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SUSTAINABLE DEVELOPMENT MODELING FOR MUNICIPALITIES

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Abstract
The issue of sustainable development modeling for cities in emerging countries was investigated in the article. The method of evaluation that based on the usage of complete hierarchical indexing indicator structure is proposed. The drawn out model consists of five levels and unites economical, environmental and social components that include ten indices: environmental management, ecosystem stability, environmental state, innovation and human resources, competitiveness, institutional development, human potential, quality of life and social infrastructure. The model based on 84 indicators and gives the possibility for quantitative evaluation and forecast of sustainable development for municipality. The city Slavutych was taken as an example and index of sustainable development was calculated.
Keywords: Sustainable development, Quantitative evaluation, Hierarchy model, Indicator structure, Analytic hierarchy process

1. INTRODUCTION

One of the most current problems of the modern society is to achieve sustainable development as a balance that consists of quality and security of life. The traditional approach - conception of triple bottom line - is used for solving this problem on global level for countries and regions. This conception has been spread over the world for last 10 years and it found the reflection in the United Nations Global Compact (2013), Equator Principles (2013), Global Reporting Initiative (2013) and Principles for Responsible Investment (2015).

This concept includes the results of economic activity, social and environmental influences. But the achievement of sustainable development in global scale is a long-term project, that is related to control of non-homogeneous complex system with taking into account a lot of factors with nonlinear relations. Thus, probably, reaching the sustainability for municipalities is more practical and controlled. Therefore, this approach was used in building practice strategies of development for cities from International Council for Local Environmental Initiatives ICLEI (2011) association in terms of European sustainable cities.

It should be noted, that a city or a town as a complex system needs less time for changes and could be managed through the direct feedback and indicators dynamic analysis. Moreover, lack of attention to the problems of sustainable development at municipalities or the non-rational decision-making process in this field can lead to a rapid and sharp increase in disparities characteristics of the city, total destabilization and uncontrollability of the system. Nowadays there are some examples of systems and models that provide the possibility of monitoring and analysis of cities, for example (Kain, 2000), (AtKisson, 2010) and (Spiekermann & Wegener, 2003). But the differences in life quality and economic development lead to additional verification of methods and approaches for sustainable cities in different countries.

Thus, the main goal of the research is to develop the model for describing the sustainable development for municipalities in purposes of its analysis, modeling and forecasting. In accordance to the goal, several tasks were estimated: the analysis of modern methods and methodologies in sustainable development modeling, the analysis of key factors of municipalities operations, drawing out the hierarchy model of sustainable development for municipality, creating the data base for indicators, calculation of the results in dynamics and their visualization.

2. METHODOLOGY

The analysis of existence methodologies shows that the optimal way for the process of drawing out the model based on the concept of sustainable development proposed by the United Nations Organization (1987), approaches for constructing complex indicators, presented by the Organization for Economic Co-operation (2008) and Development and the data coherence methods (2014), that are used at the World Data Center for Geoinformatics and Sustainable Development (WDC Ukraine, 2013) research. Therefore, the description of a higher level of the model was provided by using triple bottom line approach in terms of city development.

The economic components of the index reflects the level of life quality of the city from the financial and managerial points of view. It is necessary to mention, that an ability of a municipal management depends on possibility of making integral evaluation of the city economy and, if it is necessary, be ready for changing management strategy through political decision and local regulation. The social component gives a possibility to estimate the conditions of municipal infrastructure, safety of life, human

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development and, moreover, it also defines the quality of life. The environmental component takes into account the comfort of living for population and human impact for the environment.

Moreover, the analysis of these components allows a decision maker to consider the problems of administrative-territorial units in terms of sustainable development. This aprroch becomes the basis for balancing social, economic and environmental aspects and leads to providing all necessary reforms in purposes for increasing quality of life for local territory, represented by municipality.

