving the problem is based on the design of a solution with a maximum or minimum level of values in the objective function [1]. The assumption is that the decision maker knows the nature of criteria well and that can reliably specify the type of objective function values which represent the desired levels of satisfaction for the observed criterion - minimal or maximal.

The task can be defined as follows [8]:

$$(\max/\min)\, z_0\, [f_1(X), f_2(X), ..., f_p(X)], \quad p \geq 2 \tag{1}$$

with constrains

$$g_i(X) \leq 0, \quad i = 1,2,\ldots,m \tag{2}$$

where X is a final set of possible solutions in n-dimensional space.

The same problem can be defined in the form of linear programming, if there is a linear dependence between variables [8]:

$$(\max/\min)\, z_0 = \sum_{j=1}^{n} c_{kj} x_j\,, \; k = 1,2,\ldots,p \tag{3}$$

with constrains

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \ , \ i = 1,2,\ldots,m \tag{4}$$

$$x_j \geq 0, \ j = 1,2,\ldots,n \tag{5}$$

where are: p – number of criteria, m – number of constraints, n – number of variables, c_{kj} – coefficient of k objective function for variable j, a_{ij} – elements of constraints matrix and b_i – elements in vector of free values. Linear programming as a type of modeling is very common and suitable for most economic and environmental criteria.

As it is mentioned above, goal programming is a special case of multi-objective programming where it is possible to define preferred values for all relevant criteria in a model. The general linear model of goal programming is [6]:

$$\min \sum_{k=1}^{p} (d_k^- + d_k^+) \tag{6}$$

$$\sum_{j=1}^{n} c_{kj} x_j + d_k^- - d_k^+ = f_k \ , \ k = 1,2,\ldots,p \tag{7}$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \ , \quad i = 1,2,\ldots,m \tag{8}$$

$$x_j \geq 0, \ j = 1,2,\ldots,n \tag{9}$$

$$d_k^- \geq 0, d_k^+ \geq 0, \ k = 1,2,\ldots,p \tag{10}$$

where: f_k – preferred level of objective k, d_k^- – negative deviation from the preferred level of objective k, d_k^+ – positive deviation from the preferred level of objective k. Other variables have the same meaning as it is emphasized in the previous model.

The focus of this paper will be on the problem of defining relevant criteria for the problem described above.

3. The System of Environmental and Economic Objectives and Structure of the Model

Before formulating a concrete model, it is necessary to clarify the issue of the most appropriate ways for ecological and economic optimization, as well as the problem of providing a logical unity between the goals and measures in the model. With the introduction of environmental objectives in the economic optimization model which is usually focused on costs minimization, there are various methodological issues, starting with the general problem of competition between economic and environmental objectives in the national economy, to a particular problem of formulation environmental objectives in the chosen model.

3.1. Relations between environmental and economic objectives in the system of social objectives

The main objectives of the human community which stand out in modern constitutions are to protect and increase the welfare of people and society, as well as preserving the quality of life and social well-being. Those main purposes of social systems are subordinated to the objectives of all social subsystems, i.e. economic systems, social and health systems, education systems and so on.

Until 1960s, there was the general perception that the quality of life can be equated with the material living standard of the inhabitants, and social well-being with the total national income, or to the gross domestic product, therefore with the degree of availability of material goods. That conception has brought about economic objectives of great importance and absolute priority in the post-war period, particularly the objectives of economic growth and increase in material production, compared to other social objectives.

However, the general opinion today is that the standard of living is a "too narrow" objective that can not be considered as a general aim of social development, as well as national income or gross domestic product, which can not be a reliable indicator of social welfare. This change in considering the problem was caused mostly by environmental problems that have emerged increasingly as a result of uncontrolled growth, or "blind progress".

Furthermore, it is recognized that the quality of life and social well-being contains also non-essential components, in addition to basic material, that are indispensable for the overall well-being of man and society. These are primarily health and social security, quality of basic environment medium, education and satisfaction in work and so on. In the simulation models provided by the Club of Rome [9], the authors have started from a broader definition of the quality of life.

