Ranking the EU Countries Based on Indicators of Sustainable Development

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Abstract

Some synthetic measures of sustainable development (SD) for European Union (EU) countries are investigated. Rankings of EU countries are performed and compared. An "expert" method of ranking objects as projected on a "bad-good" axis is analyzed and compared with method based on Euclidean distances from hypothetical "best" point in multidimensional indicators' space. Conclusions with regard to SD level of individual countries are drawn and some suggestions about adequacy of certain SD indicators are made.

Keywords	***JEL code***
Sustainable development, SD indicators, ranking, ranks correlation, multiple criteria	*Q01*

INTRODUCTION

Growing consciousness of dangers, that degradation of our environment is connected with, as well as growing ethical level of political discourse, has brought a still growing interest in the subject of sustainable development (SD). Sustainable development, according to the definition of World Commission on Environment and Development (WCED), better known as the Brundtland Commission, is such a development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This definition covers the quality of life of contemporary people as well as preservation of natural capital to enable future generations to benefit the same level of well-being. The European Union Sustainable Development Strategy is based on a seven key challenges: climate change and clean energy; sustainable transport; sustainable consumption and production; conservation and management of natural resources; public health; social inclusion, demography and migration; global poverty and sustainable development challenges (Council of the European Union, 2006).

There exists a plenty of sets of sustainable development indicators (see e.g. Bell, Morse, 2008), to that extent, that all attempts to establish a "proper" one has been called "the sustainability indicator industry" (King et al., 2000). Here, we will choose indicators used by European Council to monitor progresses in the implementation of the EU Sustainable Development Strategy (EU, 2011).

Although there are controversies regarding relevance of aggregation of indicators (see e.g. Ebert, Welsh, 2004), there are still many attempts to construct one synthetic measure of sustainable develop-

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ment level, based on various sets of indicators (Hak, Moldan, Dahl, 2007). Many of these indices are weighted averages of individual indicators (e.g. Esty et al., 2005, Van de Kerk, Manuel, 2008), however, there are also more advanced approaches, e.g. based on fuzzy logic (Phillis, Grigoroudis, Kouikoglou, 2011) or principal component analysis (Hosseini, Kaneko, 2011).

In this paper we rank European Union countries according to the level of their sustainable development, taking indicators proposed by European Council and using a few different methods. We take values for 2007 year for the purpose of further extending analysis to variables not available yet for later periods. We compare rankings obtained by different methods. It appears, that according to all used methods Sweden is the top country, while Poland is one of four worst countries. Czech Republic ranks from 17th to 22nd (in a group of 27 countries).

We investigate here also applicability of an "expert" method of ranking objects. This method can be used in the situation, when one cannot be sure, which variables are favorable and which are unfavorable ones, while can be pretty sure, which object (here: country) has overall "good" characteristics and which one "bad" characteristics. To this end we compare results obtained by this method with results obtained by ranking countries according to the distance from the hypothetical ideal point in indicators' space.

This paper is organized as follows. In the following section indicators taken into account will be introduced and their values for EU countries for year 2007 will be given. The next four sections will demonstrate a few different methods of ranking countries. In section 6 these methods will be compared and some conclusions will be given. The last section will contain summary of the paper.

1 INDICATORS OF SUSTAINABLE DEVELOPMENT

According to European Council, there are more than 100 sustainable development indicators, eleven of which "have been identified as headline indicators. They are intended to give an overall picture of whether the European Union has achieved progress towards sustainable development in terms of the objectives and targets defined in the strategy" (Eurostat, 2012). From ten theme-groups seven have one headline indicator, two – two headline indicators, while one has no such an indicator. Thus there are in sum eleven headline indicators. These groups and headline indicators are presented in the Table 1 below. In the third column the symbols of indicators, that will be used in what follows, are placed and in the fourth column there are units, in which data is presented in official reports.

