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Optimization of Economic and Environmental Goals by Multicriteria Analysis Models*

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Abstract
The main goal of any society is to meet environmental standards with respect to basic economic requirements, despite all the problems it faces. After solving the major problems concerning the harmonization of environmental and economic goals, these goals could be adequately introduced in a mathematical model. In recent years, the economic theory of decision has been devoted to the methods of multi-criteria optimization of these problems. Minimum costs are regarded as an economic objective, and minimum emission as an environmental objective. In this paper we will emphasize the importance of introducing economic and environmental goals in models that deal with this problem. The implementation of successful economic policy is based on the optimal solutions of environmental modelling.

Keywords
Optimization, economic goal, environmental goal, multi-criteria analysis, decision making process.

Introduction

The concept of sustainable development is a multidimensional concept comprised of economic, social, environmental, technological and ethical components. For this reason, there can be a high level of conflict among the goals of sustainable development. Modern economic literature and practice have confirmed that the conflict between economic growth and environmental protection can be successfully overcome. By introducing environmental objectives in the economic model may result in different methodological problems – from the general problem of competition between economic and environmental objectives, to the specific problem of formulating environmental objectives in the chosen model.

After solving the major problems concerning the harmonization of environmental and economic objectives, these objectives could be properly introduced into the mathematical model. In recent years, economic decision theory has been intensively engaged in multi-criteria optimization methods of these problems. Goals can include optimization of time for performing activities, increasing marginal utility of income, risk avoidance, tendency toward engaging the workforce and meet the desirable, but not mandatory, restrictions.

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The economic model of perfect competition market represents a radical simplification of things in relation to how they behave in reality. Due to its extreme simplicity, it may be surprising that this model can still be a way to describe significant drivers of economic activity and the nature of economic institutions (i.e. striving for profit or utility, competition and purchasing power in the market). Also, there is no doubt that this model is too roughly structured for direct application of economic and environmental policies.

For example, it is obvious that in reality even individual suppliers can sometimes have a significant impact on the price of the product that they produce. This has important implications for the optimal balance in the market. Even in the extreme case of a monopoly, the supplier achieves optimal equilibrium at the point where the marginal costs are below the market price of the product. At the balance point, therefore, the marginal willingness to pay the price of the product and the marginal cost of the product are not identical, so that in this case, the social optimum amount of production cannot be achieved. Similarly, the optimality of market equilibrium is disturbed by state intervention through tariffs and taxes on certain products, leading to a significant difference between the price paid by consumers and the price received by producers. Here, again, the equilibrium between the marginal willingness to pay the price of the product and the marginal cost of production of the product has not been achieved. The result is a poor allocation of resources. Another aspect that is important in real life (and in rather complex economic models) is that the stakeholders do not have enough information for their activities, according to which they would behave in a way that has already been explained. In general, information (e.g. about product quality) can be asymmetrically distributed between the supplier and the customer. If the customer is unable to comply with all the relevant characteristics of the product before buying, poor allocation of resources may appear as a result.

Indeed, the list of differences between real life and the previously mentioned ideal model is long. However, not every item on the list is of interest for each discourse. In this regard, it should be noted that the economic model formed in these specific conditions does not aim to reflect reality. We therefore need to focus on the differences between reality and model that are important for the analysis of environmental problems: the ideal previous presentation (implicitly) assumed that only the producers and consumers are affected by the production of the product *x* (plus, of course, the market for suppliers of production factors which are required for its production). Of course, the divergence between the different simple economic models and the reality can be interacted.

Each cost or benefit effect of the product *x* is, in the ideal model, transmitted through the operation of market: the benefit of consuming good *x* goes exclusively to consumers who pay to buy it in its market. The cost of produced goods is exclusively incurred by the companies that produce them, and they compensate their costs of production through market revenues. To produce goods, producers use only those production factors that are purchased in the market of production factors. In the model of commodity *x*, there are no other relations in the production and sale of good than market relations. This fact can be seen as a drastic simplification, given the current circumstances in reality. In economics, the interdependence between individuals is mediated through the action of the market known as internal effects.

