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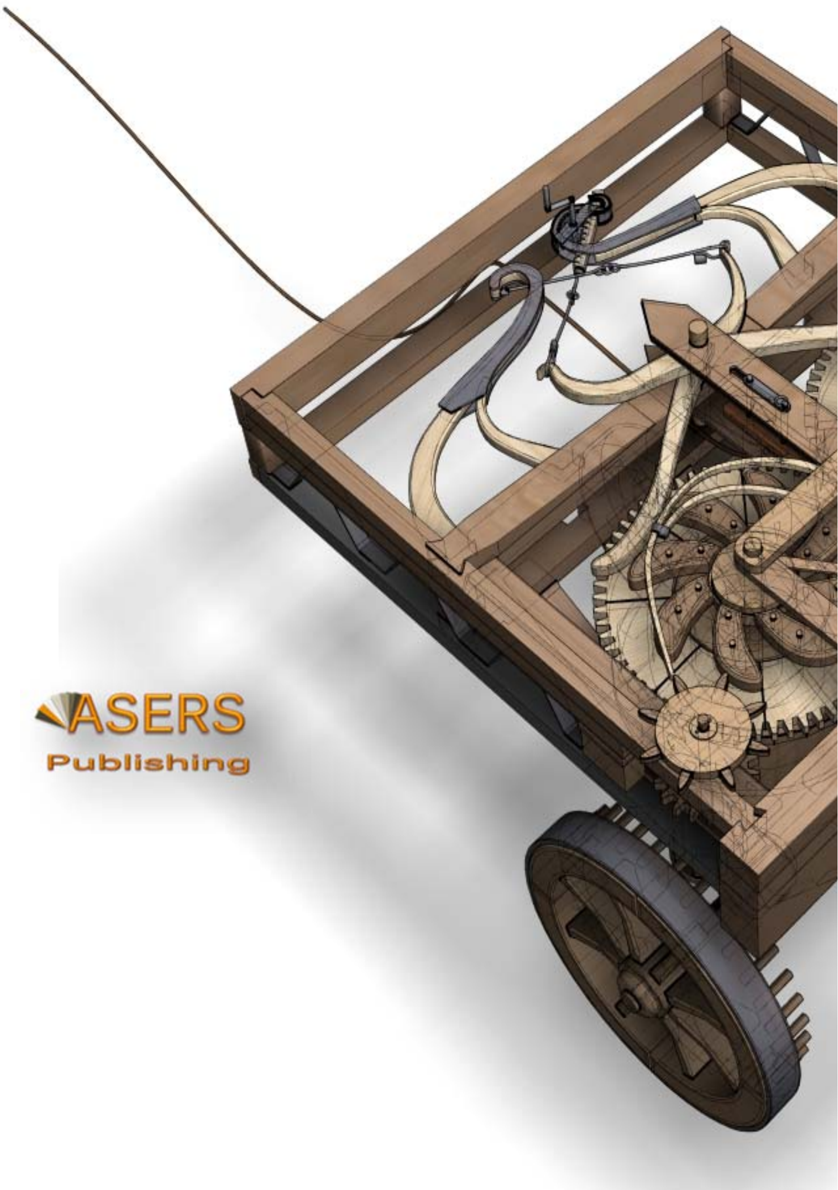

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Systemic Approach to Assessing Sustainable Development of the Regions

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Abstract

In modern conditions of the society development, there is a single direction of the development of national economies and their regions - through sustainable development. It is the consideration of the simultaneous economic, social and environmental direction of regional development that gives the greatest resultant effects of the territorial development. In turn, sustainable development requires the development of the specific evaluation methods that can give sound, accurate results of assessing the state and dynamics of sustainable development of regions. The authors propose a methodological approach that involves determining the state and dynamics of sustainable development by determining the integrated index and its components by calculating the integrated sub-indices. The method of assessing the state and dynamics of sustainable development involves the use of disparate methods, including statistical, grouping, rationing, simulation, graphical and cartographic. In addition, the use of such mathematical techniques as: correlation analysis, multiple regression, cluster and factor analysis. The approbation of this method on the example of the regions of Ukraine is carried out. In turn, the obtained calculations of the sub-indices of economic, social and environmental components and sustainable development of the regions as a whole will contribute to the development of measures to increase the level of sustainable development and achieve its goals.

Keywords: region; regional economy; sustainable development of regions; goals of sustainable development; integrated index.

JEL Classification: O10; Q56; R11.

Introduction

Modern paradigmatic aspects of the economic development of territories include the concept of sustainable development, which was initiated by the International Union for Conservation of Nature and Natural Resources in 1980 and provided by the principles developed and declared at the Earth Summit in 1992 "Rio + 20". It is these foundational events that have ensured the understanding of sustainable development as the coherence of community efforts in the social, economic and environmental spheres to ensure comprehensive, sustainable development and meet the existing needs of humanity without negatively affecting the development of future generations.

Sustainable development of regions is considered as sustainable development of regional economic systems towards achieving strategic priorities of sustainable development in the social, economic and environmental spheres by ensuring the coordination of development processes taking into consideration principles of sustainable development in line with paradigmatic global strategic directions. It is also envisaged to take into consideration the peculiarities and existing potential of the regions to improve the living standards of the population, to reduce the asymmetry of regional development and to ensure the competitiveness of the regions.

1. Literature Review

Quite a few scientists have devoted their research to the study of various issues of sustainable development of the regions, among which: Brault M.A., Guo J., Chen M., Sun X., Wang Z., Xue J. (2020); Kaldiyarov D., Kasenova A., Dyrka S., Biskupski R., Bedelbayeva A. (2021); Lindsay A.R., Sanchirico J.N., Gilliland T.E. (2021); Mabe F.N., MumuniE., Sulemana N. (2021); Mwinga K., Kipp A.M. (2020); Ngo T.T.H., Nguyen T.P.M., Duong T.H., Ly T.H. (2021); Niet T., Arianpoo N., Kuling K., Wright A.S. (2021); Shkarlet S., Ivanova N. (2020); Sugak E.V. (2021); Wu T., Lin S., Ji X. (2020); Ziglio L.A.I., Ribeiro W.C. (2019), *et al.*

Within the study of Ngo T.T.H., Nguyen T.P.M., Duong T.H. and Ly T.H. from Vietnam, the relationship between local culture and the forests of the Tai and Dao minorities and their contribution to sustainable development in Won Nhai, a mountainous region in northern Vietnam, is analyzed. Through the contribution to the conservation of natural resources, economic development and social cohesion, the potential of forest-related culture as a feature of local sustainable development was analyzed (Ngo T.T.H. *et al.* 2021).