Table 1 Theme-groups and headline indicators of sustainable development

Theme	Headline indicator	Symbol of indicator	Units
Socio-economic development	Growth rate of real GDP per capita	SDI1	%
Sustainable consumption and production	Resource productivity	SDI2	EUR / kg
Social inclusion	People at-risk-of-poverty or social exclusion	SDI3	%
Demographic changes	Employment rate of older workers	SDI4	%
Public health	Healthy life years and life expectancy at birth, by gender	SDI5	years
Climate change and energy	Greenhouse gas emissions	SDI6	%
	Share of renewable energy in gross final energy consumption	SDI7	%
Sustainable transport	Energy consumption of transport relative to GDP	SDI8	%
Natural resources	Common bird index		%
	Fish catches taken from stocks outside safe biological limits: Status of fish stocks managed by the EU in the North-East Atlantic		%
Global partnership	Official development assistance as share of gross national income	SDI9	%
Good governance	No headline indicator		

Source: EUROSTAT (http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/indicators)

In what follows we will deal with indicators SDI1-9 for 27 countries of EU based on the data for year 2007, omitting common bird index and status of fish stocks, as there is no data available for them. For interpretation simplicity we will change percentages to decimal fractions and transform SDI3, SDI6, SDI8 by: (to turn unfavorable features into favorable ones). In what follows the notion will denote the value of indicator for country . The values of indicators will be rescaled to range from 0 to 1. From amongst a few possibilities, we have chosen the following procedure of rescaling that will be applied:

$$x_i^k = \frac{\tilde{x}_i^k - \tilde{x}_i^{\min}}{\tilde{x}_i^{\max} - \tilde{x}_i^{\min}}, \tag{1}$$

where $\tilde{x}_i^{\min} = \min\{\tilde{x}_i^k\}$ and $\tilde{x}_i^{\max} = \max\{\tilde{x}_i^k\}$.

Rescaled and transformed data is presented in Table 2.

Table 2 Values of normalized sustainable development indicators for year 2007

	SDI1	SDI2	SDI3	SDI4	SDI5	SDI6	SDI7	SDI8	SDI9
Austria	0.26	0.30	0.94	0.24	0.80	0.54	0.60	0.31	0.51
Belgium	0.15	0.32	0.84	0.14	0.73	0.68	0.06	1.00	0.43
Bulgaria	0.64	0.00	0.00	0.34	0.02	0.87	0.20	0.58	0.00
Cyprus	0.29	0.12	0.76	0.66	0.69	0.00	0.07	0.97	0.07
Czech Republic	0.49	0.07	0.96	0.42	0.45	0.79	0.16	0.30	0.06
Denmark	0.05	0.26	0.94	0.73	0.49	0.64	0.41	0.47	0.86
Estonia	0.65	0.03	0.83	0.76	0.28	0.94	0.38	1.00	0.02
Finland	0.42	0.16	0.93	0.64	0.80	0.54	0.65	0.80	0.38
France	0.11	0.40	0.89	0.23	1.00	0.66	0.23	0.95	0.37
Germany	0.21	0.38	0.86	0.55	0.75	0.77	0.20	0.99	0.36
Greece	0.32	0.20	0.69	0.33	0.64	0.42	0.18	0.85	0.13
Hungary	0.02	0.11	0.67	0.11	0.16	0.77	0.13	0.31	0.02
Ireland	0.24	0.12	0.80	0.61	0.67	0.45	0.07	0.67	0.56
Italy	0.00	0.35	0.74	0.13	0.93	0.57	0.11	0.63	0.15
Latvia	1.00	0.04	0.53	0.70	0.00	1.00	0.67	0.68	0.00
Lithuania	0.98	0.07	0.68	0.60	0.08	0.96	0.32	0.64	0.06
Luxembourg	0.43	1.00	0.96	0.08	0.69	0.63	0.04	0.51	0.99
Malta	0.25	0.48	0.89	0.00	0.69	0.28	0.00	0.88	0.10
Netherlands	0.30	0.59	0.96	0.54	0.72	0.63	0.06	0.63	0.86
Poland	0.62	0.06	0.56	0.03	0.40	0.70	0.16	0.00	0.05
Portugal	0.15	0.11	0.76	0.54	0.69	0.37	0.50	0.55	0.18
Romania	0.59	0.00	0.32	0.31	0.05	0.88	0.42	0.87	0.01
Slovakia	0.98	0.08	0.84	0.17	0.23	0.87	0.16	0.86	0.03
Slovenia	0.57	0.08	0.93	0.12	0.66	0.54	0.35	0.65	0.07
Spain	0.10	0.18	0.80	0.39	0.94	0.23	0.21	0.59	0.36
Sweden	0.15	0.39	1.00	1.00	0.80	0.68	1.00	0.92	1.00
United Kingdom	0.13	0.57	0.81	0.70	0.64	0.74	0.03	0.89	0.33