If the market mechanism does not work, one might think that it should be replaced by another mechanism as quickly as possible. However, caution should prevail in such cases. Maybe one can finally show (which is what actually happens) that real allocation mechanism cannot meet the ambitious optimality criterion that maximizes net social benefit. If we reject all concepts that do not meet this criterion, then nothing will remain. Consequently, literature tends to replace the collocation “market failure” with the collocation “government failure”.

1. The principle of consumer sovereignty

According to the concept of economic optimality, the levels of different values (that is, production costs, environmental impact and benefits of consumption of goods) play a fundamental role. The central idea in the concept of value is that the base is positive or negative value that is good or bad, and decision makers can make their own assessment. The utility of a product for the consumer is estimated in economic model that is based on the consumer’s feeling of utility. The concepts of utility (preferences) of decision makers in the economy are taken as a given value. In academic and professional literature, economic theory is an extremely wide (and “biologically” dynamic) field. The subtle difference between (endogenous) preferences and (exogenous) meta-preferences is made by Cooter (1991) or Ebert and Hagen (2002), who distinguish between (exogenous) preferences and (endogenous) affinities.

The process of generating preferences, in particular, their determining in the processes of social interaction and learning, was not analyzed by the "mainstream" economic academic literature, although it is undoubtedly of great importance in practice. Moreover, attention should be paid to the fact that the "mainstream" economics is the base of this paper, in order to simplify that individual preferences are associated exclusively with the outcome of the allocation process (and, therefore, especially with the provision of goods). Regarding the ways and means by which the outcome of the allocation takes place, individuals are presumably indifferent. These (and other) limitations do not mean that traditional economic theory is worthless for explaining human behavior, but it cannot explain a significant aspect of the dynamics of human society and therefore can only be a single voice (though very important) in the "polyphonic choir" approach to explanations in social sciences (with special emphasis on the relationship between economic theory and psychology).

In consumer's evaluation of positive and negative utility, observations of decision makers are essential. They are inevitably selective. However, there is a risk of rejection of the principle of consumer sovereignty related to the weak awareness of consumers about the characteristics of the goods and the negative effects of environmental impact. On the other hand, there is the danger of authoritarian solutions. In a democratic society, the assessment of individuals should have a central role, even though they are not fully informed. According to the fact that there is a significant risk of abuse by "expertocracy", expert level information must also be assessed sceptical. They can usually see only one particular aspect of a complex and interdependent problems of environmental policy or economic policy. Although they may, therefore, provide significant contributions to complex social communication process, they have no way to change them. In relation to the role of economics in discussed problems of the level of awareness of consumers, it must be noted that there is significant improvement. Thus, the "information economy" in which the level of awareness of decision-makers is no longer treated as exogenously given, is integrated in the "body" of economic theory. The information process of production and processing is itself treated as an economic problem, based on which the statements about the optimal equilibrium are possible. These issues are discussed in more detail Varian (2006) and Macho-Stadler and Pérez-Castrillo (2001).

2. Concepts of ordinal and cardinal utility

The concept of consumer sovereignty is accepted with reservation (probably due to lack of better alternative), when often faced with new obstacles on the way to define the optimum, which should be achieved by internalization. Even if their assessment of usefulness is considered and it is assumed that it is crucial for the optimum position, we cannot yet say how it should be measured (conceptual and practical). In modern microeconomics, the utility is ordinal, not a cardinal concept.