Russian scientist Sugak E.V. claims that the analysis of the components of investment potential and investment risk in the industrial regions of Russia shows that the most critical for most of them are environmental risks. Assessment and forecasting of environmental risks is proposed to be carried out using the method and model of data extraction, which uses data from long-term observations of the environment, as well as statistics on the health of the population of these regions (Sugak E.V. 2021).

The article of D. Kaldiyarov, A. Kasenova, S. Durka, R. Biskupsky, and A. Bedelbayeva is devoted to the problem of sustainable development of rural areas as part of investment policy. The study is devoted to the analysis of investment attractiveness of rural areas of Kazakhstan and available methods of assessing the investment attractiveness of rural areas from the standpoint of their sustainable development. The authors pay attention to the method of assessing the factors that contribute to the formation of investment attractiveness of rural areas. Rural investment assessment was determined by using correlation reaction analysis, which revealed that use for potential investors (Kaldiyarov D. *et al.* 2021).

Researchers from the United States are assessing the past economic and environmental consequences of regulating agricultural capital and fisheries, with and without fisheries regulation, which prohibits the use of large vessels in coastal habitats. The authors note that while maritime policy can be a significant tool in achieving the two UN Sustainable Development Goals (poverty reduction and protection of vulnerable marine resources), their success is far from guaranteed and requires land-based and maritime socio-economic links inherent in rural areas (Lindsay A.R. *et al.* 2021).

Ukrainian scientists have determined that the developed infrastructure increases the investment attractiveness of the region, provides better accessibility of territories and reduces transaction costs. It is proved that these factors contribute to the intensity of financial, information, commodity and human flows, both internal and external, which intensify neighboring economic activities and lead to the normalization of market mechanisms in the context of sustainable development of the regions (Shkarlet S. *et al.* 2020).

A study of Mabe F.N., Mumuni E., Sulemana N. assessed whether food security in households in northern Ghana improved the awareness of small farmers of the goal of sustainable development 2. To assess the effects of the awareness of the sustainable development goal on the level of food insecurity in households the effect of the transition from regression with an ordered result (Mabe F.N. *et al.* 2021).

Based on the theory of sustainable development and environmental economic theory, the study of the Chinese scientists Wu T., Lin S., Ji X. presented the prerequisites and the idea of creating a technical model of environmental quality management, advancing the technical path, discussed the structure, elements, drivers, management scheme and management system, and management model. This study provided theoretical support for the analysis of environmental problems and existing causes and proposed measures to protect the environment to improve the capacity of environmental management and to promote regional sustainable development (Wu T. *et al.* 2020).

In their study the scientists Guo J., Chen M., Sun X., Wang Z. and Xue J. proved that industrial and technological innovation (IT) has contributed to and has become a major requirement for the Chinese sustainable development. Preliminary research of ITI systems is based mainly on static methods that separate system components and do not take into consideration feedback on adjustments. Based on systems thinking, the article develops six archetypes ("Restrictions on Growth", "Success to Success", "Public Tragedy", "Failed to Fix", "Random Opponents" and "Shift of Burden") and a system integration model (Guo J. *et al.* 2020).

Canadian researchers have concluded that the overall definition of the relationship between climate, soil, energy and water, including synergies and exchanges of health, environmental evolution and system requirements for well-being and the environment, must be expanded to effectively treat sustainable development. In most cases, the models will increase the models to consider that it is relatively simple, but open models and analysis are required to fully support the sustainable development goals (Niet T. *et al.* 2021).

Researchers from the United States and Congo have identified methodological opportunities and challenges to evaluate children's health progress that can provide insight into similar efforts during sustainable development. The authors claim it is important for countries to adapt common international objectives and dimensions to their national contexts, in view of mortal basal and health systems, developing country-specific goals (Brault M.A. *et al.* 2020).

Scientists Ziglio L.A.I. and Ribeiro W.C. have concluded that networks of non-governmental organizations on socio-environmental issues have emerged in recent decades. The study focuses on the concept of international cooperation and the Global Alliance for Recycling and Sustainable Development, a social and environmental network created by a coalition of NGOs involved in solid waste recycling (Ziglio L.A.I. *et al.* 2019).

2. Methodology

One of the most common ways to assess sustainable development of the regions is to determine indicators of the social, economic and environmental development. The authors propose to assess sustainable development using an integrated index. The purpose of this methodological approach is to determine the state and dynamics of changes in sustainable development of regional economic systems. To achieve this goal, it is necessary to substantiate the list of indicators for assessing the areas of sustainable development, which will allow on the basis of their rationing determining the integrated sub-indices of each of the components and the integrated index of sustainable development taking into account weights.

To obtain reliable results there is a need to use various methods, including:

- statistical, which makes it possible to determine statistical data for assessing sustainable development;
- grouping, to identify the social, economic and environmental components of sustainable development and their evaluation indicators;
- rationing, which is used to ration the array of statistical data, which allows to level the variations of their dimensions on the final results of calculations;
- simulation modeling, which involves identifying the impact among the indicators of each component of sustainable development on the integrated sub-index and the integrated index of sustainable development as a whole;
- graphical, which provides visualization of the results of calculations of integrated sub-indices and indices of sustainable development;
- cartographic, which allows a visual representation of the distribution of regions by the values of the integrated index of sustainable development.

Calculating the values of integral sub-indices and indices involves the use of such mathematical techniques as:

- correlation analysis, which is used to process data on statistical indicators for assessing the components of sustainable development;
- multiple regression, which reveals the impact of indicators on integrated sub-indices, as well as the impact of sub-indices on the value of the integrated index of sustainable development;

- cluster analysis, provide the separation of the system, which is a sustainable development of regions and components of sustainable development of regions;
- factor analysis, provides modeling of the main parameters of the model of sustainable development of regions.

This mathematical apparatus, namely correlation analysis, multiple regression, cluster and factor analysis allows to obtain an objective assessment of the state and dynamic changes in the components and sustainable development of the regions as a whole with a high degree of accuracy of the calculated results. In addition, it should be noted that the authors performed calculations using the software Mathcad, which makes it possible to take into account the calculation process of the error of mathematical transformations of indicators and the results of calculations of indicators of sustainable development of regions.

