Model of natural resources exploitation in protected areas

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1. Introduction

The society, an element of the present civilisation characterised by urban, industrial and consumer development, pays too less attention to and has too little knowledge of basic ecological principles and rules. We used to treat the nature as an infinite resource with an endless capacity to absorb the society's waste products. Both, the environment and mankind are affected with dangerous results of toxic emissions to the air, water and soil.

Fortunately, nowadays we are learning more and more about the problems connected with the environment, the result of which is the conception of sustainable development that means social and economical development conformable to demands of environmental protection. This has become an impulse to change the way of seeing the nature. This conception is defined as an idea of dynamic production and consumption processes characterised by emissions in the limits of environment natural absorption.

In the paper there is also used a notion of protected areas that we are going to define. From the systems analysis view, protected areas and their surroundings comprise agro-forestry systems. Such systems play simultaneously few, various roles: economic (production), social (employment), environmental (environmental protection) and recreational (tourism) one. To describe economic, ecological and social (EES) systems, a multicriterial model in which risk is described by fuzzy coefficients can only be used.

The beginning of 90'ies in Poland meant the change of structural conditions for environment protection management and assumptions of ecological policy confirming. At the moment we are facing the problem of working out local and regional development plans corresponding with the European Union's demands in the domain of sustainable development. The paper is an attempt to employ models and algorithm of linear fuzzy programming in order to support self-governments' decisions dealing with local and regional development plans. This paper is an extension of results obtained by Krawiec and Markiewska – Krawiec [1].

2. The method

To realise the research we are going to use one of interactive methods of linear programming, e.g. multiobjective linear programming.

Multiobjective linear programming (MOLP) with fuzzy coefficients can be defined by the following formula:

$$\mathrm{MIN}\begin{bmatrix}\tilde{c}_1 x\\ \dots\\ \tilde{c}_k x\end{bmatrix} \tag{1}$$

$$\tilde{a}_i x \le \tilde{b}_i \qquad \text{for i = 1,..., m} \tag{2}$$

$$x \ge 0 \tag{3}$$

$\tilde{a}$

x where:

$\tilde{c}_1,\dots,\tilde{c}_k$ is n-dimension column vector of real decision variables,
are n-dimension row vectors of fuzzy coefficients in

$\tilde{z}_1,\dots,\tilde{z}_k$ objective ,
is the i-th row of fuzzy coefficient matrix,

$\tilde{b}$ is its corresponding fuzzy right-hand side.

As one can see from definition, as well in criteria as in constraints a multiplication of fuzzy numbers by real ones has appeared together with addition of fuzzy numbers. These rules defined by Zadeh's extended principle are numerical inefficient. To reduce this disadvantage, the L-R type representation is introduced (Piegat [2]).

To improve the effectiveness of operations on fuzzy numbers, each fuzzy coefficient is of L-R type, e.g. the number $\tilde{a}$ is a three of parameters (a, α, β) with the membership function:

$$\mu_{\tilde{a}}(x) = \begin{cases} L((a-x)/\alpha) \\ R((x-a)/\beta) \\ 0 \end{cases} \tag{4}$$

where:
a is the most possible value,
a and b are properly added left and right-hand dispersion of $\tilde{a}$,
L,R are symmetric corresponding functions decreasing within the interval of (0, ∞) such as: L (0) = R (0) = 1 and L (1) = R (1) = 0.

Assuming that fuzzy coefficients of criteria are defined as: $\tilde{c} = (c_l, \varepsilon_l, \kappa_l)_{LR}$ $l = 1, 2, \dots, k$, criteria for the given can be presented as fuzzy numbers $\tilde{c}_l \quad x = (c_l x, \varepsilon_l x, \kappa_l x)_{LR}$ for $l = 1, 2, \dots, k$.