In many areas of application of economic theory (and research programs), it is also appropriate to use the concept of utility, according to which they are in a position to choose situations that are appropriate to their level of desirability without the possibility to assess the utility which is done quantitatively or interpersonally comparable. It is necessary to define the socio-economic optimum, for example, the optimal amount of emissions. The claim that the optimal amount of emissions defined by the fact that the marginal cost of reducing emissions and the marginal damages equal means that both quantities can be determined quantitatively in one the same dimension. In addition to the practical difficulties in measuring, it was pointed out to a conceptual problem: environmental damage and costs of reducing emissions entail the loss of utility. Later we will determine the utility losses of refraining from the use of resources for alternative (e.g. consumer) purposes ("opportunity costs"). According to the definition of the social optimum approximate value of utility, strictly speaking, cannot be measured as a cardinal, but it may take a willingness to pay (or demand for compensation, respectively) by the relevant decision makers. The demand curve that is used to estimate consumer goods shows, as already explained, nothing other than the relevant consumer's marginal willingness to pay for a product. Similarly, the marginal damage curve shows the willingness of individuals to pay for damage reduction. The second (related) interpretation shows the demand of the injured party to pay for tolerating externalities.

It is important to note that the use of market value, or substitutes derived from market analogous procedure, is introduced in the assessment in addition to preferences, as well as income and assets. Apparently, the "rich" decision-maker is able to manifest a greater willingness to pay on the market than the "poor". One cannot consider whether it is basically wrong, but instead, each individual assessment should be placed in a social assessment of the same importance. However, it points to the incorrect use of the will to pay as value that implicitly accepts the existing distribution of income.

3. Multi-criteria programming in ecology

European urban areas are faced with a number of environmental challenges. Although the scope and intensity of the problems vary, a common set of issues to overcome problems can be identified. The problems primarily include poor air quality, high intensity of traffic and congestion, high noise levels, lack of areas for sport, play and recreation, neglect of the built environment, high levels of greenhouse gas emissions, urban sprawl and generating large amounts of waste and wastewater. These environmental challenges are serious and have a significant impact on the health, environmental and economic performances. These problems are caused, in part, to changes in lifestyle, and partly to demographic trends (a growing dependence on private cars, increasing of resource use per capita). Environmental problems in cities are particularly complex and interconnected.

Environmental issues that are closely associated with the costs, revenues and benefits have a growing problem with modern companies around the world. Environmental management today in modern society involves very complex processes and procedures that require decision-makers to know the environmental, economic, social and other principles (Morrissey & Brown, 2004) that are relevant to the consideration of all possible problems in ecology.

Multi-criteria optimization is a set of popular methods that are used to solve problems that are based on consideration of more different requirements, both qualitative and quantitative. One of the requirements may be finding and selecting optimal locations for management of environment, alternative, or its strategy (Chang, Wen, & Chen, 1996; Wen & Lee, 1998; Chang & Wei, 1999, Radukić, Popović, & Stanković, 2012). However, multicriteria analysis has difficulty in solving the problems that include both qualitative and quantitative objectives under consideration. Environmental and economic objectives should be properly introduced into the mathematical model using the multi-criteria optimization method.

Problem multicriteria programming can be most easily shown in the example of linear programming with two objectives. If one takes the minimum cost as an economic goal, and minimum imission[2] as an environmental goal, and if there are a number of technological and other constraints, the criterion set of possible solutions, in principle, has the form shown in Figure 1.

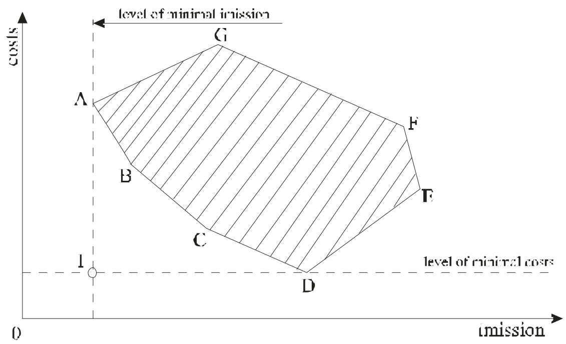

Figure 1 The criterion set by two goals (minimum costs and minimum imissions)
Source: Authors

All points in hatched field ABCDEFG and all points on the border line represent possible solutions. The aim of minimal cost is achieved at point D, and the goal of minimal imissions at point A. All points on the line ABCD are effective solutions, i.e. effective compromises. The set of all efficient solutions represent a complete solution of the problem (Zimmermann, 1976, p. 455). The optimal solution, i.e. the optimal compromise, is determined on the basis of complete solution using additional criteria. Depending on the applied procedure, Martić and Zimmerman distinguish the following basic methods for determining the optimal compromise, i.e. the next groups of multicriteria linear models (Martić, 1977; Zimmermann, 1976):

- models with valuation (weighting) goals,
- targeted programming, and
- interactive methods for seeking an optimal compromise.