To assess sustainable development, the authors selected the regions of Ukraine, and calculations for the Autonomous Republic of Crimea were not conducted, as statistics are not available since 2015. The list of statistical indicators used to assess the sustainable development of regions is presented in Table 1.

Table 1. List of statistical indicators for assessing the components of sustainable development of Ukraine's regions

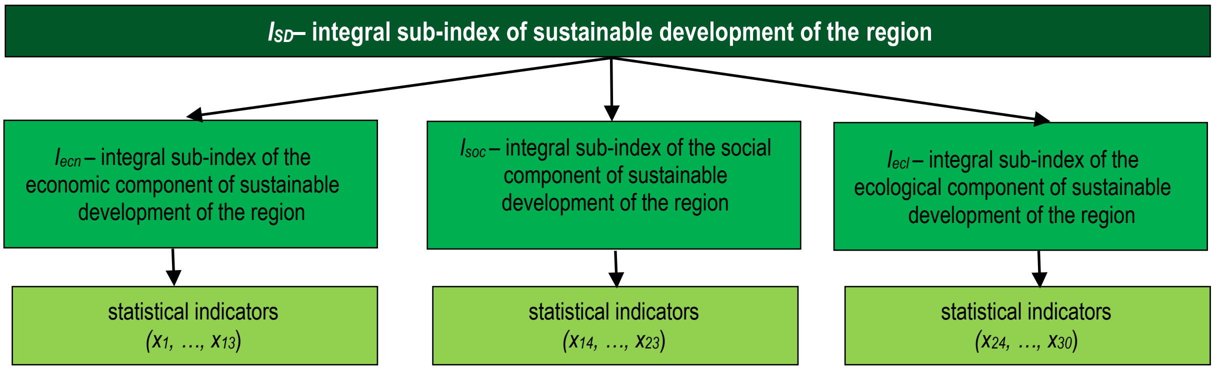
№	Indexes
	Economic development
x_1	GRP per person, UAH
x_2	Production of agricultural products per capita, at constant prices in 2010, UAH
x_3	Volume of sold industrial products (goods, services) per capita, UAH
x_4	Profitability of operating activities of enterprises, interest
x_5	Capital investments, per person, UAH
x_6	Direct investment (share capital) per capita by regions of Ukraine, USD USA
x_7	Total exports of goods, million dollars USA
x_8	Total exports of services, million dollars USA
x_9	Density of public railways, km per 1000 km² of territory
x_{10}	Density of paved public roads, km per 1000 km of territory
x_{11}	Freight turnover of road transport, million t. km
x_{12}	Passenger turnover of buses, million passes. km.
x_{13}	Departure of passengers by rail, million people
	Social development
x_{14}	Number of people engaged in economic activity, thousand people
x_{15}	Natural increase (decrease) of population, persons
x_{16}	Migratory increase (decrease) in population, thousand people
x_{17}	Disposable income per capita, UAH
x_{18}	Commissioning of housing for 1000 people, m² total area
x_{19}	Housing stock, thousand m2 of total area
x_{20}	Provision of the population with doctors of all specialties (at the end of the year), number of doctors per 10,000 population
x_{21}	Provision of the population with hospital beds (at the end of the year), number of beds per 10,000 population
x_{22}	Number of higher education institutions (at the beginning of the school year), units
x_{23}	Number of students of higher education institutions per 10,000 population (at the beginning of the academic year), persons
	Environmental development
x_{24}	Current costs for environmental protection (in actual prices), UAH million
x_{25}	Capacity of treatment facilities, million m³
x_{26}	Emissions of pollutants into the atmosphere from stationary sources of pollution, thousand tons
x_{27}	Discharge of polluted return waters into surface water bodies, million m3
x_{28}	The total amount of waste accumulated during operation in waste disposal sites of hazard class IV (at the end of the year), thousand tons
x_{29}	Waste generation per person (hazard class IV)
x_{30}	Capital investments in environmental protection, at actual prices; UAH million

Source: compiled by the authors.

The indicator presented in Table 2, was chosen by the authors based on the principle of systematization. According to this principle, indicators should be a certain logically built system that reflects the specific aspects of each component of sustainable development. These are the following components: economic, social and environmental development, which simultaneously demonstrate the features of sustainable development in each region. It should be noted that this system of indicators is quite flexible and can be changed, for example, depending on the available statistics of a particular country. Also, a broad representation of statistical indicators can be used to calculate and compare integrated sub-indices and integrated indices of sustainable development of the regions of different countries. Such a comparison will provide an opportunity to explore the features of institutional support for regional development and the implementation of positive experiences to achieve the goals of sustainable development.

In Figure 1, the construction of a qualimetric calculation of the integrated index of sustainable development of the regions (I_{SD}) and integrated sub-indices of economic (I_{ecn}), social (I_{soc}) and environmental (I_{ecl}) components of sustainable development is presented.

Figure 1. Construction of the calculation of the integrated index of sustainable development of the regions



Source: compiled by the authors.

Since statistical indicators have different units of measurement and numerical orders of value, it requires a procedure for their rationing. Rationing makes it possible to achieve a single adjacent measurement of indicators, but, at the same time, to preserve the functional influence of indicators on the values of the integrated sub-indices of the components of sustainable development.

To normalize statistical indicators, it is proposed to use the method of mathematical expectation, because this method provides the least error than, for example, bringing the indicator to the reference value for a given year in a particular region. Thus, the rationing is carried out using the formulas 2.1 and 2.2:

$$x_{ij}^{k} = \frac{x_{ijk}}{x_{icpjk}}, \qquad 2.1$$

$$X_{ij}^{k} = \left(x_{1ik}, x_{2ik} \ldots x_{jik}\right), \qquad 2.2$$

where x_{ij}^{k} is the normalized value of the j-th statistical indicator of sustainable development of the region j = 1,…, 30, which characterizes the region (i = 1,…, 25);

xi_{jk} - the natural value of the j-th statistical indicator;

hysrjk - an estimate of the mathematical expectation of the selected j-th statistical indicator, which was taken for standardization during the study period;

k - research period, years (from 2012 to 2019) (k = 1,…, 8);

Y_{ij}^{k} – matrix of statistical indicators for the study period.