Source: Own calculations based on EUROSTAT (http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/indicators)

Let us briefly analyze the nature of various indicators. The first one, growth rate of gross domestic product per capita is probably the most controversial one. As it does not reflect non-marketed environmental and social capital, it is often criticized as a measure of welfare (see, e.g., Arrow et al., 1995, Galbraith, 1958, Sen, 1976). Moreover, SDI1, together with SDI6 and SDI8 are relative values. They thus measure the development of any phenomenon rather than this phenomenon itself. It may be considered "unjust" to take them into account while appraising individual countries. For example, a country with smaller emission of greenhouse gases both in base and examined year may be characterized by an index of worse value than another country emitting more greenhouse gases both in base and in examined year. In case of any measured variable a country lasting in an "optimal" state will come fall worse than the country still approaching this optimal state.

The other problem concerning SD indicators that will be mentioned here is how to treat SD indicators: as all of them having the same significance or to choose some weights? In particular, most of themes, instead of two, have just one headline indicator. As for "climate change" and "natural resources", both of them are characterized by two leading indicators: however, there is no data available for the two latter. One could put a question, whether wouldn't it be more appropriate to take some average of the two former, not to overweight the influence of "climate change"? Aware of the fact, that the problem of "weighting" indicators has not even approached its final solution, we will treat in what follows all indicators equally. As for two headline indicators for the same theme ("climate changes"), SDI6 and SDI7, we suppose that it would be proper to treat each of them on an equal footing with all the others, as the themes themselves are chosen arbitrarily and, on the other hand, correlation between SDI6 and SDI7 has not too large value, 0.21. However, we will also check the influence of taking one averaged indicator, instead of two distinct ones, on the final result.

2 MEASURES OF SUSTAINABLE DEVELOPMENT BASED ON INDIVIDUAL RANKS

First of all let us check how the ranking of particular countries depends on an indicator that ranking is done with respect to. Table 3 shows these rankings according to 9 indicators in question. No matter, whether raw or normalized data is used here, as linear and positive transformations do not change the ranks of values. Note, that here and hereafter the rank 1 refers to the "worst" country while rank 27 – to the "best" one.

Table 3 Ranks of UE countries according to sustainable development indicators

	Ranks according to								
	SDI1	SDI2	SDI3	SDI4	SDI5	SDI6	SDI7	SDI8	SDI9
Austria	13	18	23	10	23	8	24	4	22
Belgium	8	19	15	7	20	16	4	26	21
Bulgaria	23	1.5	1	13	2	22	14.5	8	1.5
Cyprus	14	12	9	22	16.5	1	6	24	10.5
Czech Republic	19	6	25	15	9	21	10	2	8.5
Denmark	3	17	22	25	10	13	21	5	24.5
Estonia	24	3	14	26	7	25	20	27	4.5
Finland	17	14	20	21	23	9	25	16	20
France	5	23	19	9	27	14	17	23	19
Germany	10	21	17	18	21	20	14.5	25	17.5
Greece	16	16	7	12	11.5	5	13	17	13
Hungary	2	10	5	4	5	19	9	3	4.5
Ireland	11	13	11.5	20	14	6	7	14	23
Italy	1	20	8	6	25	10	8	11	14
Latvia	27	4	3	24	1	27	26	15	1.5
Lithuania	25.5	7	6	19	4	26	18	12	8.5
Luxembourg	18	27	24	3	16.5	12	3	6	26
Malta	12	24	18	1	16.5	3	1	20	12
Netherlands	15	26	26	16.5	19	11	5	10	24.5
Poland	22	5	4	2	8	17	11.5	1	7
Portugal	8	11	10	16.5	16.5	4	23	7	15
Romania	21	1.5	2	11	3	24	22	19	3
Slovakia	25.5	9	16	8	6	23	11.5	18	6
Slovenia	20	8	21	5	13	7	19	13	10.5
Spain	4	15	11.5	14	26	2	16	9	17.5
Sweden	8	22	27	27	23	15	27	22	27
United Kingdom	6	25	13	23	11.5	18	2	21	16