To transform fuzzy criteria into conjugate determined criteria, it is proposed to decrease a kind of "distance" between fuzzy criteria and aspiration levels
$\tilde{g} = (g_i, \tau, v_l)_{LL}$, $l = 1, 2, \dots, k$. A minimisation of the distance is achieved by a maximisation of the σ($\tilde{g}_l > \tilde{c}_l x$) index which is as follows:

$$\sigma\left(\tilde{g}_l > \tilde{c}_l x\right) = L\left(\left(c_l x - g_l\right) / \left(\varepsilon_l x + v_l\right)\right) \; ; \quad l = 1, 2, \dots, k \tag{5}$$

In consequence, for the given certainty parameters, the fuzzy problem MOLP is transformed into the following determined problem:

$$\max. \begin{bmatrix} f_1(x) = L\left(\left(c_1 x - g_1\right) / \left(\varepsilon_1 x + v_1\right)\right) \\ f_2(x) = L\left(\left(c_2 x - g_2\right) / \left(\varepsilon_2 x + v_2\right)\right) \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ f_k(x) = L\left(\left(c_k x - g_k\right) / \left(\varepsilon_k + v_k\right)\right) \end{bmatrix} \tag{6}$$

regarding constraints

$$Ax \le b \tag{7}$$

$$x \ge 0 \tag{8}$$

In the paper, parameters of matrix A and of vector b are assumed to be determined. Compromising solutions are interactively searched by the use of the FLIP programme in which risk is described by fuzzy coefficients (Slowinski, Czyzak [3]). First, an initial point is fixed. Then, efficient points of the feasible set, in the number pre-fixed by a decision maker, but being multiple of a number of criteria are computed. Having criteria analysed, one the most satisfactory solution is chosen which becomes an initial point in the second step of the procedure. Solutions are presented to the decision-maker both, in a numeric and graphic way, illustrating interposition of criteria and aspiration levels, as well as, left- and right-hand sides of constraints.

Estimation of solutions quality takes into account:
• value of fuzzy criteria in relation to aspiration levels,
• dispersion of fuzzy criteria value, corresponding to uncertainty,
• certainty of solution or risk of not fulfilling constraints when making constraints fuzzy.

If the solutions quality does not correspond to at least one of the above conditions, decision-maker has a possibility to change certainty parameters, aspiration levels or fuzzy coefficients of the model. The interactive process is over when the most satisfactory efficient point is found.

The employment of the model and method (MOLP) in the sphere of natural resources exploitation has been presented on the example of one of Polish national parks surrounding.

3. Characteristic of Drawa National Park and its surrounding

3.1. The Drawa National Park and Drawno Commune

The Drawa National Park, covering the area of 7600 hectares, is one of 19 national parks of Poland. It preserves an example of typical countryside of the southern slopes of Pomeranian Lake Region. The rivers of the Park are typical lake region rivers, i.e. are characterised by large hydraulic gradients and fast midstream. The lakes of the Park have a very diversified character from the viewpoint of ecology. Well-preserved mosaic of forests and waters have caused that numerous animals, requiring such life conditions, still occur, for example otters, beavers, white-tailed eagle, osprey or kingfisher.

The main objective of Drawa National Park creation was to realise the protection of nature as a superior task but to some extent the needs of tourism are taken into account, especially the so-called exclusive tourism, for which the Park is a very attractive object. Within the Drawa National Park natural educational programmes are also realised, that is a statutory duty of national parks in Poland.

The Drawa National Park is a kernel of a larger region of relatively little deformed nature (e.g. Drawno Commune). The whole forest complex, surrounding the Park and adjacent to the protected area forest clearings of agricultural character can serve as a testing ground for new forestry management methods, as well as the region of development of pro-ecological tourism.

The city of Drawno is a seat of self-governing authorities for the town and the commune. 5800 residents inhabit the commune. Arable land covers the area of 7300hectares. No industrial activities are run in the town and the commune. Forests being a part of Drawa Great Forest cover 2/3 of the total commune area.

In 1993, a new sewage treatment plant was launched in Drawno that along with the expected completion of the town's sewage system should improve significantly the quality of water. At the same time, Drawno town and commune have the lowest emission of pollution among all the towns and communes of the region.