Standardization of statistical indicators makes it possible to proceed directly to the calculations using the correlation method. The use of the correlation method is justified by the fact that a fairly large amount of statistical data is used for calculations, as 30 indicators were taken for 8 years in 25 regions of Ukraine. This requires removing the autocorrelation relationships between the indicators if they exist, *i.e.* |k| <0.7, which makes it impossible to obtain zero determinants of quadratic matrices used to calculate the integrated indices of the components of sustainable development.

The formula for calculating the pairwise correlation of statistical indicators for assessing the components of sustainable development is as follows (Formula 2.3):

$$k_{xg,xp} = \frac{cov(x_g, x_p)}{D[x_g^2] \cdot D[x_p^2]}, \quad (2.3)$$

where $cov(x_g, x_p)$ – covariance between samples of statistical indicators x_g, x_p;

$D[x_g^2]$, $D[x_p^2]$ – variances of normalized statistical indicators that are not equal to zero.

The matrix of normalized indicators for assessing the components of sustainable development has the form (Formula 2.4):

$$Yn = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{18} \\ x_{21} & x_{22} & \dots & x_{28} \\ \dots & \dots & \dots & \dots \\ x_{js} & x_{js} & \dots & x_{jk} \end{bmatrix}, \quad (2.4)$$

where Y_n is a matrix of standardized indicators of the components of sustainable development for a certain period (eight years, k = 8).

Calculations of integrated indices make it possible to determine the impact factors formed among the indicators for assessing the components of sustainable development, as well as among the integrated sub-indices in relation to the integrated index of sustainable development of the regions. Coefficients of influence are regression functions that determine the effect of normalized indicators on the integrated sub-index, or the effect of integrated sub-indices on the integrated index of sustainable development.

The formula for calculating the integrated sub-indices of economic (I_{ecn}), social (I_{soc}) and environmental (I_{ecl}) components of sustainable development are as follows (Formulas 2.5 – 2.7):

$$I_{ek} = K_{10} + \sum_{j=1}^{13} K_{1i} \cdot x_i, \quad (2.5)$$

$$I_s = K_{20} + \sum_{j=14}^{23} K_{2i} \cdot x_i, \quad (2.6)$$

$$I_{eco} = K_{30} + \sum_{j=24}^{30} K_{3i} \cdot x_i, \quad (2.7)$$

where the coefficients of influence are determined by the formulas 8-9:

$$K_T = \left[(Y_T^T \times Y_T)^{-1} Y_T^T \right] \cdot I_T, \quad (2.8)$$

$$K_{SR} = \left[(Y_{SR}^T \times Y_{SR})^{-1} Y_{SR}^T \right] \cdot I_{SR}, \quad (2.9)$$

where K_{10}, … , K_{30}, K_{SR0} - constant component of the coefficient of influence;

K_1, … , K_3 - weighting factor of the n-th component of sustainable development of regions;

x_i - indicators of the n-th component of sustainable development of regions (n = 3);

Y_n - matrix of partial indicators of the integral sub-index;

Y_{SR} - matrix of integral sub-indices of sustainable development;

I_n – indicator of the nth integral sub-index of sustainable development of the regions (n = 1,…, 3).

The presented model solution makes it possible to calculate the integrated sub-indices of the economic component of sustainable development of the region (I_{ecn}), the social component of sustainable development of the region (I*soc*), the environmental component of sustainable development of the region (I_{ecl}), and to calculate integrated indices. According to the values of integrated indices, it is possible to group regions for further development of mechanisms to intensify the achievement of the goals of sustainable development of the regions.

3. Case Studies

Paradigmatic vectors of the global economic development prove that the direction of simultaneous efforts on economic, social and ecological development of countries and regions is able to give the maximum positive synergy effect for the economy. The authors propose an approach to the assessment and dynamics of sustainable development of the regions, which, in contrast to existing approaches, is based on calculations of integrated sub-indices of economic, social and environmental components of sustainable development taking into account weights using such mathematical apparatus as correlation analysis, multiple regression, cluster, factor analysis and provides an opportunity to obtain objective results of sustainable development of the regions.

4. Results

The proposed model solution makes it possible to calculate the integrated sub-indices of the components of sustainable development and the integrated index of sustainable development of the regions on the example of Ukraine. In Table 2, the results of calculations of the integrated sub-index of the economic component of sustainable development of the regions of Ukraine are presented.

Table 2. Calculated values of the integrated sub-index of the economic component of sustainable development of the Ukraine's regions (I_{ecn}), 2012-2019

Regions	I_{ecn}								$I_{ecn\ avg}$
	2012	2013	2014	2015	2016	2017	2018	2019	The average, 2012-2019
Vinnytsia	0,211	0.221	0.235	0.255	0.281	0.242	0.297	0.316	0.257
Volyn	0.067	0.069	0.071	0.069	0.084	0.070	0.090	0.100	0.078
Dnipropetrovsk	0.289	0.328	0.324	0.258	0.256	0.307	0.286	0.331	0.297
Donetsk	0.053	0.063	0.069	0.055	0.055	0.047	0.038	0.014	0.049
Zhytomyr	0.091	0.101	0.110	0.109	0.113	0.111	0.131	0.143	0.114
Transcarpathian	0.073	0.075	0.076	0.081	0.086	0.077	0.092	0.096	0.082
Zaporizhzhia	0.261	0.263	0.268	0.281	0.287	0.272	0.309	0.327	0.284
Ivano-Frankivsk	0.150	0.160	0.167	0.179	0.191	0.174	0.196	0.205	0.178
Kyiv	0.766	0.859	0.926	0.713	0.759	0.845	0.913	0.979	0.845
Kirovograd	0.150	0.122	0.144	0.163	0.139	0.347	0.163	0.149	0.172
Luhansk	0.037	0.040	0.037	0.031	0.026	0.034	0.022	0.019	0.040
Lviv	0.163	0.177	0.184	0.202	0.208	0.194	0.222	0.239	0.199
Mykolaiv	0.088	0.090	0.093	0.099	0.104	0.097	0.111	0.121	0.100
Odesa	0.151	0.164	0.171	0.111	0.164	0.172	0.206	0.209	0.168
Poltava	0.205	0.228	0.238	0.254	0.262	0.247	0.266	0.268	0.247
Rivne	0.082	0.096	0.124	0.115	0.112	0.129	0.080	0.052	0.099
Sumy	0.080	0.091	0.095	0.096	0.099	0.095	0.101	0.102	0.095
Ternopil	0.070	0.073	0.084	0.082	0.101	0.091	0.109	0.111	0.090
Kharkiv	0.284	0.324	0.324	0.259	0.250	0.312	0.278	0.319	0.294
Kherson	0.063	0.068	0.071	0.078	0.082	0.073	0.087	0.092	0.077
Khmelnytsky	0.223	0.255	0.270	0.296	0.299	0.286	0.310	0.316	0.282
Cherkasy	0.072	0.082	0.086	0.086	0.089	0.086	0.091	0.092	0.086
Chernivtsi	0.139	0.144	0.155	0.165	0.166	0.156	0.173	0.160	0.157
Chernihiv	0.178	0.193	0.202	0.226	0.238	0.209	0.248	0.283	0.222
Kyiv city	0.616	0.669	0.698	0.628	0.442	0.704	0.840	0.980	0.697
The arithmetic mean value of the integral sub-index for all regions ($I_{ecn\ avg}$)	0.182	0.198	0.210	0.196	0.196	0.216	0.227	0.241	0.208