Source: Own calculations

The correlation between ranks according to different indicators are shown in Table 4, below diagonal. They reflect Pearson correlation coefficients, also shown in Table 4, above diagonal.

Table 4 Spearman rank (below diagonal, normal font) and Pearson (above diagonal, italics) correlations

	SDI1	SDI2	SDI3	SDI4	SDI5	SDI6	SDI7	SDI8	SDI9
SDI1	**1**	*–0.42*	*–0.36*	*0.02*	*–0.71*	*0.55*	*0.16*	*–0.03*	*–0.45*
SDI2	–0.62	**1**	*0.49*	*–0.12*	*0.54*	*–0.17*	*–0.26*	*0.12*	*0.71*
SDI3	–0.2	0.6	**1**	*0.13*	*0.66*	*–0.31*	*0.05*	*0.11*	*0.55*
SDI4	0.04	–0.09	0.09	**1**	*–0.05*	*0.09*	*0.52*	*0.33*	*0.29*
SDI5	–0.62	0.72	0.54	–0.07	**1**	*–0.67*	*–0.08*	*0.18*	*0.51*
SDI6	0.49	–0.46	–0.25	0.17	–0.64	**1**	*0.21*	*–0.06*	*–0.15*
SDI7	0.21	–0.41	–0.01	0.43	–0.05	0.2	**1**	*0.03*	*0.17*
SDI8	0.01	0.18	0.03	0.31	0.19	0.08	–0.04	**1**	*0.01*
SDI9	–0.55	0.81	0.71	0.14	0.75	–0.51	–0.08	0.02	**1**

Source: Own calculations

It is intuitively understandable, that some of these measures correlate negatively, as caring of temporary economical or social welfare may be not in agreement in concern for ecological goals. Thus, also the ranks of countries according to some pairs of indicators also correlate negatively. The simplest idea of building some aggregate measure of sustainable development that takes into account all nine indicators is just to calculate an average rank for each country. The results of such ranking are shown in Table 5. First column contains the ranks while the four following columns – the names of countries in the order that take into regard all indicators (second column); all but the first one (third column); all indicators, two belonging to the same theme group averaged (fourth column); and all indicators excluding relative ones (fifth column).

Table 5 Ranks of UE countries according to averaged ranks of individual variables. Italics denote countries ex aequo

Rank	All indicators	Without GDP dynamics	SDI6 and SDI7 averaged	Without dynamical indicators
1	Hungary	Poland	Poland	Bulgaria
2	Poland	Hungary	Bulgaria	*Hungary*
3	Bulgaria	Bulgaria	Hungary	*Poland*
4	Italy	Romania	Romania	Romania
5	Romania	Greece	Latvia	Slovakia
6	Malta	Malta	Lithuania	Latvia
7	Greece	*Czech Republic*	Slovakia	Lithuania
8	Portugal	*Slovenia*	Czech Republic	Greece
9	*Spain*	Slovakia	Slovenia	Malta
10	*Cyprus*	Lithuania	Greece	Czech Republic
11	Czech Republic	Cyprus	Portugal	Estonia
12	Slovenia	Latvia	Italy	Cyprus
13	Ireland	Italy	Malta	Slovenia
14	Slovakia	Portugal	Cyprus	Italy
15	Lithuania	Ireland	*Ireland*	Belgium
16	Latvia	Spain	*Spain*	Ireland
17	*Luxembourg*	Luxembourg	Estonia	United Kingdom
18	*United Kingdom*	Estonia	Luxembourg	Portugal
19	Belgium	Belgium	Austria	Luxembourg
20	Denmark	United Kingdom	Belgium	Spain
21	Austria	Austria	United Kingdom	Germany
22	Estonia	Denmark	Denmark	France
23	Netherlands	Netherlands	Netherlands	Netherlands
24	France	Finland	Finland	Denmark
25	Germany	France	France	Austria
26	Finland	Germany	Germany	*Finland*
27	Sweden	Sweden	Sweden	*Sweden*

