УДК 504.052

THE NEW METRICS OF SUSTAINABLE DEVELOPMENT AND ITS APPLICATION

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The concept which unites the three main components (economic, ecological and social) of sustainable development of society is considered. A new sustainable development measuring system is proposed. These metrics makes it possible to obtain quantitative estimations of the sustainable development process depending on the groups of economic, ecological and social indicators and datasets. The influence of the information society on sustainable development is studied on a global and a regional scales on the basis the sustainable development mathematical model.

The problem which forms the subject of this study is based on the concept of sustainable development. This concept has become a continuation of the theory of **noosphere** formulated by the Russian academician Vladimir Vernadsky (1922) and French mathematician Edward Le Roy (1927). The **noosphere** may be seen as the "sphere of human thought» derived from the Greek word ("nous") meaning "mind" in the same manner as the terms "atmosphere" and "biosphere". In the original theory of Vernadsky, the noosphere is the third in a succession of phases of the Earth evolution, after the geosphere (inanimate matter) and the biosphere (biological life) [1]. So, the noosphere is the modern stage of the development of biosphere connected with the emergence of the human being as an active factor that is beginning to greatly influence the further geological evolution of the planet.

The theory and practice testify, that at the turn of the centuries V. Vernadsky's doctrine about the noosphere proved to be the necessary platform for development of the triune concept of sustainable ecological, social and economic development. The generalization of this concept was made at the world summits of the United Nations in 1992 and 2002, with the participation of more than 100 countries of the world, many international organizations and scientists. Thus, the new concept has united three main components of sustainable development of the society: economic, ecological and social.

The economic approach consists in an optimum use of limited resources and application of material and energy saving technologies for the creation of a stream of the cumulative income, which would provide at least preservation (not reduc-

[1] The author is grateful to students of the Institute for Applied System Analysis Dmitry Prilutsky and Boris Jakovlev for the executed computer simulation.

tion) of the cumulative capital (physical, natural or human) used for the creation of this cumulative income.

At the same time transition to the information society results in a change of the cumulative capital structure in favor of human, non-material streams of the finance, information and the intellectual property. By now these streams exceed seven times the volumes of the material goods moving [ru.wikipedia.org.en]. Development of new, «weightless» economy (economy of knowledge) is stimulated not only by the deficiency of natural resources, but also by the growth of volumes of the information, and knowledge is getting a new value.

From the point of view of ecology, the sustainable development should provide integrity of biological and physical natural systems, their viability. The global stability of biosphere depends on it. Special significance is attached to the ability of such systems to self recrudesce and adaptation to various changes, instead of being preserved in a certain static condition or degrading and losing biological variety.

Social component is oriented to human development, preservation of stability of public and cultural systems, reduction of quantity of conflicts in the society. The human being should become not an object, but the subject of development. He or she should take part in the formation of their own lives, making and realization of decisions, exercising control over their implementation. In providing these conditions an important part belongs to the pluralism of opinions and tolerance in relations between people, preservation of the cultural capital and its variety, fairly distribution of the benefits between people (reduction of a so-called GINI-index).

The system coordination of these three components is a problem of huge complexity. In particular, the interrelation of social and ecological components results in the necessity of preservation of the identical rights of the today and future generations to the use of natural resources. Interaction of social and economic components demands the achievement of validity in distribution of material benefits between people and granting targeted help to poor layers of the society. And at last, the interrelation of nature protection and economic components demands cost estimation of technologies influences on the environment. The solution of these problems is the main challenge of today for the national governments, the authoritative international organizations and all progressive people of the world.

1. SUSTAINABLE DEVELOPMENT METRICS

The important problem on the way of embodiment of the sustainable development concept is formation of measures (indices and indicators) for quantitative and qualitative estimation of this very complicated process. The main requirements to the specified measures (metrics) are their information “completeness” and the adequacy of representation of the interconnected triad of the sustainable development components. Now in this direction well-known international organizations and numerous scientists are working, but the unequivocal coordination of these measures has not been achieved yet.

Let us represent the metrics of sustainable development which were suggested by the Institute for Applied System Analysis of the National Academy of Science of Ukraine.

The essence of the concept of sustainable development (fig. 1) is system coordination of economic, ecological and human development in such a way that the quality and safety of life should not decrease from one generation to another. The environmental conditions should not worsen and the social progress should meet the needs of every person.