This level creates the main theoretical framework for the research, but it can not provide enough information for calculations. Therefore, the main factors and statistical indicators, that estimate the municipality activities, were analyzed for finding the way of three components description. 84 indicators were chosen for the bottom level of the model as a result of this analysis. They were united in subgroups which logically describe the different aspects of components. Such aggregation gives a possibility for additional analysis of key indicators structures and allows their usage as separate models - instruments for decision support. Thus, the environment management, ecosystem stability, environment state, potential of human development, institutional development, quality of human life, social infrastructure, economic competiveness, innovation and human resources were selected as subgroups for indicators that described the third level of hierarchy model (Figure 1).

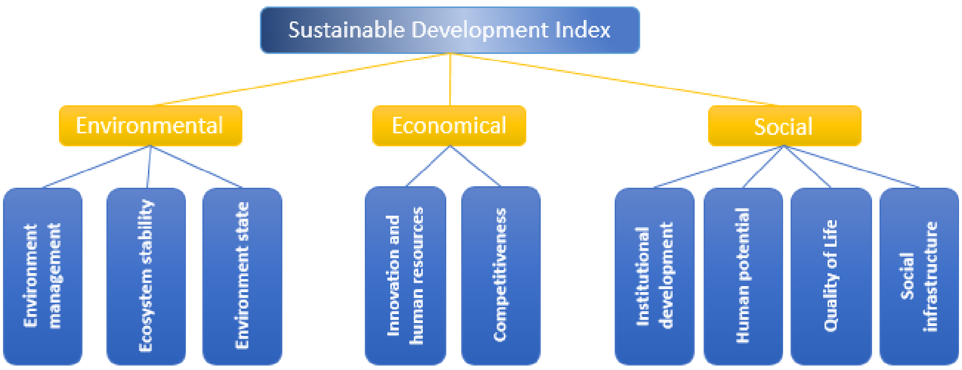

FIGURE 1 - THREE LEVELS OF HIERARCHY MODEL

This approach allows to show environmental component from three dimensions: the evaluation of current ecosystem condition, probable threats estimation and efficiency of environmental management through estimation of resources usage. The economical component is described by competitiveness and financial opportunities. And the last, the social component unites the institutional development quality of life and social threats.

The process of indicators selection was based on data limitation principles:

- Statistical data openness: the ability to access data through the official sources and municipalities' databases (through the work with city's departments).
- Indicators' comparability: only those indicators were used, that are typical for, at least most of cities in one country.
- Indicators data prospect and horizon: the estimation of data history was taken into account. In addition, the probability that the indicators will be updated and available in the future was estimated. This gives a possibility to avoid obsolescence and of the model for some period.
- Indicators relevance: indicators that effect on the development characteristics of the municipal were selected.
- Data completeness: the selected data sets must have minimum number of empties.

It is necessary to mention that the indicators' selection has three iteration. Firstly, the analysis of different researches, methodology of governmental statistics, principal component analysis (PCA) and experts' choices were provided for choosing possible pull of indicators in terms of each component. Secondly, the principles, mentioned above, were used for cutting "wrong" indicators. Thirdly, the list of indicators was given back to expert who corrected the indicator's description of each component.

The final list of indicators became the bottom part of the hierarchy model and gave a conception for structure the data base Sustainable Development Index (SDI) for municipalities.

It is necessary to underline the common issues of data processing. The logistic normalization of numerical indicator values, presented by formulas (1) – if indicator $\mathrm{k}_{i,j}$ gives a positive influence on municipality sustainable development; (2) – if it gives a negative influence, was used.

$$Norm(\mathrm{k}_{i,j}) = \left(1 + e^{\frac{a-\mathrm{k}_{i,j}}{b}}\right)^{-1} \quad (1)$$

$$Norm(\mathrm{k}_{i,j}) = 1 - \left(1 + e^{\frac{a-\mathrm{k}_{i,j}}{b}}\right)^{-1} \quad (2)$$

The parameters a and b in formulas (1) and (2) are calculated as mean value and standard deviation of data set.