Source: Own calculations

Average rank is a rather crude measure, as ranks according to individual indicators do not take into account the degree of advantage of one country over another. For example, thousandfold advantage in respect of one indicator of a country A over a country B may be compensated by a little, say, twofold, advantage in respect of another indicator of the country B over the country A. To construct ranking that takes whole the information available into account, a concept of "ideal points" will be introduced.

3 MEASURES OF SUSTAINABLE DEVELOPMENT BASED ON DISTANCE FROM "IDEAL POINT"

In order to define "ideal points" we need to use rescaled data. In this case, as all indicators have been transformed to become favorable and to range from 0 to 1, the hypothetical "worst" point in the 9-dimensional space is (0, 0, 0, 0, 0, 0, 0, 0, 0), and the hypothetical "best" point – (1, 1, 1, 1, 1, 1, 1, 1, 1). Note, that none of them refers to any existing country, as they reflect the worst and the best values of all nine indicators chosen from the whole set of EU countries. For example, point (0, 0, 0, 0, 0, 0, 0, 0, 0) is characterized by the value of growth rate of GDP due to Italy, resource productivity value due to Bulgaria and Romania and so on (compare values 0 and 1 in Table 2). The ranking of countries proposed here will be based on the distance of particular countries from the "worst" point: the greater value of this distance the "better" the country is and the higher will be its rank. Note, that in this case it is possible not only to determine the rank of a given country but also to quantify it: that is, to calculate the distances between subsequent countries.

We will use here two metrics. One is taxicab metrics (known also as city block distance or Manhattan distance) and the second – Euclidean metrics. In the first case a distance between and countries is given by:

$$d_M^{kl} = \sum_{i=1}^{D} \left| x_i^k - x_i^l \right|, \tag{2}$$

and the distance of a country from the "worst" point (0, 0, 0, 0, 0, 0, 0, 0, 0):

$$d_M^{k0} = \sum_{i=1}^{D} x_i^k, \tag{3}$$

where denotes the dimensionality, that is, the number of variables taken into account.

The Euclidean distance between countries and is given by:

$$d_E^{kl} = \sqrt{\sum_{i=1}^{D} \left(x_i^k - x_i^l \right)^2}, \tag{4}$$

and distance of a country from the "worst" point:

$$d_E^{k0} = \sqrt{\sum_{i=1}^{D} \left(x_i^k \right)^2}. \tag{5}$$

Tables 6 and 7 present results: ranking (with distances from the theoretical "worst" point) of EU countries carried out according to Manhattan and Euclidean distances, respectively. Note, that the distances are given as values relative to the maximum possible distance (that is, the distance between "worst" and "best" points). This relative distances will be denoted by $\tilde{d}_{M,E}^{kl}$. Taking into regard Manhattan distances the maximum distance equals to 9 while taking all indicators into account; without GDP it equals to 8; 7 while averaging two indicators belonging to the same theme group; and 6 while omitting indicators of relative character. That is, $\tilde{d}_M^{k0} = d_M^{k0}/D$. In the case of Euclidean distances maximum value equals to 3 (while taking all indicators into account); without GDP it equals to $\sqrt{8}$; $\sqrt{7}$ while averaging two indicators belonging to the same theme group; and $\sqrt{6}$ while omitting indicators of relative character. In this case, $\tilde{d}_E^{k0} = d_E^{k0}/\sqrt{D}$.