To meet this concept it is necessary to introduce some measurement systems (metrics) of the sustainable development.

The sustainable development measurement has been done by the introduction of the corresponding index (I_{sd}) (fig. 1).

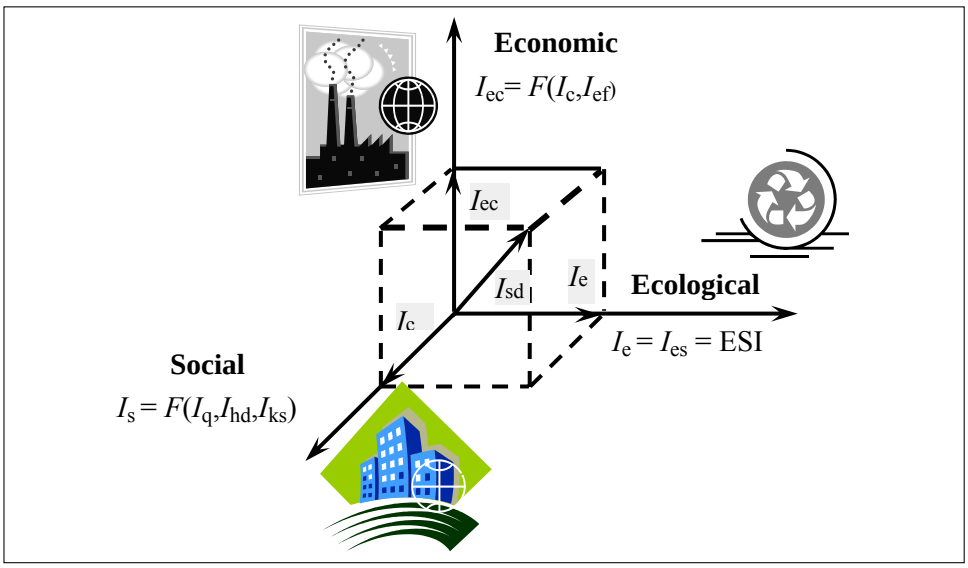

Fig. 1. Global dimensions of sustainable development

This index is determined by three dimensions: economic (I_{ec}), ecological (I_e) and social (I_s). In its turn, each of the indices (I_{ec}), (I_e), (I_s) is calculated by six global indices widely used in the international practice (table 1).

Table 1. The set of global indices

Measure of sustainable development	Global index	Constituents (49 indicators, 188 datasets)	Source
Economic (I_{ec})	I_c — Growth competitiveness index	3 indicators, 47 sets of data	World Economic Forum [www.weforum.org]
	I_{ef} — Economic freedom index	10 indicators, 50 sets of data	Heritage Foundation [www.heritage.org]
Ecological (I_e)	I_{es} — Environmental Sustainability Index	21 indicators, 76 sets of data	Yale University, USA [www.yale.edu/esi]
Social (I_s)	I_q — Quality-of-life index	9 indicators	Economist Intelligence Unit [www.en.wikipedia.org]
	I_{hd} — Human development index	3 indicators	United Nation Development program [www.hdr.undp.org]
	I_{ks} — Knowledge society index	3 indicators, 15 sets of data	UNDESA, [UN, NE.04.C.1.2005]

An index of economic dimension (I_{ec}) shall be generated from two global indices:

Growth Competitiveness Index (further — an index of competitiveness — I_c), which was developed by the organizers of World Economic Forum. This index is annually defined for 117 economies of the world and published in the form of so-called «the Global Competitiveness Report». We use this report for 2005-2006 [2]. The index of competitiveness is formed of such three indicators: *the indicator of technological development of a country; the indicator of civil institutes and the indicator of the macroeconomic environment.* In their turn, these three indicators are calculated on the basis of 47 data sets regarding the conditions of technologies transfer and innovational development of a country, level of development of information and communication technologies, level of outlay for researches and development, level of foreign investments, level of business independence from the government, level of corruption in a country, and others.

Economic Freedom Index (I_{ef}), developed by the intellectual centre of Heritage Foundation [3]. It is annually printed in the Wall Street Journal. The *Economic Freedom Index* is formed of the following ten indicators: trade policy of country, fiscal load on the part of government, governmental intervention in economy, monetary policy, streams of capitals and foreign investments, bank and financial activity, policy of formation of the prices and payment, rights to private property, policy of regulation, informal activity of the market. These ten indicators are received, using 50 sets of economic, financial, legislative and administrative data.