[2] According to the Law on Environmental Protection of the Republic of Serbia (Sl. glasnik RS, no.135, 2004) the emission means the release of pollutants or energy from the individual and/or diffuse sources in the environment and its media, while imission means concentration of pollutants materials and energy in the environment which expresses the quality of the environment at a particular time and place.

Methods of the third group were developed for those situations in which the decision-maker's preferences cannot be formulated in advance, but only on the basis of additional information on possible alternative consequences, obtained in a dialogue with the computer (Martić, 1977).

Zimmerman describes the other group of models as models in which the optimum compromise solution is determined in such a way as to minimize the distance from the ideal solution (Zimmermann, 1976, pp. 456-457). The ideal solution is presented at the point where all goals reached its optimum level (point I in Figure 1).

At first glance, one can easily get the impression that the goal programming models provide a "purely mathematical" determination of unambiguous optimal compromise, without the need for any evaluation systems. However, Zimmerman suggests that the use of the parameter "distance" as a criterion of optimality just implies the existence of an appropriate system of preferences (Zimmermann, 1976, p. 457).

4. The formulation of the economic objective - the minimum cost objective

According to the academic and professional literature on the optimization of energy structure, some authors take the position that the sum of the cost (which should be minimized) –comprised of the sum of the cost of primary production and transformed energy, as well as the cost of transport and distribution – should also be included, preferably, and all the costs to the consumer (Požar, 1977). This position can be justified by the fact that the process of energy does not end in energy management, but that it continues in the sectors of final energy consumption. Energy needs, in fact, are the needs for useful energy, and useful energy is characterised narrowly limited opportunities for transport and storage so, as a rule, it must be produced by the consumer. Therefore, each final consumer of primary and transformed energy is also the producer of the useful energy.

As the energy structure of economy should be provided satisfying the overall energy needs, the optimal energy structure will be achieved, in a theoretical sense, in the case when the total social costs of produced useful energy in all sectors of economy are minimal. In addition, the concept of social costs also allows and includes all these costs (valued consumption of manpower and resources for operation) which result in non-productive sectors of economy, for example, in the sectors of general, common and private consumption. In this context, one should note the fact that the "social costs", as a rule, occur in the form of the damage cost and remedial measures that have been largely borne by final consumers, which has a negative impact on individual well-being and standard of living. These costs of the final consumers are indirectly included in the model over the cost of the protective (preventive) measures, which are, in our case, replaced by the cost of damage and remedial measures. The model, therefore, may introduce the useful energy production cost of non-productive sectors of final energy consumption, that is, estimated consumption of manpower and resources required for work in households. Similarly, the cost of damage and remedial measures, and labour consumption in the household, as well as the costs of energy installations, also affects the individual well-being and the standard of living. The protective measure in this case is to move the process of useful energy production from the household sector to the energy management, such as, for example, transfer of heat for home heating in private dwellings to district heating plants and boiler facilities. In this case, the operation reduces the consumption in the household, and increases the well-being of the individual. Thus, in the case of production of useful heat for space heating, using stoves within households themselves, the costs are large for consumers and should include the cost of procurement of fuel, the cost of transportation to the front of an apartment building, transport costs in the basement or storage, transport costs from the basement to the apartment and the removal of ashes. Another group of costs includes investments in the furnace, including the chimney, and the need to increase floor space for accommodation oven and storage of fuel, etc. The problems related to the method of determining these costs will not be discussed in this paper, but it is important here to emphasize that their introduction into the model, from a theoretical standpoint, is entirely justified.