Table 6 Ranks of UE countries with respect to Manhattan distance

	All indicators		Without GDP dynamics		SDI6 and SDI7 averaged		Without dynamical indicators	
	Country	**dist.**	**Country**	**dist.**	**Country**	**dist.**	**Country**	**dist.**
1	Hungary	0.26	Poland	0.24	Bulgaria	0.21	Bulgaria	0.09
2	Poland	0.29	Bulgaria	0.25	Poland	0.22	Romania	0.18
3	Bulgaria	0.29	Hungary	0.29	Hungary	0.26	Hungary	0.20
4	Romania	0.38	Romania	0.36	Romania	0.31	Poland	0.21
5	Malta	0.40	Czech Rep.	0.40	Czech Rep.	0.39	Slovakia	0.25
6	Italy	0.40	Slovakia	0.41	Slovakia	0.39	Lithuania	0.30
7	Cyprus	0.40	Malta	0.42	Lithuania	0.40	Latvia	0.32
8	Czech Rep.	0.41	Cyprus	0.42	Latvia	0.40	Czech Rep.	0.35
9	Greece	0.42	Slovenia	0.42	Slovenia	0.42	Malta	0.36
10	Spain	0.42	Lithuania	0.43	Greece	0.45	Greece	0.36
11	Portugal	0.43	Greece	0.43	Malta	0.45	Slovenia	0.37
12	Slovenia	0.44	Italy	0.45	Italy	0.47	Estonia	0.38
13	Ireland	0.47	Latvia	0.45	Portugal	0.47	Cyprus	0.39
14	Slovakia	0.47	Spain	0.46	Cyprus	0.47	Italy	0.40
15	Belgium	0.48	Portugal	0.46	Spain	0.50	Belgium	0.42
16	Lithuania	0.49	Ireland	0.50	Estonia	0.51	Portugal	0.46
17	Austria	0.50	Belgium	0.52	Austria	0.52	Ireland	0.47
18	Latvia	0.51	Austria	0.53	Ireland	0.53	Spain	0.48
19	France	0.54	Estonia	0.53	Belgium	0.55	UK	0.51
20	UK	0.54	UK	0.59	Denmark	0.61	Germany	0.52
21	Denmark	0.54	France	0.59	France	0.61	France	0.52
22	Estonia	0.54	Denmark	0.60	Finland	0.61	Austria	0.56
23	Germany	0.56	Germany	0.61	UK	0.62	Finland	0.59
24	Netherlands	0.59	Finland	0.61	Germany	0.62	Denmark	0.61
25	Finland	0.59	Luxembourg	0.61	Luxembourg	0.65	Netherlands	0.62
26	Luxembourg	0.59	Netherlands	0.62	Netherlands	0.66	Luxembourg	0.63
27	Sweden	0.77	Sweden	0.85	Sweden	0.85	Sweden	0.86

Source: Own calculations

Table 7 Ranks of UE countries with respect to Euclidean distance from the ideal "worst" point