Index of ecological dimension (I_e) shall be evaluated on the basis of well known *Environmental Sustainability Index (ESI)* designed by the Centre of ecological legislation and policy of Yale University (USA) for 146 countries of the world [4]. ESI is generated from 21 ecological indicators which, in their turn, are defined by use of 76 sets of ecological data, level of environmental pollution in the past and present, efforts of country in the management of ecological conditions, the ability of a country to improve ecological characteristics and other.

ESI quantitatively defines the ability of this or that country to protect the environment both in current period of time, and in long-term prospect, proceeding from five criteria: availability of national ecological system; ability to counteract ecological influences; reduction of people's dependence on ecological influences; social capabilities of a country to meet ecological challenges; the possibility to exercise the global control over ecological condition of a country. Also this index can be used as a powerful tool for decision-making at an analytical level with allowance for social and economic measurements of sustainable development of a country.

An index of social dimension (I_s) shall be generated by averaging of three global indexes:

Quality of Life Index (I_q), developed by the international organization Economist Intelligence Unit [5]. This index is formed with the help of the following nine indicators: gross national product per capita by the parity of purchasing capacity; average life expectancy of the population of country; rating of political stability and safety of a country; quantity of the divorced families per 1000 popu-

lation; level of public activity (activity of trade unions, public organizations and so on); distinctions on geographical breadth between warmer and colder regions of country; rate of unemployment in country; level of political and civil freedom in a country; a ratio of an average salary of men and women.

Human Development Index (I_{hd}) which is used by the United Nations Development Program [6]. It is formed on the basis of the following three indicators: average life expectancy of the population of a country; level of education; the standard of life of the population of a country which is measured by gross national product per capita by the parity of purchasing capacity.

Index of Knowledge Societies, or K — societies (I_{ks}), developed by department of the United Nations on economic and social affairs — UNDESA [7]. This index is defined by three basic indicators: the assets indicator; advancement indicator and foresightedness indicator, which, in turn, are formed with the help of 15 data sets on level of involvement of the youth in education and information, investment climate in a country, level of corruption, inequality of distribution of material and social benefits (GINI-index), level of children's death rate, etc.

As seen from table 1, the sustainable development index (I_{sd}) is defined in terms of 49 indicators and 188 data sets. On the basis of compositions of different indicators and data sets for these three dimensions, the mathematical model as a system of linear algebraic equations (fig. 2) was developed for calculation of the sustainable development index (I_{sd}).

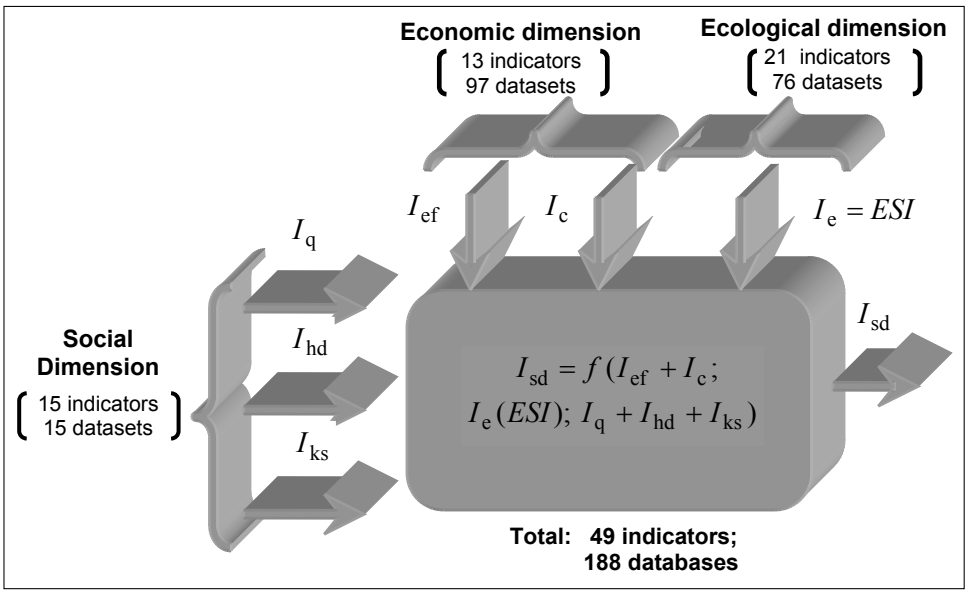

Fig. 2. Mathematical model for calculation of sustainable development index (Model 1)