The problems of data harmonization for index convolution purpose were solved by using the logistic normalization and Euclidean norm for the radius vector (3):

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$$\| \bar{I} \| = \sqrt{{I_{econ}}^2 + {I_{env}}^2 + {I_{soc}}^2} \qquad (3)$$

That means that quantitative estimation of the sustainable development for municipality defines as the projection of this normal vector on the ideal vector with coordinates $(1; 1; 1)$ that describe "ideal" values for economic, environmental and social components (4):

$$I = \sqrt{{I_{econ}}^2 + {I_{env}}^2 + {I_{soc}}^2} \cdot \cos(\alpha) \qquad (4)$$

Radius vector deflection angle α from the ideal vector is determined using $I_{econ}, I_{env}, I_{soc}$ measured indexes by the formula (5):

$$\alpha = \arccos \frac{I_{econ} + I_{env} + I_{soc}}{\sqrt{3} \cdot \sqrt{{I_{econ}}^2 + {I_{env}}^2 + {I_{soc}}^2}} \qquad (5)$$

$$0 \leq \alpha \leq \arccos \frac{1}{\sqrt{3}}$$

The estimation of the spatial position of the radius vector shows the balance of system that represent the level of sustainable development. Therefore, these three coordinates corresponds to harmonious management for all three index's components. Approximation of this vector to one of these coordinates indicates system destabilization due to the priority development of one of the components and ignoring the other two.

Hence, a decision maker can get an estimation of the balance between economic, environmental and social components using model of sustainable development for municipality.

However, it is necessary to describe the bottom level indicators integration scheme. The principle of constructing the index hierarchy structure of the sustainable development on bottom levels takes the following form (6):

$$I = \sum_{i=1}^{n} \alpha_i k_{i,j}, \; j \in \overline{1, m} \qquad \sum_{i=1}^{n} \alpha_i = 1 \qquad (6)$$

in the space of indicators $K^1 \times K^2 \times \cdots \times K^m$, , where:

α_i– weight coefficient, that estimates the influence of separate indicator of the i-th level on indicator of $(i-1)$-th of the hierarchical system.

$k_{i,j}$ – numerical indicator values.

Weight coefficients for hierarchical level were calculated using the Analytic Hierarchy Process method (AHP) (Saaty, 2008), but instead of using pairwise comparison of the criteria by the relative importance, Pearson correlation coefficient was used.

$$\omega_p = \frac{c_p}{\sum_{k=1}^{n} c_k}, \quad c_p = \left(\prod_{k=1}^{n} |a_{pk}|\right)^{1/n} \qquad (7)$$

With help of the developed method can not only calculate the index of sustainable development for the municipality and its components for the period, but also the values of sustainable development for each level of the hierarchy, which can be used for detailed analysis of the current situation in each of the fields and for construction of major developments' tendencies.

Since the high level of sustainability by itself does not indicate a stable and harmonious development of system, interesting is the analysis of the index of sustainable development in a pair with harmonization index. Harmonization index is calculated using the formula (8) and indicates the possible availability of priority development of one of components at neglecting the other two; in another words, reflects a balance between economic, environmental and social components:

$$G = 1 - \alpha \qquad (8)$$

The analysis of the internal connections' system, ie external and internal connections of each hierarchical level is very important. Analysis of hierarchical level external relations can be done by calculation the values of weight coefficients, e.g. impact of each indicator of a certain hierarchical level on a higher level in the hierarchy and on indicators' structure as a whole. Analysis of hierarchical level internal relations can be obtained as a result of construction of the correlation matrix for its indicators. Analysis of the internal connections' system can be used to find problem areas, trends of development and to construct possible strategies for municipality development.

The practical realization of this approach is provided for Slavutych (Ukrainian city - satellite of Chernobyl Nuclear Power Station (CNPS)).