One of the key messages of the Club of Rome was pointing to the divergent development of material and ecological components of social welfare as a result of continuous economic growth, as well as the possibility of *World*[1] system collapse due to the increase in the pollution of the environment.

With the help of a computer program *World-3*[2], after two years of work, some conclusions were drawn. Future development of initial variables indicates the existence of limits of growth that could be achieved in the next hundred years if the current trends continue in the future [13].

In the first reactions, resulting in fear, it is required to stop the economic growth and to make fundamental revision of the system of social objectives. Later, it was shifted to the so-called requirement of "organic growth" [10] or on requirement of "qualitative rather than quantitative growth." Based on the discussions, the following conclusions were derived:

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[1] In Jay Forrester's model *World- 2* the quality of life depends on four factors: 1) food availability, 2) the standard of living, 3) the degree of agglomeration of population and 4) the degree of environmental pollution [2].

[2] *World-3* computer program is based on a dynamic system and illustrates the changes in a complex system over time. This program follows the movement of population, industrial capital, pollution and arable land. There are many objections to this computer program, and one of them is that it does not make a difference between geographic areas in the world and does not separate the rich parts from the poor parts of the world [11].

- That the system must include social objectives and environmental objectives (objectives of environmental protection);
- That the increase in material welfare (economic growth) is still the basic social objective, but no longer with absolute priority, but in accordance with environmental and other social goals;
- That without the effective implementation of protective and corrective measures there is a conflict, i.e. competition between the economic objectives of economic growth and environmental objectives of unpolluted environment, because the current level of engineering and technology, as well as many of the key manufacturing processes and consumables (e.g. power plants, cars) have damaging effects on the environment[3];
- That in effective implementation of protective and corrective measures, there is a conflict (competition) between the social objectives of increasing material welfare, on one hand, and the social objectives of protecting the environment, on the other hand, because the implementation of protective measures employs a part of the available economic funds and resources, therefore it can not be used to produce other goods. Thus, in the case of limited resources and the full utilization of production capacity, any improvement of environmental quality necessarily goes to the expense of material welfare.

In terms of economic growth and increase of available resources, the basic conflict between the material living standards and environmental quality can be solved without an absolute reduction of material welfare of inhabitants. On the other hand, the view is presented that even productions of investment goods, which serve to protect the environment (e.g. water purification plants, or air) increase the total social welfare, because the production activities increase the total national income or gross domestic product. This argument is further evidence of the existing shortcomings of the indicators of social well-being.

3.2. Principal problems of harmonization of environmental and economic objectives

In the system of social objectives, conflicts between competing objectives must be resolved through compromise. Among many possible compromises, the one that contributes most to achieving the objective of social capital, i.e. social well-being, may be considered as the optimal. Therefore, the possibility of determining the optimal compromise between competing objectives depends, in a decisive extent, on the availability of measures for comparing alternative compromises and the possibility of measuring the contribution of individual objectives and the degree of their contribution to the overall social welfare.

3.2.1. *Effective compromises between environmental and economic objectives*

The set of all possible compromises between the objectives of greater material welfare, on one hand, and better quality of the environment, on the other hand, is shown in

[3] An effort to develop and apply technical procedures with a neutral effect on the environment (the so-called clean technology) resulted from that information [16]. Forcing clean technologies is one of the environmental sub-objectives under the National Environmental Protection Program of the Republic of Serbia [12].

the 0ZR surface in Figure 1. The ordinate shows the material welfare of the society and the quality of the environment is given on abscissa. Point Z is the maximum level of material welfare which can be achieved with a given (limited) resources, with the condition that the environmental protection does not spend any funding. On the other hand, point P is the maximum level of environmental quality, achieved by the intensive use of available resources to protect against pollution.

