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GAME-THEORETICAL RESOURCE MODEL OF BALANCED TECHNOLOGICAL DEVELOPMENT

Abstract. *This article proposes a game-theoretical resource approach to the modeling of sustainable development processes. Initial system is considered as an aggregate of various resources and participants consuming and creating these resources to meet their needs or interests. The system participants are not divided by economic, environmental and social subsystems. Their strategies or technologies are aimed at deriving income from the production and consumption of resources, which in turn serves to the participant coalition interests. The strategic and cooperative coalition game built on this basis describes the development process of the system. Its optimal strategy, which is represented by the Shapley value, provides the compromise strategy of the system balanced technological development.*
Key words: *game theory, sustainable balanced development, cooperative model, resource*

Introduction

The challenge of finding a sustainable development strategy as proposed by Agenda 21 (UN, 1992) requires, among other things, finding a compromise among all the participants of the combined social-ecological-economic system (UN, 2013).

This compromise is usually defined only in the "binary projections" of the problem thru research of social-economic, ecological-economic and other bilateral influences. However, the system is characterized by interaction of three players. And this interaction has no constructive approaches in finding the needed common compromise of the processes being practically considered. Instead, we find that the models of the mentioned subsystems are segregated; their components are estimated on the sustainability of development with different details and objectives pertaining to the original task ((Bossel, 1999, UN, 2009)).

In (Polumiienko et al., 2013), is presented a game-theoretical model of sustainable development, based on a multilevel coalition strategic game (Polumienko, 1992), the optimal situation of which provides the common strategy of sustainable development. This model is a union of submodels of the social, environmental and economic systems, but it is too bulky and counter-productive.

Nevertheless, its analysis gave another foundation for constructive finding of balanced development strategies presented below.

1. Cooperative Model of Balanced Technological Development

The vital activity of any social-ecological-economic system is based on the resources which are produced and used by its participants. At least, just this possibility for the next generations is declared by the Agenda 21 as a sustainable development.

Suppose Res(tk) is a resource vector of the initial social-ecological-economic system with the components Resm(tk) at the moment of time tk of the breakdown of the time interval [t0, T], m = 1, ..., M. Components of the vector Res(tk) are defined by a higher-level player GI, for example, by the government, which analyzes the system, works out development strategies, etc. The resource components may be described by different known indicator systems.

In contrast to conventional approaches, the system participants that are identified as lower-level players $i \in I$, are not divided by social, ecological or economic subsystems. In order to serve their needs or interests the players $i \in I$ produce and use necessary resources within their environment. Such actions of them represent their strategies $si \in Si$, $i \in I$. Here Si is the set of strategies of the player i, and these strategies are considered as having either a restorative or destructive effect on the system resources. The permissibility of the strategies is determined by the player GI, limiting or stimulating the sets of strategies Si for all $i \in I$.

The players' strategies are designed to satisfy their interests using the received payoffs and this characterizes the system development process. The initial goal of achieving sustainable development requires identification of the participants' common interest. It may be considered as the augmentation of the common resources under the condition of their balance preservation.

The players $i \in I$ within the system are considered as infinitesimal ones. That is, they cannot influence the entire system individually. To increase this influence and receive higher income, they unite in coalitions. These coalitions $c \in C$ act as the single player with a strategy sc, $sc \in Sc$, where Sc is the union of the strategies sc. So, the players may carry out strategies within different unions and receive a share of their respective payoffs.

Therefore, at the moment of time tk we have the vector sit(tk) of the coalition strategies sc, $c \in C$, which will be named as a situation $sit(tk) \in Sit(tk)$, where Sit(tk) is the set of all the situations. That is, it is the union of all possible actions of the system participants at the moment of time tk. So, the payoff or income of the coalition depends on the situation. Since all situations can vary, determination is made by taking into account the diversity of the resources. They should be represented in transferable values for the transmission between the game participants.