All data, indicators and indices which are included in the model (fig. 2) are measured in different units and have various interpretations. That is why they are reduced to the normal form in such a way that their changes and the changes of the indices themselves were in the range from 0 to 1. In this case the lowest values of the above indicators will correspond to the numerical values close to 0, and the highest — will approximate these values to 1. Such normalization allows calculate each of the indices I_{ec}, I_e, I_s and I_{sd} in the form of an averaged sum of

its constituents with the corresponding weighting coefficients. In their turn, the weighting coefficients in the calculation formula of the sustainable development index (I_{sd}) are chosen in such a way that allows provide the same weights of economic, ecological and social measures in this index.

As a result, according to the mathematical model, the sustainable development index (I_{sd}) is calculated for 48 countries (table 2) by using the introduced measures, global indices, corresponding indicators and datasets (fig. 2).

Table 2. The sustainable development index for top 48 countries

Ranking	Country	GGP per capita by the parity of purchasing capacity (thous. dol. USA)	Index of sustainable development	Index of the economic measure	Index of the ecological measure	Index of the social measure
1	Finland	29,650	0,786	0,567	0,751	0,802
2	Iceland	41,804	0,780	0,561	0,708	0,839
3	Sweden	30,590	0,774	0,538	0,717	0,84
4	Norway	39,590	0,755	0,488	0,734	0,829
5	Switzerland	33,580	0,738	0,538	0,637	0,82
6	Luxemburg	69,737	0,738	0,558	0,618	0,816
7	Denmark	32,490	0,731	0,563	0,582	0,828
8	Canada	34,150	0,720	0,525	0,644	0,777
9	Ireland	36,790	0,716	0,559	0,592	0,779
10	Australia	31,010	0,716	0,532	0,61	0,792
11	New Zealand	25,110	0,713	0,526	0,61	0,79
12	Austria	31,420	0,708	0,504	0,627	0,785
13	USA	41,529	0,695	0,562	0,53	0,779
14	Germany	28,250	0,687	0,51	0,57	0,777
15	Netherlands	30,920	0,684	0,524	0,537	0,787
16	Japan	30,750	0,680	0,48	0,573	0,793
17	England	31,150	0,674	0,543	0,502	0,773
18	Estonia	14,800	0,662	0,533	0,582	0,658
19	Uruguay	8,869	0,647	0,382	0,718	0,659
20	Chile	12,120	0,642	0,511	0,536	0,678
21	France	30,640	0,641	0,438	0,552	0,754
22	Spain	25,370	0,626	0,455	0,488	0,758
23	Israel	21,310	0,623	0,454	0,509	0,725
24	Latvia	11,862	0,618	0,42	0,604	0,649
25	Belgium	30,660	0,615	0,468	0,444	0,755
26	Italy	27,960	0,613	0,411	0,501	0,759
27	Kosta Rika	9,000	0,607	0,372	0,596	0,685
28	Czech Republic	17,600	0,602	0,459	0,466	0,703
29	Slovakia	15,513	0,601	0,428	0,528	0,673
30	Hungary	16,047	0,601	0,424	0,52	0,686
31	Croatia	11,870	0,596	0,367	0,595	0,661
32	Korea	23,360	0,591	0,444	0,43	0,729
33	Malaysia	10,450	0,590	0,413	0,54	0,643

34	Greece	22,340	0,586	0,392	0,501	0,703
35	Panama	6,760	0,583	0,363	0,577	0,646
36	Brazil	8,760	0,581	0,347	0,622	0,61
37	Columbia	7,330	0,565	0,35	0,589	0,597
38	Poland	12,825	0,559	0,401	0,45	0,667
39	Bulgaria	8,664	0,549	0,365	0,5	0,628
40	Mexico	10,000	0,546	0,373	0,462	0,649
41	Tunis	7,910	0,544	0,37	0,518	0,586
42	Bolivia	3,680	0,542	0,322	0,595	0,556
43	Romania	6,105	0,519	0,34	0,462	0,616
44	Russia	9,81	0,515	0,319	0,561	0,52
45	Moldova	2,280	0,506	0,33	0,512	0,529
46	Trinidad	11,720	0,500	0,391	0,363	0,599
47	Ukraine	6,500	0,485	0,319	0,447	0,554
48	Egypt	3,930	0,484	0,337	0,44	0,535

2. APPLICATION THE METRICS FOR ESTIMATION OF INFORMATION SOCIETY IMPACT ON THE SUSTAINABLE DEVELOPMENT

One of the major components in the model of sustainable development is the group of indicators and the data sets describing the concept of the information society [8]. In terms of the main criterion: "No decrease of quality and safety of human life" the question arises — how does the level of the information society development, as one of the products of human activities, influence sustainable development on the global and regional scale?