The line shows the effects of ZP compromise and redistribution of limited resources between two goals: starting from the point Z, the increase in environmental quality is only possible with the reduction of material welfare. This also applies vice versa for the increase in material standards, starting from point P. ZP line is, therefore, a "transformation curve" of competing goals, which shows how much is lost in achieving an objective when it increases the degree of realization of another goal. For example, increasing the environment quality causes the losses of amount *m* ("opportunity costs") in the amount *n* of material welfare (Figure 1).

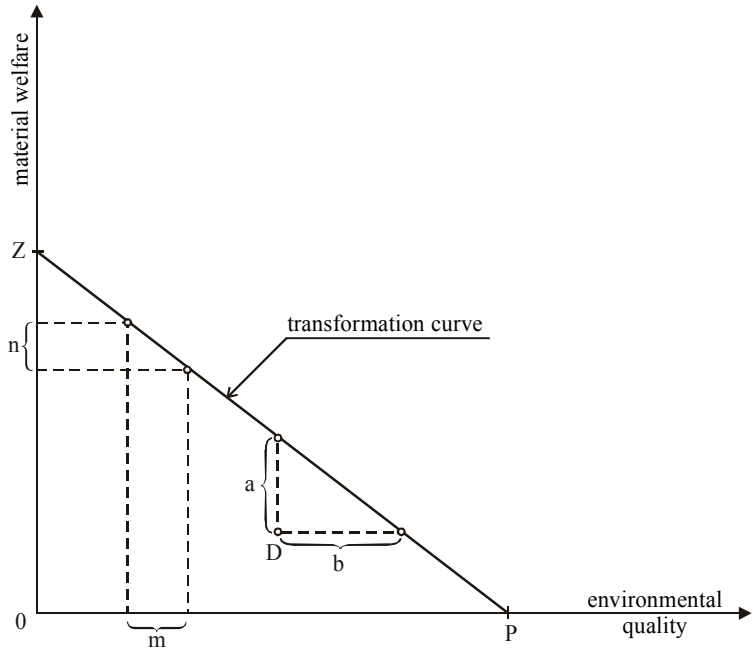

Fig. 1. The space of possible compromise between the objectives of material welfare and environmental quality, source: [4]

However, the ZP line represents the total amount of available resources, which limit the space of possible compromise between both objectives. The ZP line includes all possible compromises with the full use of resources, and below the line all compromises with incomplete use of the resources (for example, a compromise at point D). Realization of the objectives in the space above the line ZP due to a lack of resources is not possible.

All the compromises that are on the transformational line ZP, are actually effective compromises[4] of the objectives and they are optimal in the sense of Pareto [14], because the degree of realization of one objective can not increase without a simultaneous loss in the realization of another goal. Conversely, inefficient compromises are suboptimal in terms of Pareto: the compromise D in Figure 1 - the quality of the material standards may be increased by the amount of *a*, without reducing the quality of the environment, and environmental quality can be increased by the amount of *b*, without reducing the material welfare.

"Pareto efficiency does not imply fairness. Use all available community resources and technological capabilities that put consumers in an advantageous position, provided that all other consumers remain at the same level of utility, resulting in the allocation that is Pareto optimal, but it is not desirable from the standpoint of distribution"[15].

3.2.2. *Value system and determination of optimal compromise*

The fact that all efficient compromises in terms of Pareto optimal does not mean that they can equally contribute to the achievement of the main social goal, i.e. increase social welfare. On the contrary, experience has shown that forcing the material welfare unilaterally at the expense of environmental quality reduces the overall welfare of the society. Therefore, to determine the optimal compromise between the objectives of material welfare and environmental quality, an additional criterion should be introduced, namely the contribution to overall social welfare compromise, and its social benefits[5]. The social benefit of compromise depends on the relative importance attached to alternative degrees of realization of certain objectives and components of welfare, and that means the system of social values. In economic theory, a system of values is usually formulated ordinal ranking of alternatives using preference relations and equivalent alternative to running through the indifference curve. Therefore, to determine the optimal compromise between competing objectives requires a scale of social preferences in the form of indifference curve system.