3.2. Forest economy

The forest economy in the state-owned forests is run in compliance with the following three main principles:

- principle of general forest protection,
- principle of maintenance of the forest durability and usage continuity,
- principle of increase of forest resources.

An essential problem in the Drawa Forest Inspectorate, that administrates on the area of 22 000 hectares, is the problem of land assigned to afforestation. There are many, agriculturally non-used grounds, left after the liquidation of the state-owned farms that are planned to be transferred to the Inspectorate for the afforestation purposes. A mean annual area of forest grounds intended for afforestation is 220 hectares in open terrain and about 50 hectares under the shield of forest stands. At the same time, an annual quota of forest clearings in the years 1997-2001 equals to 50000 cubic metres, including about 32000 cubic metres for the timber cutting use.

In the forest economy administration in the Drawno Inspectorate a significant attention is paid to the matter of forest protection, fire protection, nature protection or hunting economy.

3.3. Tourism

The Drawa River offers excellent opportunities for practising water sports. A large number of bivouac sites have been prepared in order to ensure the participants' needs for rest after successive stages of the canoe rally. Additional accommodation opportunities are provided by the riverside hostel situated in Drawno offering 170 rooms and at the campsite. There are also many villages in Drawno commune which fulfil all functions of summer resorts.

In the summer time, there are opportunities for inexpensive rest at several campsites. As a rule, they are located near rivers, lakes and forests, and they are supervised by Drawno Forest Inspectorate. All state-owned waters are accessible to the public for angling, but in the case of angling within the terrain of Drawa National Park, consent of the director of the park is required. On the terrain of forest complexes and lakes, zones of silence have been established. In the period of late summer and early autumn, there are splendid opportunities for the rest, associated with mushroom gathering. It is also possible to practice hunting. That is why 40000 tourists annually visit the Drawa National Park.

3.4. Agriculture and fishing

On the area of 7300 hectares, there is carried on an agricultural activity comprising both, animal and plant production. The first one includes milk cattle, slaughter pigs, the second one – cereals, potatoes, rape and fodder crops. The productivity of plant production is low that is a result of low fertilisation (70 kilos of NPK per 1 hectare). Ecological food is also produced, though for a small scale, on the area of about 200 hectares. Food and agricultural industry are represented in the region by a diary, meat and forest fruits processing plants. Pig breeding and diary are hazardous for the environment because part of contamination may infiltrate to the Drawa River and lakes. In the park surrounding there are 800 hectares of lakes used for fishing.

4. Model and its solutions

The linear, static model of the system has been built on the base of data characterising an especially protected area and its surrounding. Criteria functions with fuzzy coefficients are as follows:

1. income from production – max.,
2. employment – max.,
3. income from tourism –max.,
4. costs of environment pollution and wear of natural resources (water, minerals) – min.

A technical coefficients matrix (A) and constraints (b) are determined (not fuzzy).

The most important economic activities and those connected with tourism are described by the decision variables presented in table 1.

Table 1. Model solutions

Decision variables	Ideal solutions				Efficient solution
	1	2	3	4	5
1. Plant production	7320	7350	7270	7300	7290
2. Animal production [units]	1490	2700	1230	750	1620
3. Agricultural industry [tons]	1720	2420	1300	1100	1910
4. Forest acreage [hectares]	22000	22000	22000	22000	22000
5. Forest clearing [hectares]	230	300	-	-	190
6. Afforestation [hectares]	280	350	110	180	230
7. Undergrowth processing [tons]	210	240	180	-	190
8. Acreage of ecological food cultivation 210 [hectares]	320	200	240	250	
9. Fishing (lakes usable acreage) [hectares]	800	800	520	400	620
10. Summer resorts [hectares]	160	150	250	130	180
11. Tourism [number of visitors]	46200	48800	57000	29000	48200
12. Investments [thousands of PLN]	460	480	455	228	428
13. Employment [number of people]	1420	1810	1180	720	1310
1. Income from production [thousands of PLN]	10500				9180
2. Employment [number of people]		1810			1310
3. Income from tourism [thousands of PLN]			1210		1100
4. Costs of environment pollution and wear of natural resources [thousands of PLN]				620	880

Values of economic, demographic and production data refer to the year 2000. The model constraints regard to the acreage of plough – land, animal production capabilities (for example, 1 conversion unit = 1 cow = 5 pigs), acreage of forests surrounding the park, investment expenditures on production and afforestation, sale of grounds for summer resorts possibilities.