We carry out research of the sustainable development index dependence on this component.

Proceeding from the analysis of the mathematical model (fig. 2) we see that 48 indicators and 188 datasets are used to calculate the sustainable development index. 14 indicators and datasets directly characterize the content of the information society (table 3).

They are included into the index of knowledge society (l_{ks}) and the growth competitiveness index (l_{c}). Taking into account the weighting coefficients of the above indicators and datasets in the indices (l_{ks}) and (l_{c}) the impact of the information society on sustainable development will be estimated by the formula [9]:

$$\text{Impact} \quad = F_{\text{is}} \left(Q_{\text{ks}} I_{\text{ks}} \; + \; Q_{\text{c}} I_{\text{c}} \right) .$$

After transformation we have:

$$\text{Impact} = 5{,}37 \frac{I_{\text{c}}}{I_{\text{sd}}} + 6{,}6 \frac{I_{\text{is}}}{I_{\text{sd}}},$$

where F_{is} is an impact factor of the information society on sustainable development; Q_{ks}, Q_{c} are summarized weighting coefficients of indicators and datasets which characterize the information society and are included in the indices (l_{ks}) and (l_{c}), respectively.

Table 3. The set of indicators and datasets which characterize the information society

№	Description	Weighting coefficients
	A. Index of the knowledge society (I_{ks})	
1	Years of schooling	0,066
2	Young population	0,066
3	Newspapers per 1000 pop.	0,066
4	Internet users per 10000 pop.	0,066
5	Main Phone Lines per 100 pop.	0,066
6	Cell Phones per 100 pop.	0,066
7	R&D Expenditure (% of GDP)	0,066
8	Pupils per teacher	0,066
9	Gini Index	0,066
		Q_{ks}=0,60
	B. Growth Competetiveness Index (I_c)	
10	Cell Phones per 100 pop.	0,050
11	Internet users per 10000 pop.	0,050
12	Internet hosts per 10000 pop.	0,050
13	Main Phone Lines per 100 pop.	0,050
14	Personal Computers per 100 pop.	0,050
		Q_c=0,25

To determine the dependence of the sustainable development index (I_{sd}) on the impact factor of the information society (F_{is}) *in the global context* the calculations were made by using the model of sustainable development (fig. 2) and the system of estimating the impact factor (F_{is}) of the information society on sustainable development (fig. 3).

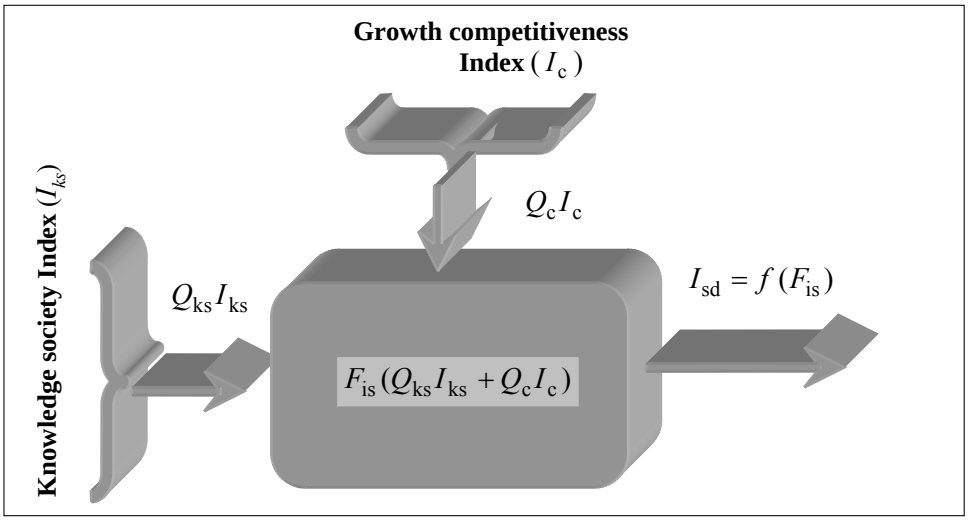

Fig. 3. Estimation of the information society impact on sustainable development (Model 2)

The ranking of 46 countries by the impact factor of the information society on sustainable development is given in table 4.