City was chosen for analysis because of several reasons:

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- Officially, city refers to Kyiv region and is under the direct subordination of Kyiv, but geographically city is located of Chernihiv region.
- City is located in special economic zone "Slavutych".
- Due to the closure of Chernobyl, more than 50% of the adult population (9,000 people) worked on power plant.
- City is characterized by extremely low mortality and high fertility rates (more than a third of the population - children).
- City in terms of development level in Ukraine is one of 10 of the best, what is a significant result for the small city of regional importance.
- The city is new (about 20 years), and about 25 000 people live in it that gives an opportunity for practical implementation of the developed approach.

Taking into account the environmental problems and the future perspective of closure the township-forming enterprise that leads to the diversification in economical and social spheres, this city needs the new strategy.

Through data collecting from open sources and official statistical materials of the city plan for 2020 (Strategy plan, 2013) for the analysis of the model, some indicators have been adapted for the current municipality cause of certain environmental and economic characteristics. Restoring the fullness of some data, analysis of each indicator relevance were made. These became the basis for model adaptation.

The results for the city of Slavutych were compared with similar indicators (based on other model, but with the same scale) calculated for the Kiev region for assessing the adequacy of the developed methods (Figure 2).

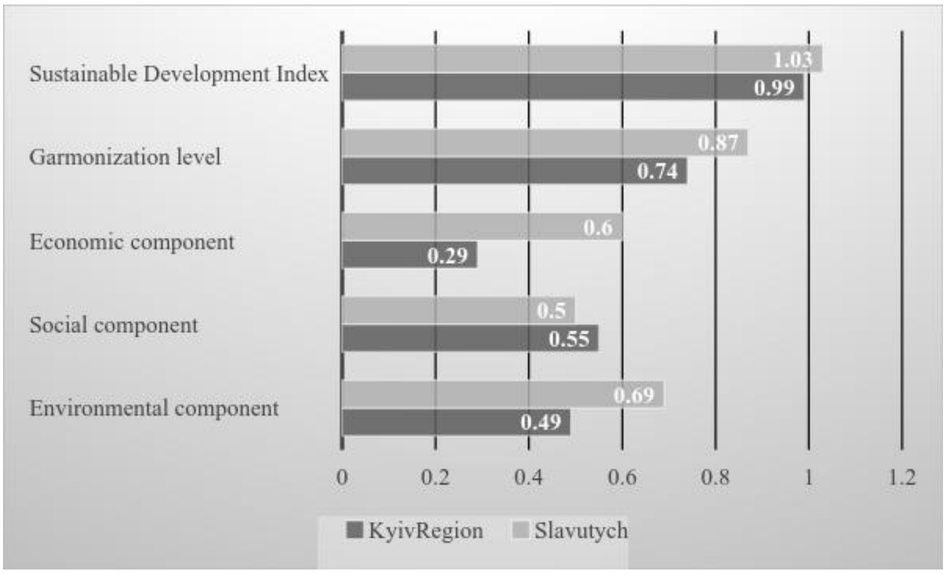

FIGURE 2 - COMPARISON THE RESULTS FOR SLAVUTYCH AND KYIV REGION.

The results affirmed compliance key indicators for sustainable municipality development with the similar indicators on the region. Some differences in the values (e.j.: economic component) can explain certain features of the selected city, such as geographic location and economic autonomy.

3. CONCLUSIONS

To sum up, the model of sustainable development for municipalities was drawn out as a part of decision-making support system for purpose of reduction the urgent problems of society. Its practice realization is the strategy for the life quality increasing (or, in current situation, at least, freezing the life quality) for municipality.

The model is based on hierarchical structure that consists of 84 indicators. The issue of indicators choice was solved with the inclusion of a selection criteria set and consideration of expert assessments. The weight coefficients received as a combination of the analytic hierarchy method and correlation analysis.

Adequacy of the developed methods was tested on the example of city-satellite of Chernobyl Nuclear Power Station - Slavutych. The choice of the city is caused due to its modern infrastructure, specific environmental and economical situation.

The results and the developed method in general can be used for the creation of city ratings and city development evaluation in dynamics in side one country or for different countries in case of the same indicator base.

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