The model of the system has been optimised in two stages. In the first step, the aspiration levels g_i ($i = 1,2,3,4$) have been obtained by the separate maximisation of the first three criteria functions and minimisation of the last one. Acquired results are as follows (see table 1): $g_1 = 10500$ thousands PLN (income from production), $g_2 = 1810$ (annual number of employed), $g_3 = 1210$ thousands PLN (income from tourism), $g_4 = 620$ thousands PLN (costs of environment pollution and wear of natural resources). In the next step, aspiration levels (g_i) have been made fuzzy from 5 to 20% of their value. After repeated optimisation of the model, twelve solutions have been obtained. The efficient solution denoted by number 5, presented in table 1 is the best one because of the smallest distance between aspiration levels and obtained values of criteria. This is the solution with the smallest uncertainty of realisation, because fuzzy criteria values of the solution number 5 agree in part with fuzzy values of aspiration levels g_i. The graphic illustration of solutions for individual criteria is shown in the Fig. 1.

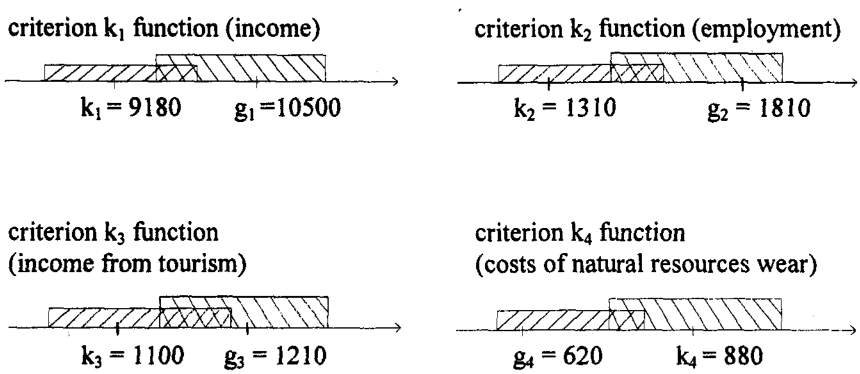

Figure 1: Graphic illustration of solutions for individual criteria

5. Conclusions

The issues presented in the paper may be divided into two types. The first one deals with methods of economic, ecological and social (EES) systems modelling. The second one is connected with application of certain methods to solve sustainable development problems.

Considering the choice of modelling methods, with no doubt only multiobjective and fuzzy models are able to render complicated character of EES systems and describe their behaviour (e.g. conflicts between criteria, uncertainty and solutions risk). To simplify, not linear and dynamic character of EES systems, occurring in reality, is ignored. Abilities of FLIP method, chosen in order to optimise the model, have been used only in part because of the model construction in which only parameters of criteria function are fuzzy. The model that has been built is only a meagre illustration of possibilities given by methods of multiobjective, fuzzy linear programming.

In Poland these methods have not been employed to solve decision problems in EES systems, up to now. At the moment, self-governments in Poland are facing the problem of working out development plans for regions and communes. These plans must take into account conditions of sustainable development before the unification of Poland with the European Union. The principles, methods and model presented in the paper together with the employed algorithm may be helpful in order to support self-governments in this domain. However, it should be mentioned that full adoption of the discussed method in practice requires testing it on models of another type, creation of data base for the needs of models building and taking into account dynamic character of economic and social spatial systems. The EES model presented in the paper should be taken as an attempt to application of linear fuzzy programming to decision supporting in regional economic policy.

References

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