In Figure 2 is inscribed indifference curve system whose shape is based on the assumption of hypo-substitution and the gradual saturation[6], i.e. on the assumption that each target with increasing degree of his negligence is gaining increasing importance in relation to the second objective, which is realized, even to the extent that the loss in the first objective can not be compensated more in the second objective. As a general view, such a relationship exists between objectives of material welfare and environmental quality, or between material and ecological components of social of welfare.

All equivalent compromises, i.e. all compromises, which equally contribute to the overall social welfare, are on one particular curve. Scale preference was given in such a manner that the social benefit increases by switching to a different indifference curve, according to the relation $k_1 > k_2 > k_3$, etc.. That is, the social benefit of any compromise on the curve k_1 is greater than the social benefits of any compromise that is on the wrong k_2 and so on.

[4] In theory, linear programming, efficient compromises between competing objectives are referred to as "effective solutions".[18]

[5] In decision theory, the term "benefit" is used mostly in the field of utility theory or game theory, which deal with conflict situations resolution [7].

[6] Possible forms of value system are described in detail in [3].

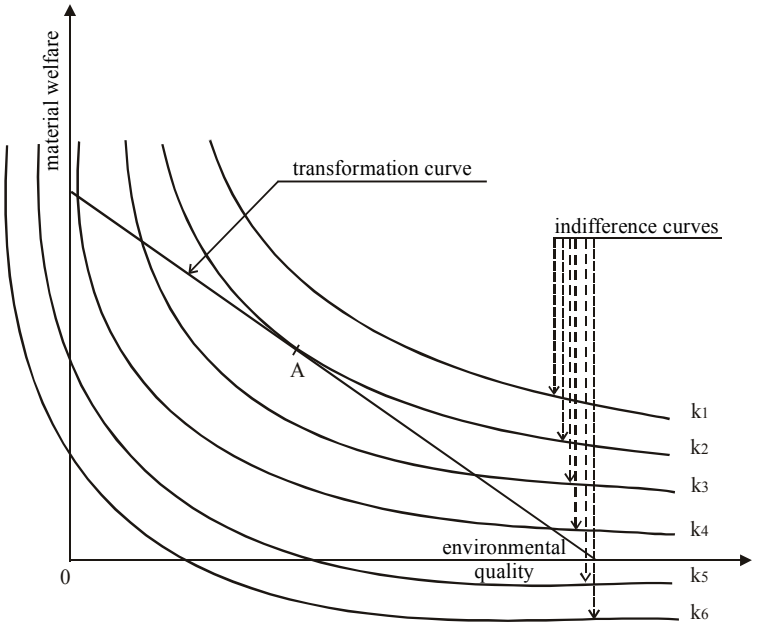

Fig. 2. Determination of the optimal compromise between the objectives of material welfare and environmental quality

With such a system of social values, the transformation curve (Figure 1) can be determined theoretically as an optimal compromise between the objectives of material welfare and environmental quality for any given level of available resources. The optimal compromise is the one which achieves the highest social benefit, i.e. the one that lies on the indifference curve with the highest value. It is the compromise in Figure 2 at point A, where the indifference curve k_2 is tangent of transformation curve. It is clear that the optimum compromise has to be at the same time effective compromise, i.e. efficiency is a necessary condition for optimality of compromises [4].

3.2.3. *The problems of determining the system of social values*

Contrary to the presented theoretical approach, determining the optimal compromise between the objectives of material welfare and environmental quality in practice poses great difficulties, which mainly originate from a variety of problems that occur in determining the system of social values such as:

- The phenomena of partial inconsistency in systems of individual and social preferences;
- Formal problem of aggregating individual system of values in social values (problems of inter-subjective comparability of values);
- Institutional problem of aggregating individual system of values in social values (political processes and compromises).