Source: calculated by the authors.

The presented calculations of the integrated sub-index of the economic component of sustainable development of the regions of Ukraine allow us to note that in general the arithmetic mean value of the integrated sub-index until 2015 had a positive trend, which in 2015 changed to the opposite, primarily due to military conflict in Eastern Ukraine and the annexation of part of the territory of Ukraine, namely the Autonomous Republic of Crimea. Since 2017, there have been positive changes in the values of the integrated sub-index by its arithmetic mean value for all regions. In 2019, the value reached 0.241, which is higher than the average value of the integrated sub-index of the economic component of sustainable development for 2012-2019 in all regions, which is 0.208.

It should be noted that in Ukraine there is a fairly high differentiation in the value of the integrated sub-index of the economic component. Thus, in Kyiv the average integrated sub-index for 2012-2019 is 0.697, which is 9 times more than in Volyn region (0.078) and 17.4 times more than in Luhansk region, with the value of sub-index 0.040.

Table 3 presents the calculations of the integrated sub-index of the social component of sustainable development of the regions of Ukraine, which were carried out by the authors according to the proposed approach.

Table 3. The values of the integrated sub-index of the social component of sustainable development of the Ukraine's regions (I_{soc}), 2012-2019

Regions	I_{soc}								$I_{soc\ avg}$
	2012	2013	2014	2015	2016	2017	2018	2019	The average, 2012-2019
Vinnytsia	0.177	0.158	0.166	0.162	0.152	0.158	0.192	0.231	0.175
Volyn	0.118	0.098	0.141	0.105	0.089	0.098	0.115	0.124	0.111
Dnipropetrovsk	0.201	0.162	0.134	0.116	0.109	0.134	0.188	0.352	0.174
Donetsk	0.071	0.074	0.085	0.066	0.069	0.065	0.055	0.061	0.068
Zhytomyr	0.109	0.124	0.114	0.105	0.094	0.120	0.107	0.114	0.111
Transcarpathian	0.069	0.069	0.067	0.067	0.069	0.065	0.063	0.061	0.066
Zaporizhzhia	0.201	0.203	0.209	0.213	0.215	0.220	0.218	0.220	0.212
Ivano-Frankivsk	0.217	0.203	0.151	0.137	0.131	0.147	0.207	0.226	0.276
Kyiv	0.304	0.096	0.307	0.259	0.410	0.202	0.169	0.300	0.257
Kirovograd	0.144	0.148	0.171	0.162	0.366	0.157	0.140	0.159	0.181
Luhansk	0.052	0.058	0.059	0.043	0.045	0.034	0.031	0.041	0.045
Lviv	0.106	0.112	0.119	0.129	0.149	0.162	0.174	0.194	0.166
Mykolaiv	0.088	0.089	0.092	0.094	0.095	0.097	0.096	0.097	0.094
Odesa	0.205	0.213	0.213	0.205	0.191	0.184	0.197	0.220	0.204
Poltava	0.142	0.099	0.118	0.157	0.206	0.205	0.139	0.096	0.146
Rivne	0.083	0.096	0.093	0.087	0.076	0.077	0.081	0.091	0.086
Sumy	0.066	0.068	0.072	0.073	0.067	0.065	0.066	0.077	0.069
Ternopil	0.084	0.085	0.088	0.090	0.090	0.092	0.091	0.092	0.089
Kharkiv	0.233	0.230	0.219	0.226	0.228	0.219	0.242	0.247	0.231
Kherson	0.072	0.076	0.079	0.080	0.070	0.068	0.071	0.076	0.074
Khmelnytsky	0.217	0.219	0.226	0.229	0.215	0.201	0.219	0.238	0.221
Cherkasy	0.055	0.057	0.060	0.060	0.056	0.054	0.055	0.055	0.057
Chernivtsi	0.173	0.172	0.204	0.193	0.160	0.170	0.189	0.202	0.183
Chernihiv	0.241	0.268	0.250	0.231	0.208	0.201	0.236	0.288	0.238
Kyiv city	0.155	0.157	0.161	0.165	0.166	0.170	0.168	0.170	0.164
The arithmetic mean value of the integral sub-index for all regions ($I_{soc\ avg}$)	0.143	0.133	0.144	0.138	0.149	0.135	0.140	0.161	0.143

Source: calculated by the authors.

The results of calculations, given in Table 4, show that only in the last of the studied years in 2019 there was a significant increase in the arithmetic mean of the integral sub-index of the social component of sustainable development to 0.161, which is greater than the average value for all years. At the same time, there is a slightly different dynamics of change in the integrated sub-index of the social component of sustainable development over the years than the economic component. In addition, there is almost three times less asymmetry in the value of the average integral sub-index of the social component than the economic component of sustainable development. The difference between Ivano-Frankivsk region, which has the value of the integral sub-index 0.276, and Luhansk region, with the value of the sub-index 0.045, is 6 times.

In Table 4, the authors present the results of calculations of the integrated sub-index of the environmental component of sustainable development of the regions of Ukraine.

The data presented in Table 5 show that in 2012-2016 there was a decrease in the value of the arithmetic mean integrated sub-index of the environmental component of sustainable development, which in 2017 changed to positive dynamics and in 2018-2019 the value of the sub-index was higher than its average value. The difference in the values of the integral sub-index between Kyiv region 0.537 and Luhansk region 0.024 is 17.3 times.