Table 4. The ranking of countries by the impact of information society on sustainable development

Ranking	Country	Index of sust. development (I_{sd})	Index of economic dimension (I_{ec})	Index of ecological dimension (I_{e})	Index of social dimension (I_{s})	Impact of IS on sust. develop-ment, %
1	Denmark	0,731	0,563	0,582	0,828	11,046
2	Japan	0,680	0,480	0,573	0,793	10,847
3	Great Britain	0,674	0,543	0,502	0,773	10,808
4	Germany	0,687	0,510	0,570	0,777	10,682
5	Israel	0,623	0,454	0,509	0,725	10,664
6	Netherlands	0,684	0,524	0,537	0,787	10,614
7	Belgium	0,615	0,468	0,444	0,755	10,606
8	Sweden	0,774	0,538	0,717	0,840	10,545
9	USA	0,695	0,562	0,530	0,779	10,496
10	France	0,641	0,438	0,552	0,754	10,343
11	Switzerland	0,737	0,538	0,637	0,820	10,298
12	Iceland	0,780	0,561	0,708	0,839	10,289
13	New Zealand	0,713	0,526	0,610	0,790	10,247
14	Austria	0,708	0,504	0,627	0,785	10,213
15	Czech Republic	0,602	0,459	0,466	0,703	10,210
16	Spain	0,626	0,455	0,488	0,758	10,149
17	Norway	0,755	0,488	0,734	0,829	10,128
18	Finland	0,786	0,567	0,751	0,802	9,968
19	Poland	0,559	0,401	0,450	0,667	9,892
20	Hungary	0,601	0,424	0,520	0,686	9,879
21	Luxemburg	0,735	0,557	0,618	0,815	9,833
22	Tunis	0,544	0,370	0,518	0,586	9,820
23	Italy	0,612	0,411	0,501	0,759	9,763
24	Malaysia	0,589	0,413	0,540	0,643	9,741
25	Slovakia	0,602	0,428	0,528	0,673	9,698
26	Australia	0,716	0,532	0,610	0,792	9,692
27	Canada	0,721	0,525	0,644	0,777	9,502
28	Romania	0,519	0,340	0,462	0,616	8,781
29	Egypt	0,482	0,337	0,440	0,528	9,399
30	Mexico	0,545	0,373	0,462	0,649	9,394
31	Costa Rika	0,606	0,372	0,596	0,685	9,348
32	Greece	0,586	0,392	0,501	0,703	9,340
33	Estonia	0,662	0,533	0,582	0,658	9,296
34	Bulgaria	0,549	0,365	0,500	0,628	9,288
35	Chile	0,642	0,511	0,536	0,678	9,272
36	Latvia	0,618	0,420	0,604	0,649	9,183
37	Croatia	0,596	0,367	0,595	0,661	9,031
38	Moldova	0,506	0,330	0,512	0,529	8,996
39	Ukraine	0,486	0,319	0,447	0,554	8,996
40	Trinidad	0,500	0,391	0,363	0,599	8,955
41	Panama	0,583	0,363	0,577	0,646	8,928

42	Ireland	0,717	0,559	0,592	0,779	8,784
43	Russia	0,515	0,319	0,561	0,520	8,618
44	Uruguay	0,648	0,382	0,718	0,659	8,358
45	Columbia	0,566	0,350	0,589	0,597	8,189
46	Brazil	0,581	0,347	0,622	0,610	7,850

In regional aspect such dependencies were revealed for a group of the leading countries in accordance with the sustainable development index (these countries were referred to as SMART societies, table 5).