Suppose voll,m and prl,m are the volume and weight (or value) of the m-th resource type Resl,m(tk) in the l-th region of the country. Let us also assume that the value

$$\mathrm{rs}_{\mathrm{l,m}}(\mathrm{t}_{\mathrm{k}}) = \mathrm{vol}_{\mathrm{l,m}}\, pr_{l.m}(\mathrm{t}_{\mathrm{k}}) \,/ \sum_{l} \mathrm{vol}_{\mathrm{l,m}}(\mathrm{t}_{\mathrm{k}})\, pr_{l,m}(\mathrm{t}_{\mathrm{k}}),$$

is the relative volume of the resource m within the region l, 0≤ rsl,m(tk) ≤1. If we consider rsl,m(tk) instead of the resources Resl,m(tk), then that allows us to unify substantially different resources. For the sake of simplicity, we will not define the complete index of the region and will denote it as rsm,i(tk) and rsm,c(tk) – respectively as the share of resources rsm(tk) held by the player i∈I and the coalition c∈C, of which it is a member as,

$$\mathrm{rs}_{\mathrm{m,c}}(\mathrm{t}_{\mathrm{k}}) = \sum_{i \in c} \mathrm{rs}_{\mathrm{m,i}}(\mathrm{t}_{\mathrm{k}}) \; .$$

In carrying out the strategies, the coalitions spend some resources and consume other resources, deducting or adding certain value to their components. These actions may include savings, production means, natural resources, etc., and could be either individual or common.

In terms of their strategies, the coalitions may be matched to types of specific economic activities, intrinsic to the system. This specific classification could be made by the player GI on the basis of different systems of indicators describing the system. We suppose that coalitions c∈C and their strategies sc∈Sc are in compliance with such classification and consider the initial task as the division of resources between different types of coalitions claiming identical resources.

Thus, we have to find a situation which provides the balance between the coalitions c∈C within the identical, as well as different types of strategies. Within the same set of them to which corresponds single coalition, this situation is regulated by agreements between its participants and by the player GI - a market, social sphere and the natural environment. Within different types of strategies – this is done by finding a balanced situation for the resource components m. In this case, coalitions c∈C are interested in increasing or retaining their share of the necessary resource. As an example, this could happen with the required air or water, and then - during the allocation of the income from the created resource.

Thus, balanced development corresponds to the balance of resources, revenues of the coalitions from the use of resources by their components m, and to the dependent on the preservation of this balance achievable increase of the cumulative resources of the system.

Balanced resource status is determined by the player GI on the basis of the analysis of the resources rsm(tk) and specific features of the region. It therefore represents a heuristic evaluation, which. determines a certain initial state of the system resources, while further analysis is intended to achieve improvement of it.

Let us proceed from the initial state of the resources rsm(t0) , without determining its balanced state. Balanced state may be considered, for example, as an increase of the resources on the aggregate of all the components or for each of them individually. While for negative resources, such as waste, negative values may be used.

Suppose Arsm,c(sit(tk)) and Drsm,c(sit(tk)) - added and spent by the coalition c values of resources for the component m, m = 1, ..., M, at the moment of time tk, and

$$\mathrm{Ars_c(sit(t_k))} = \sum_{m=1}^{M} \mathrm{Ars_{m,c}(sit(t_k))},$$

$$\mathrm{Drs_c(sit(t_k))} = \sum_{m=1}^{M} \mathrm{Drs_{m,c}(sit(t_k))}, \qquad (1)$$

Arsc(sit(tk)) and Drsc(sit(tk)) - their final values. Then the value

$$rsc(sit(tk)) = Arsc(sit(tk)) - Drsc(sit(tk)) + rsc(tk\text{-}1), \qquad (2)$$

reflects the result of implementation of the strategy of the coalition c in the situation sit(tk), rsc(tk-1) is the value of rsc(sit(tk)) at the moment of time tk-1. Considering that the coalitions are all corresponded to certain types of activities, instead of the sum Arsc(sit(tk), its individual summand Arsm,c(sit(tk)) may be considered, and thus in (2) we will have this value and the sum of all the resources spent by the coalition. Proceeding from (2), let's determine a payoff function of the coalition c in the situation sit(tk) as

$$Hc(sit(tk)) = rsc(sit(tk)) - rsc(sit(tk\text{-}1)) = Arsm,c(sit(tk)) - Drsc(sit(tk)). \qquad (3)$$

For their activities, resources are also needed by the other coalitions $c \in C$, and their payoff according to (3) is the result of a certain compromise. Subject to further development, this compromise is also conditioned by the maximum possible increase of the total resources during the time interval [t0, T] –

$$\mathrm{H(sit(T))} = \sum_{t_k \in [t_0, T]} \sum_{c \in C} \mathrm{H_c(sit(t_k))}.$$

As a result, we have a coalition game

$$G = < rsm(tk), C, Sit(tk), Hc(sit(tk)), c \in C, m = 1, ..., M, tk \in [t0, T] >, \qquad (4)$$

which describes the development of the (regional) social-ecological-/economic system.