Table 4. The values of the integrated sub-index of the ecological component of sustainable development of the Ukraine's regions (I_{ecl}), 2012-2019

Regions	I_{ecl}								$I_{ecl\ avg}$
	2012	2013	2014	2015	2016	2017	2018	2019	The average, 2012-2019
Vinnytsia	0.206	0.206	0.191	0.188	0.182	0.194	0.215	0.242	0.203
Volyn	0.086	0.076	0.060	0.051	0.048	0.052	0.056	0.066	0.062
Dnipropetrovsk	0.248	0.270	0.252	0.248	0.263	0.245	0.259	0.267	0.256
Donetsk	0.043	0.050	0.030	0.023	0.029	0.022	0.024	0.028	0.031
Zhytomyr	0.092	0.089	0.087	0.082	0.081	0.082	0.083	0.082	0.085
Transcarpathian	0.058	0.063	0.062	0.050	0.042	0.052	0.060	0.062	0.056
Zaporizhzhia	0.166	0.180	0.183	0.186	0.194	0.203	0.217	0.220	0.194
Ivano-Frankivsk	0.294	0.245	0.210	0.217	0.245	0.262	0.266	0.273	0.251
Kyiv	0.596	0.542	0.472	0.464	0.464	0.504	0.588	0.658	0.537
Kirovograd	0.243	0.224	0.217	0.205	0.196	0.186	0.189	0.196	0.207
Luhansk	0.024	0.041	0.030	0.028	0.023	0.013	0.013	0.023	0.024
Lviv	0.191	0.203	0.194	0.212	0.209	0.188	0.215	0.224	0.208
Mykolaiv	0.082	0.080	0.074	0.072	0.077	0.085	0.087	0.082	0.080
Odesa	0.215	0.207	0.192	0.178	0.175	0.183	0.212	0.264	0.203
Poltava	0.252	0.220	0.214	0.211	0.202	0.184	0.178	0.187	0.206
Rivne	0.073	0.082	0.092	0.099	0.084	0.083	0.073	0.067	0.082
Sumy	0.084	0.083	0.074	0.067	0.063	0.072	0.074	0.077	0.074
Ternopil	0.071	0.065	0.057	0.048	0.042	0.053	0.066	0.067	0.058
Kharkiv	0.183	0.227	0.247	0.221	0.183	0.160	0.172	0.204	0.257
Kherson	0.047	0.050	0.051	0.052	0.050	0.050	0.051	0.052	0.050
Khmelnytsky	0.251	0.195	0.174	0.161	0.148	0.171	0.206	0.220	0.191
Cherkasy	0.072	0.067	0.069	0.076	0.070	0.075	0.076	0.058	0.070
Chernivtsi	0.208	0.244	0.205	0.178	0.172	0.223	0.211	0.196	0.205
Chernihiv	0.131	0.149	0.159	0.154	0.143	0.122	0.125	0.143	0.141
Kyiv city	0.079	0.100	0.128	0.134	0.146	0.167	0.183	0.198	0.142
The arithmetic mean value of the integral sub-index for all regions ($I_{ecl\ avg}$)	0.160	0.158	0.149	0.144	0.141	0.145	0.156	0.166	0.155

Source: calculated by the authors.

In Table 5, the results of calculations of the values of the integrated index of sustainable development are presented. The overall significant growth of the integrated index of sustainable development has been observed only in the last two years, which show the values of the arithmetic mean values of the integrated index, which are greater than the average value of 0.311. The regions of Ukraine with the highest value of the integrated index of sustainable development include Kyiv region (0.834), Kyiv (0.706) and Dnipropetrovsk region (0.601). The regions with the lowest values of the integrated index include Transcarpathia (0.141), Donetsk (0.120) and Luhansk (0.086) regions. According to the value of the integrated index of sustainable development between Kyiv region and Luhansk, the difference is 9.7 times. Only two regions of Ukraine during the study period showed an increase in the value of the integrated index of sustainable development, the Zaporizhzhia region from 0.465 to 0.576, *i.e.* an increase of 1.2 times and Lviv region from 0.249 to 0.347, *i.e.* 1.4 times. However, we can note that in all other regions there are fluctuations in the values of the integrated index of sustainable development, and a constant decline in values was not found in any of the regions of Ukraine, which can be assessed as a positive dynamic of achieving sustainable development goals in the country as a whole.

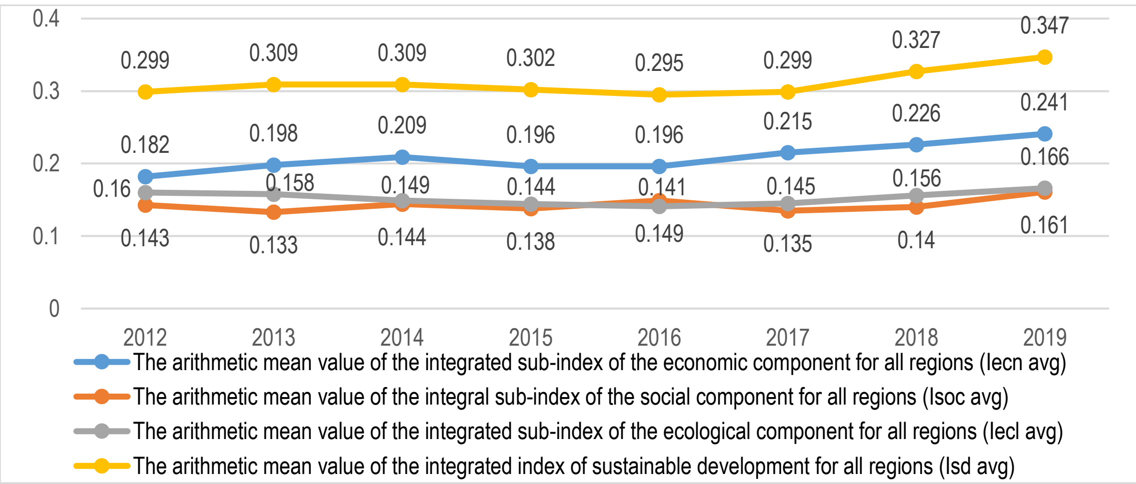
Table 5. The values of the integrated index of sustainable development of the Ukraine's regions (I_{SD}), 2012-2019