Table 5. Ranking of Smart countries by the impact of information society on sustainable development

Ranking	Country	Index of sustainable development (I_{sd})	Index of economic dimension (I_{ec})	Index of ecological dimension (I_{e})	Index of social dimension (I_{s})	Impact of IS on sustainable development, %
1	Denmark	0,731	0,563	0,582	0,828	11,046
2	Sweden	0,774	0,538	0,717	0,840	10,545
4	Switzerland	0,737	0,538	0,637	0,820	10,298
3	Iceland	0,780	0,561	0,708	0,839	10,289
5	Norway	0,755	0,488	0,734	0,829	10,128
7	Finland	0,786	0,567	0,751	0,802	9,968
6	Luxemburg	0,735	0,557	0,618	0,815	9,833
8	Australia	0,716	0,532	0,610	0,792	9,692
9	Canada	0,721	0,525	0,644	0,777	9,502
10	Ireland	0,717	0,559	0,592	0,779	8,784

Table 6. Ranking of G8 countries by the impact of information society on sustainable development

Ranking	Country	Index of sustainable development (I_{sd})	Index of economic dimension (I_{ec})	Index of ecological dimension (I_{e})	Index of social dimension (I_{s})	Impact of IS on sustainable development, %
1	Japan	0,680	0,480	0,573	0,793	10,847
2	Great Britain	0,674	0,543	0,502	0,773	10,808
3	Germany	0,687	0,510	0,570	0,777	10,682
4	USA	0,695	0,562	0,530	0,779	10,496
5	France	0,641	0,438	0,552	0,754	10,343
6	Italy	0,612	0,411	0,501	0,759	9,763
7	Canada	0,721	0,525	0,644	0,777	9,502
8	Russia	0,515	0,319	0,561	0,520	6,360

For G8 countries these dependences are given in table 6 and for the group of the former socialist countries — in table 7.

Table 7. Ranking of the former socialist countries by the impact of information society on sustainable development

Ranking	Country	Index of sustainable development (I_{sd})	Index of economic dimension (I_{ec})	Index of ecological dimension (I_{e})	Index of social dimension (I_{s})	Impact of IS on sustainable development, %
1	Czech Republic	0,602	0,459	0,466	0,703	10,210
2	Poland	0,559	0,401	0,450	0,667	9,892
3	Slovak Republic	0,602	0,428	0,528	0,673	9,698
5	Estonia	0,662	0,533	0,582	0,658	9,296
6	Bulgaria	0,549	0,365	0,500	0,628	9,288
7	Latvia	0,618	0,420	0,604	0,649	9,183
8	Croatia	0,596	0,367	0,595	0,661	9,031
9	Moldova	0,506	0,330	0,512	0,529	8,996
10	Ukraine	0,486	0,319	0,447	0,554	8,996

Thus, the developed mathematical models or metrics allow carry out various researches with the purpose of revealing a measure of influence of different factors on sustainable development.

In table 8, for example, the average values of the impact factor Fis for all 46 countries, and for groups of G8, Smart countries, and the former socialist countries are presented. We see that the influence of the information society on sustainable development is the most essential for G8. For Smart countries this influence is somewhat weaker, while for the former socialist countries it is even less.

Table 8. Average impact values and correlation characteristics

Groups of countries	Average Impact, %	Correlation between F_{is} and I_{sd}	Correlation between Corruption Perception and I_{sd}
1	2	3	4
46 countries	9,711	0,87	0,916
G8	10,132	0,783	0,833
Smart countries	10,008	0,737	0,707
Post Sov. Countries	9,409	0,985	0,904

The correlation between the impact factor F_{is} and the sustainable development index I_{sd} was calculated by the formula:

$$Kxy = \frac{\sum_i x_i\, y_i}{\sqrt{\sum_i x_i^2 \sum_i y_i^2}}.$$

This correlation is the greatest for the former socialist countries. For G8 members and for Smart countries it is lower. The former socialist countries, on the other hand, demonstrate the highest development rates of the information society despite its current low positions, unlike the G8 members and other Smart

countries. Besides the character of the development of the information society in the former socialist countries mostly corresponds to the character of sustainable development.

The correlation of the corruption perception index and the index of sustainable development is presented in column 4 of table 8, for comparison. We see that this correlation is the highest for the former socialist countries, while being at a lower level for G8 and at much lower level for Smart countries, respectively.

3. CONCLUSIONS

1. The new sustainable development measuring system (metric) was worked out. This metric allows obtain quantitative estimations of the sustainable development process depending on the groups of economic, ecological and social indicators and datasets.

2. The impact of the information society on sustainable development was studied on the global and regional scale based on the sustainable development mathematical model.

3. The created tool allows develop some recommendations regarding the ways of improving the standards of life quality and safety in particular countries and regions of the world by the advance of the information society and competitive growth parameters.

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Received 14.11.2006

From the Editorial Board: the article corresponds completely to submitted manuscript.