The solution of the game will be a specific situation satisfying all the coalitions, and therefore providing the balanced set of the system development strategies.

Suppose n is the number of players, I and the coalition C are its sub-aggregate. The function v, which assigns to each coalition C the highest payoff v(C) (sharing x = (x1, ..., xn)), which is surely received by it is called a characteristic function of the game (Danilov, 2002). The aggregate <I, v(C)> is thus called a cooperative game in the form of a characteristic function if:

$$xi \geq \upsilon,(i) \text{ for } i \in I \text{ and } \sum_{i \in I} x_i = v(I),$$

In contrast to the strategic game (4), where the players' actions in different coalitions are analyzed, in the cooperative game the coalition players united on the certain agreements, must act as a single player against the other players, and the result of such interaction is analyzed.

Let us determine the function

$$\mathrm{v}(\mathrm{c},\mathrm{t}_\mathrm{k}) = \max_{\mathrm{S}_\mathrm{c}(t_k)} \min_{S_{C\setminus c}(t_k)} H_c(sit(t_k)) = \max_{Sit(t_k)}\min H_c(sit(t_k)). \tag{5}$$

The following aggregate

$$GR(tk) = < rs(tk),\ C,\ Sit(tk),\ v(c,tk),\ m = 1, ..., M,\ tk \in [t0,\ T] >, \tag{6}$$

will be considered as a cooperative game with the characteristic function (5), which is built on the basis of the game (4).

The solution of this game is determined as the Shapley value (Aumann, Shapley, 1974). It describes what the coalition can achieve after completion of the game. We can define the sharing corresponding to this Shapley value as the required balance of resources during the system participants interaction. According to it the most effective will be the balanced strategies providing the maximum possible value of the available resources.

These strategies are versatile technologies used by the players and coalitions in the process of the creation and consumption of the resources. An increase in their volume most certainly leads to the improvement and growth of the region's potential.

Finding a reliably effective way of development is implemented through the strategies sGI∈SGI (managerial technologies) of the upper-level player GI. This is accomplished thru strategies of the support or limitation of the technologies used by the system participants.

Achievement of the balance and growth of the system resources also ensures the further sustainable existence of the GI itself and the entire system managed by him. The level of satisfaction with the system state, i.e. the satisfaction of the player GI interests, can be identified, for example, by the following logical functions:

$$\mathrm{G}(t_\mathrm{k}) = \sum_m P_{nc}(rs_m(t_\mathrm{k}), rs_m(t_{\mathrm{k}-1}))\alpha_m,\ \sum_m \alpha_m = 1,\ 0 \le \alpha_{lm} \le 1,\ m = 1,..,M.$$

Predicates in these amounts may be based on the values of the indicators of balanced development.

Let's name the aggregate

$$SD(tk) = < GR(tk),\ GI,\ SGI,\ G(tk),\ tk \in [t0,\ T] >, \tag{7}$$

as a game-theoretical model of balanced development.

Union of such games by regions of the country, which may be made both at the level of the players GI, and at the lower level of the game (7), will reflect the problem of its balanced development. In this case, the task of finding a balance may be assigned to a player of an even higher level which regulates the behavior of the players GI and their coalitions for the benefit of the system by establishing legislative rules and other standards. Therefore, this player (the government) will represent the interests of the country at the international level by advocating the national interests.

Conclusion

The built model constitutes the basis for the development of balanced development algorithms; however it allows to make some conclusions even now. As of today, finding the balance is in conflict with relations determined by the market; the necessity of stable economic growth of companies, ensuring improvement of the population welfare, etc. This balance involves the fostering of a conscious limitation of the volumes of consumption, accumulation, and in a word, the fair spending and allocation of resources. The need for providing the community with resources requires substitution of the accumulation interests by the priorities of creation of diversified and durable utilities of public and individual importance. None of which is a very common practice at the moment.

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