The economic theory of welfare ("Welfare theory") that deals with these problems, has not found satisfactory and applicable solutions yet. By not engaging in doubts of economic welfare theory, we believe that the political programs and legislation in companies

today contain enough elements to approximate the system of social values in the observed problems. The objectives for environmental quality are formulated as permitted immission values, with the aim to ensure that air quality, water, etc., which is considered necessary for the overall well-being of people and society ("minimum welfare standards").

Depending on the technical and economic possibilities of the society, the short and medium immissions standards are set less stringent by long-term. This reflects the fact that in their determination in the process of political decision compromises between the objectives of material welfare and environmental quality have already been taken into account. What follows is that immissions standards are not only limits but also the optimal level of environmental quality in relation to the targets set for economic growth. In this way, the formal analysis has determined the optimal compromise between the objectives of material welfare and environmental quality: the optimum efficiency is the compromise that is at the height of ecological constraints (point A in Figure 3).

The system of indifference curves, corresponding to this mode of evaluation objectives, is a simple form shown in Figure 3 This form implies that the total social welfare, after the implementation of minimum requirement of environmental quality depends solely on the amount of material welfare, and that is below the minimum level of environmental losses in environmental quality which can hardly be compensated by increasing the material welfare. Such a simplified system of social values, deduced from optimality of social conditions given in immission standard, is acceptable in the conclusion of this paper. Suppose that the total social welfare maximization can optimize material welfare provided it maintains the minimum required quality of the environment.

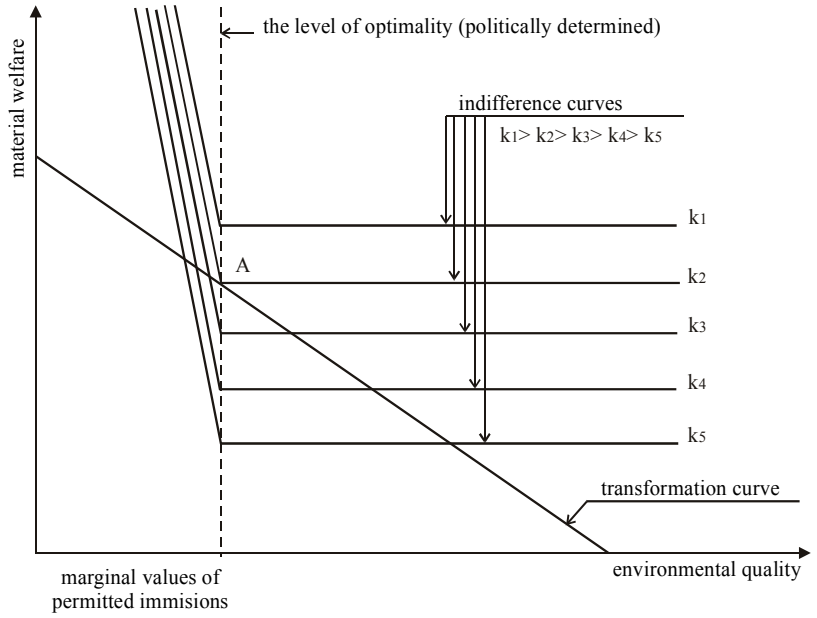

Fig. 3. The system of social preferences deduced from social optimality conditions of immission standards [4]

3.2.4. *Introduction of environmental objectives over the goal constraints*

In the present situation, the formation of a complex function of weighted economic and environmental objectives would be an extremely difficult task, mainly because of mutual incompatibility of certain environmental objectives. On the other hand, environmental objectives are in the process of political decision already determined by the optimal compromise between material welfare and environmental quality, and are formulated as permitted immission values. This suggests that for the purpose of ecological and economic optimization in the structural models of energy and economic development is most appropriate to introduce environmental objectives through the system of constraints, provided that the objective function contains only the economic objectives of minimum total cost. The treatment of environmental objectives as constraints by the introduction of direct permitted immission values in the model completely corresponds to the structure of real systems.