The view that the amount of costs to be included, if possible, and all costs of consumer, satisfies the above conditions for optimal energy structure, by which the optimal energy structure will be achieved in the case of the minimum social cost of useful energy produced in all sectors of the economy. Does this mean that the model should include the cost of useful energy production of all sectors and industries of the economy?

If we start from the basic economic principle that it consists of the application of the planned target of an organizing system achieved with minimal investment, and if this principle is applied to create a model for optimizing energy structure, then the answer to this question is negative. The corresponding energy (output) model should, in fact, be created with a minimal investment of work and means for obtaining all relevant parameters in the (input) model, which means that we should ignore any parameter for the validity of the model that is not necessary. To find the optimal energy structure it is not necessary to introduce all the processes and costs of production of useful energy. On the contrary, only one process (with appropriate costs) should be introduced in the model, for which there is a realistic alternative options, in which, therefore, there is a possibility to choose the optimum expression, because the processes are not alternatives and their costs as do not affect the optimization of the process and its outcome. For this reason, we can formulate the following two principles for the optimal structure of the model:

1. *The principle of symmetry between the length and volume of a series of the energy costs*. The costs incurred by the consumer should be introduced in the model exactly to the extent to which energy arrays include energy processes in the consumer, i.e. the true costs should follow and complement all the processes in the energy bursts.
2. *The principle of optimal length of power series*. The energy arrays in the model should be extended only to the extent of transformation and transportation of energy, where there is a choice between alternative processes.

Because of the tight interconnectedness, both of these principles in the process of modelling the optimal energy structure must always be performed together. It follows from their use that energy arrays in the model should not be unnecessarily extended to the useful energy, if at this stage a range of energy there are no real alternative options, that is, in this case, any extension of power series in the model with unnecessary burden on the technical and economic (cost) parameters.

Also, when we determining the cost of complex economic systems, then there is always a danger that the same costs are calculated repeatedly. This is especially true for the cost of the energy bursts, in which the *output* of the previous process has as *input* to the next process. The problem to compute the total cost is essentially the same as the problem of determining the gross domestic product in the overall economy.[3]

In a complex system, which needs to be optimized, costs add up in such a way as to avoid the duplication of cost elements. For a system which comprises, for example, coal mines, power plants, heating plants and gas works, this actually means that the objective function must not impose the costs of coal consumption and power generation in thermal power plants and heating plants, or the cost of consumption of coal, electricity and thermal energy in the gasworks. In order to achieve optimization of complex systems, flows of material between the various sub-systems should not be evaluated. The latter statement is true both for consumption as raw material for transformation, and the auxiliary energy consumption in all the processes of production, transformation, transportation and distribution of energy. In the multiplicative energy balance, the processes of transport and distribution are considered as energy processes. This fact should be taken into account in the models of and a target function set in such a way that, when summing up, the cost comes to the small "doubling" of certain cost elements. According to this concept, the entire cost (in the form of specific total costs) should be calculated only for the first level of power series, i.e. for primary energy production and imports of energy, as well as the transportation and distribution of energy. For the other energy processes, it is calculated with a certain "net cost", as follows:

- for the production process of transforming energy with (specific) fixed costs of energy installations, and
- for the production processes of useful energy by the final consumer with the (specific) fixed costs of installations related to energy process, as well as with the (specific) variable costs for spent workforce (Požar, 1977, p. 31).

[3] It is known that the gross domestic product is an economic category, which measures the performance of production in a way that excludes the multiple calculations. However, there is a risk that the intermediate products are calculated at least twice, first to the manufacturer of theraw materials, intermediate products, etc., and second time by the manufacturer of the finished product. Because of determining the results of production, itrequires the calculation of intermediate production of goods that enter the manufacture of other products as raw materials.

The concept of fixed and variable costs which is applicable to the production of useful energy in the final consumer should be definitely applied to all production processes of transforming energy, because auxiliary materials and other elements of production occur in all the processes of transforming energy.