Regions	I_{SD}								$I_{SD\ avg}$
	2012	2013	2014	2015	2016	2017	2018	2019	The average, 2012-2019
Vinnytsia	0.450	0.444	0.441	0.437	0.453	0.422	0.537	0.454	0.450
Volyn	0.216	0.201	0.188	0.170	0.163	0.175	0.185	0.202	0.188
Dnipropetrovsk	0.630	0.608	0.572	0.560	0.538	0.544	0.606	0.752	0.601
Donetsk	0.128	0.146	0.143	0.138	0.134	0.108	0.093	0.066	0.120
Zhytomyr	0.215	0.225	0.226	0.219	0.213	0.225	0.237	0.248	0.226
Transcarpathian	0.136	0.141	0.141	0.134	0.134	0.141	0.149	0.152	0.141
Zaporizhzhia	0.465	0.477	0.484	0.491	0.506	0.520	0.553	0.576	0.509
Ivano-Frankivsk	0.248	0.243	0.213	0.205	0.204	0.217	0.256	0.270	0.232
Kyiv	0.867	0.823	0.815	0.771	0.755	0.773	0.886	0.981	0.834
Kirovograd	0.252	0.248	0.246	0.242	0.239	0.237	0.238	0.240	0.243
Luhansk	0.088	0.113	0.108	0.081	0.083	0.061	0.062	0.089	0.086
Lviv	0.249	0.260	0.263	0.282	0.299	0.303	0.325	0.347	0.291
Mykolaiv	0.197	0.199	0.203	0.208	0.211	0.209	0.223	0.229	0.210
Odesa	0.268	0.271	0.267	0.257	0.233	0.248	0.278	0.313	0.267
Poltava	0.310	0.301	0.307	0.319	0.336	0.337	0.319	0.301	0.316
Rivne	0.186	0.209	0.235	0.233	0.215	0.213	0.183	0.159	0.204
Sumy	0.179	0.203	0.203	0.195	0.184	0.200	0.209	0.217	0.199
Ternopil	0.160	0.159	0.166	0.168	0.164	0.184	0.193	0.197	0.174
Kharkiv	0.522	0.585	0.598	0.570	0.502	0.473	0.511	0.568	0.542
Kherson	0.152	0.156	0.163	0.166	0.160	0.163	0.172	0.183	0.164
Khmelnytsky	0.337	0.367	0.345	0.348	0.348	0.388	0.440	0.493	0.383
Cherkasy	0.185	0.197	0.206	0.206	0.197	0.190	0.197	0.197	0.197
Chernivtsi	0.246	0.254	0.260	0.246	0.224	0.245	0.251	0.255	0.248
Chernihiv	0.225	0.242	0.241	0.235	0.228	0.221	0.234	0.261	0.236
Kyiv city	0.576	0.643	0.679	0.661	0.645	0.687	0.833	0.920	0.706
*The arithmetic mean value of the integral subindex for all regions (**$I_{SD\ avg}$**)*	0.299	0.309	0.309	0.302	0.295	0.299	0.327	0.347	0.311

Source: calculated by the authors.

In Figure 2, the dynamics of integrated sub-indices of economic, social and environmental components and sustainable development in general are presented.

Figure 2. Dynamics of arithmetic mean integrated indices and sub-indices of sustainable development components, 2012-2019

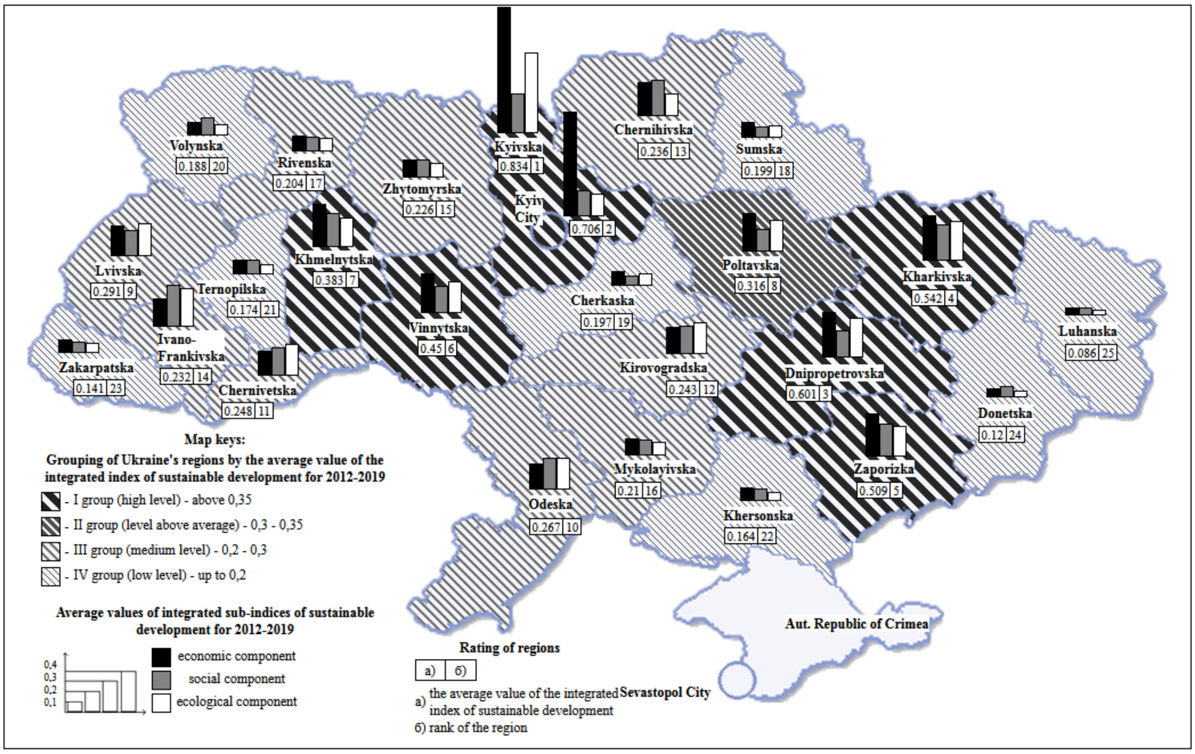


Source: constructed by the authors based on the results of calculations.

The dynamics of arithmetic mean integrated sub-indices of sustainable development illustrates that their values do not have a common absolutely identical dynamics, but, at the same time, it has no fundamental differences. All integral sub-indices and the index of sustainable development, as well as its arithmetic mean value illustrate the positive dynamics over the last two years.