The introduction of environmental objectives over the goal constraints assumes the classification of objectives into two groups: (1) the "main objective" such as minimum cost function represented by the objective function and (2) the "secondary objectives" such as maximum permitted immission presented by system of constraints.

This division of the "main objective" and "secondary objectives", however, has essentially only a formal character, because it can not be said that for determination of optimal solution the objective function is "more important" than the system of constraints, or vice versa. In any linear problem, the objective function and system of constraints are unity and the necessary conditions for finding the optimal solution [17].

By determining the levels of specific environmental objectives, therefore, it is determined by the relative importance of specific environmental objectives in relation to the economic objective. The system of specific immission standards is, therefore, together with the objective function of the minimum cost, a weighted system of economic and environmental objectives. The evaluation of objectives is always done previously in the process of political decision-making based on social preferences.

By converting environmental objectives in constraints, the mathematical procedure of multi-criteria programming comes down to the "classical" linear programming assignment with a goal variable. The solution of this task is, normally, an effective solution and the optimum is the extent to which weighted system of environmental and economic objectives correspond to the real social preferences. In principle, it can start from the assumption that the immission standards for available data are determined as an optimal compromise between the objectives of social and material welfare of the environment. To review the system of objectives, mathematical analysis can give valuable information in this way, as for alternative levels of environmental objectives defined losses or gains in achieving economic goals ("opportunity costs"), which therefore increases the level of knowledge in the process of political decision making.

4. CONCLUDING REMARKS

The application of mathematical models and optimization methods in designing sustainable development strategies imposes itself as a modern scientific standard. These procedures represent an important tool in the process of harmonizing contradictory objectives arising from contemporary business and living environment. The paper described

optimization procedures in detail, as well as the underlying problems and conflicts between economic and environmental objectives and the ways to overcome them.

Regardless of the global trends, the application of quantitative methods of optimization in designing strategies for sustainable development in Serbia is limited. In fact, only few studies have dealt with this issue. On the other hand, the adoption of development strategies in Serbia is still, unfortunately, more-less a political issue and a matter of political consensus.

That paper represents a theoretical basis for applying multi-objective programming to solve the described kind of problems. Also, the paper highlights the possibilities of establishing connections between multi-objective and goal programming through a different way of introducing environmental objectives in the model. Thus, the authors want to draw attention to the scientific approach to designing development strategies. Applying this approach in determining the future development strategy would mean respecting, to a great extent, the provisions of the National Environmental Protection Program of the Republic of Serbia and thus achievement of both economic and environmental objectives of growth and development.

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EKONOMSKI I EKOLOŠKI KRITERIJUMI U PROBLEMIMA VIŠECILJNOG PROGRAMIRANJA

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Svest o aktuelnom i potencijalnom konfliktu interesa između ekonomskog rasta i očuvanja životne sredine rezultirala je konceptom održivog razvoja. Održivi razvoj predstavlja multidimenzionalni koncept koji obuhvata ekonomske, sociološke, ekološke, tehnološke i etičke perspektive. Iz ovakve definicije se može zaključiti da ciljeve održivog razvoja karakteriše visok stepen konfliktnosti. Štaviše, termini "razvoj" i "održivost" sami po sebi predstavljaju kontradiktorne pojmove. U tom smislu, višekriterijumska optimizacija predstavlja adekvatan pristup u rešavanju konflikata održivosti kako na mikro, tako i na makro nivou. Cilj ovog rada je da definiše neke značajne ekonomske i ekološke kriterijume relevantne za probleme višeciljnog programiranja, ali i da istakne njihove konflikte.

Ključne reči: *višeciljno programiranje, ekonomski kriterijumi, ekološki kriterijumi, zaštita životne sredine.*