According to the invested elements of production, there are the three major groups of costs: the cost of materials, the cost of operating funds and the labour costs. On the other hand, by the dynamics of spending we distinguish between: the fixed costs, the relatively fixed costs, and proportional costs. For the purpose of modelling the structure of the energy, it is sufficient to group the costs in the following manner:

- the costs of funds for construction work and technical installations as a fixed cost,
- the labour cost and non-energy auxiliary materials[4] as variable (i.e. proportional and relatively fixed) costs.

Therefore, these two sets of costs should be provided so as to produce useful energy, and transformed energy for the production, then estimated from the available data.

Finally, it is worth noting that even in the production of primary energy, and also in the transport and distribution of energy, strictly speaking, the full (i.e. specific total) cost should not count, but only the total cost less the value of the auxiliary consumed energy in these processes. So, in cost of the coal should not include the cost of consumed electricity in the coal mine, and in cost of rail transport of coal should not enter the cost of energy used in transportation of coal, so as to avoid duplication of such costs in the target function. However, in practical modelling procedure, the elimination of these costs due to scarce data is very complex, and error greater than the error of “doubling” of costs may be introduced in the model. For this reason, a compromise between the theoretical justification and practical application of this concept should be found in exercising the net-cost concept.

Also, all other objectives are introduced in the model as a target limit. In terms of the logical unity of objectives and measures, the adopted concept of economic and environmental goals determines the range of measures that can be introduced into the model. The economic objective of minimum costs based on the concept of the cost of the protective (preventive) measures, plus the environmental objectives, are formulated as a maximum allowable emission of pollutants and waste heat. It follows that the model mainly includes safeguards to somehow influence the reduction of total emissions.

[4] In complex energy systems, the costs of “energetic material” (energy as a raw material) and auxiliary power is not introduced into the sum of the total costs.

Conclusion

The use of mathematical models and methods of optimization in defining sustainable development strategies is imposed as a modern scientific standard. These procedures are an important tool in the process of harmonization of conflicting objectives related to modern business and the environment. In this article, the authors describe the optimization procedure, as well as the main problems and conflicts between economic and environmental goals and ways to overcome them.

Starting with the most important model for planning energy structure, on one hand, and a general theoretical model of the process of pollution and protection of the environment on the other, the most important goals for the economic and environmental optimization of energy structure of the economy are formulated. There is a general applicability of this methodology, as well as the general theoretical and methodological considerations in this paper, such as, for example, a general theoretical model of pollution and protection of the environment, the discussion of the mutual relations of the economic and environmental goals, and the manner of their introduction into models of energy and economic development, establishing a logical unity between the appointed objectives and selected measures in the model and so on.

A possible practical application of the model for economic and ecological optimization of energy structure of the economy will depend on, above all, the availability of suitable input data for all the observed processes and regions (data on energy requirements, technical and economic coefficients, energy processes), among which the most important data related to the processes of pollution and protection of the environment are:

- the information on maximum permitted levels of emissions of certain pollutants and waste heat for each type of pollution and each region based on the maximum allowable imissions, as well as a transmission characteristics of each region,

- the information on the technical characteristics and the specific costs of the all protective (preventive) measures in the model,
- the information about specific programs of energy processes, and
- the data on emissions of non-energy processes in each region.

Some of these data are difficult to determine for various reasons, such as, for example the different meteorological, climatic and geographic conditions in each region. However, in the long run, each region will have to have such data in their own interest, in order to implement effective local environmental policies.

In line with global trends, the use of quantitative optimization methods in defining a sustainable development strategy in Republic of Serbia is limited. In fact, only a few studies dealing with this issue. On the other hand, the implementation of a strategy for sustainable development in Republic of Serbia is still more or less a political issue and a matter of a political consensus.

This article presents a theoretical basis for the application of multi-criteria programming for solving environmental problems. It also indicates the possibility of introducing environmental targets in models of multi-criteria analysis. So, the intention of the authors is to pay attention to the scientific approach in defining strategies and policies for sustainable development. SM

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