In Figure 3, a cartographic analysis of the results of calculations on the obtained arithmetic mean value of the integrated index of sustainable development and its components is presented.

Figure 3. Grouping of regions by the arithmetic mean value of the integrated index of sustainable development, 2012-2019



Source: constructed by the authors

The regions that are leaders in the values of the integrated index of sustainable development include five regions and Kyiv, namely: Kyiv region (0.834), Kyiv (0.706), Dnipropetrovsk (0.601), Kharkiv (0.542), Zaporizhzhia (0.509) and Khmelnytsky (0.383) regions. The regions that according to the values of the integrated index of sustainable development belong to the second group with an almost high level of sustainable development include only one region, namely Poltava region (0.316). The most numerous is the third group of regions with an average level of sustainable development according to the calculated integrated index, this group includes nine regions: Lviv (0.291), Odesa (0.267), Chernivtsi (0.248), Kirovograd (0.243), Chernihiv (0.236), Ivano-Frankivsk (0.232), Zhytomyr (0.226), Mykolaiv (0.210), Rivne (0.204) regions.

The regions with a low level of sustainable development include eight regions, including: Sumy (0.199), Cherkasy (0.197), Ternopil (0.174), Kherson (0.164), Transcarpathian (0.141), Volyn (0.188), Donetsk (0.120), Luhansk (0.086) area.

Thus, this distribution as a whole does not illustrate the positive results, as only seven regions have high and above average levels of sustainable development according to the integrated index, and most regions, namely seventeen, which is almost 70% of the total are middle and middle regions, low level of sustainable development.

Conclusion

The methodological approach proposed by the authors involves the study of the state and dynamics of sustainable development by determining the integrated index and its components by calculating the integrated indicators. This method involves the use of such mathematical techniques as: correlation analysis, multiple regression, cluster and factor analysis. Researchers tested this method on the example of the regions of Ukraine.

According to the results of the study, the following conclusions were reached:

- firstly, different regions of leaders and outsiders observe different integral sub-indices of the components of sustainable development;

- secondly, the dynamic changes in the time of sub-indices are different, but, at the same time, there are no fundamental differences in the dynamics;
- thirdly, all values of integrated sub-indices are differentiated between regions, the value of the integrated sub-index of the economic component is 17.4 times between Kyiv and Luhansk region, the value of the social component sub-index is 6 times between Ivano-Frankivsk and Luhansk regions, and 17.3 times between Kyiv and Luhansk region, and according to the general integrated indicator of sustainable development 9.7 times between Kyiv and Luhansk regions.

The calculated values of the integrated indices make it possible to divide the regions into groups according to the level of sustainable development. This division in further research will provide an opportunity to develop measures to improve the economic, social and environmental components of sustainable development, which will act as a further search for authors.

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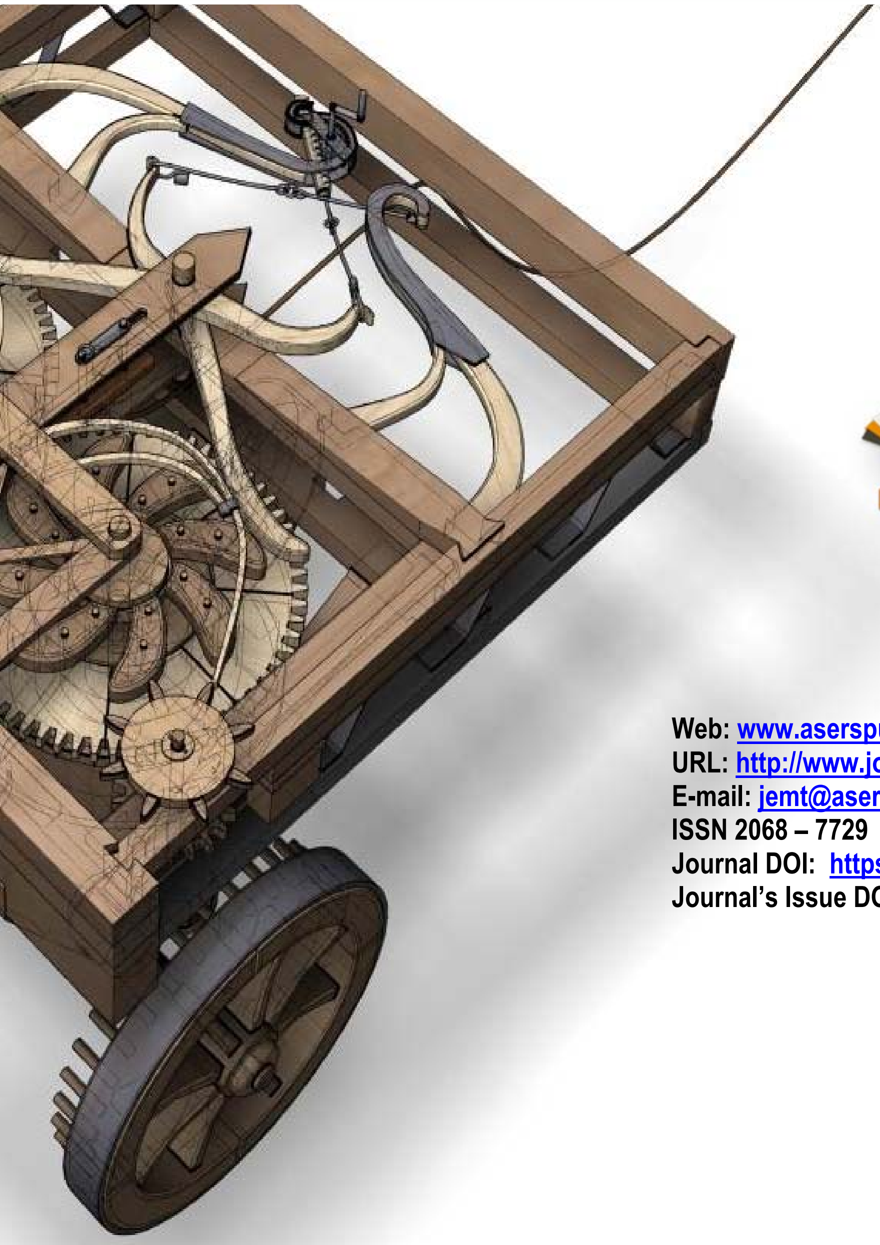

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