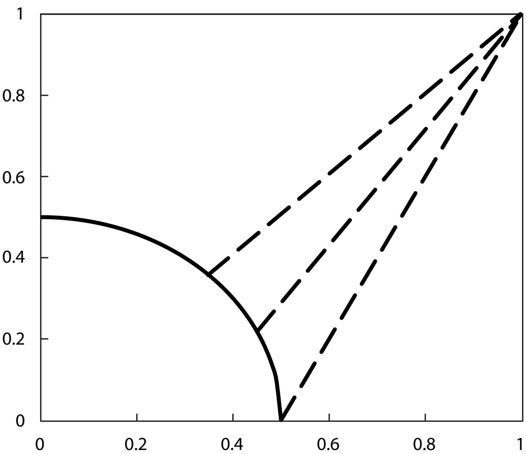
	All indicators		Without GDP dynamics		SDI6 and SDI7 averaged		Without dynamical indicators	
	Country	**dist.**	**Country**	**dist.**	**Country**	**dist.**	**Country**	**dist.**
1	Hungary	0.37	Poland	0.35	Poland	0.31	Bulgaria	0.16
2	Poland	0.39	Hungary	0.39	Bulgaria	0.33	Romania	0.25
3	Bulgaria	0.43	Bulgaria	0.40	Hungary	0.34	Poland	0.29
4	Greece	0.48	Romania	0.49	Romania	0.44	Hungary	0.29
5	Portugal	0.48	Greece	0.50	Czech Rep.	0.48	Slovakia	0.37
6	Romania	0.50	Czech Rep.	0.51	Lithuania	0.49	Lithuania	0.40
7	Czech Rep.	0.50	Portugal	0.51	Slovakia	0.51	Greece	0.43
8	Spain	0.50	Slovenia	0.52	Greece	0.52	Latvia	0.45
9	Italy	0.51	Lithuania	0.53	Portugal	0.52	Czech Rep.	0.47
10	Malta	0.52	Spain	0.53	Latvia	0.53	Slovenia	0.49
11	Slovenia	0.53	Italy	0.54	Slovenia	0.53	Estonia	0.50
12	Ireland	0.53	Slovakia	0.54	Italy	0.55	Malta	0.50
13	Cyprus	0.53	Malta	0.54	Spain	0.56	Cyprus	0.50
14	Austria	0.55	Cyprus	0.55	Malta	0.57	Belgium	0.51
15	Belgium	0.58	Ireland	0.55	Ireland	0.58	Italy	0.51
16	Lithuania	0.60	Austria	0.58	Austria	0.58	Portugal	0.52
17	Denmark	0.60	Latvia	0.58	Cyprus	0.59	Ireland	0.55
18	Slovakia	0.60	Belgium	0.61	Belgium	0.62	Spain	0.56
19	UK	0.61	Denmark	0.64	Estonia	0.63	Germany	0.56
20	Germany	0.63	UK	0.64	UK	0.65	UK	0.58
21	France	0.63	Estonia	0.65	Denmark	0.65	France	0.60
22	Finland	0.63	Finland	0.65	Finland	0.66	Austria	0.62
23	Latvia	0.64	Germany	0.66	Germany	0.66	Finland	0.64
24	Netherlands	0.64	France	0.66	France	0.68	Denmark	0.66
25	Estonia	0.65	Netherlands	0.67	Netherlands	0.69	Netherlands	0.69
26	Luxembourg	0.68	Luxembourg	0.71	Luxembourg	0.73	Luxembourg	0.75
27	Sweden	0.82	Sweden	0.87	Sweden	0.87	Sweden	0.89

Source: Own calculations

While dealing with Manhattan distance it is clear, that the distance of any point from the "worst" point determines uniquely its distance from the "best" one:

$$d_M^{k1} = \sum_{i=1}^{D}\left|1 - x_i^k\right| = D - \sum_{i=1}^{D} x_i^k = D - d_M^{k0} = D\left(1 - \tilde{d}_M^{k0}\right). \quad (6)$$

Figure 1 Line of equal Euclidean distance to (0, 0) (solid line) and different distances to (1, 1) (dashed lines as examples)



Source: Own construction

Thus, the ranking determined by the distance from the "worst" point will be strictly the same as the one determined by the distance from the "best" one (note, that in this case the smaller distance the higher position of the country in the ranking).

However, as we are dealing here with a space with more than one dimension, Euclidean distance from the "worst" point does not determine its distance from the "best" one. There may exist, for example, two points of the same distance from the "worst" point but with different distances to the "best" point (see Figure 1 for an example in two dimensions). Using Euclidean metrics, the distances from the second ideal point should also be taken into regard. Let us check the ranking of the countries while taking the distance from the "best" ideal point into regard.

Table 8 Ranks of EU countries with respect to Euclidean distance from "best" point

	All indicators		Without GDP dynamics		SDI6 and SDI7 averaged		Without dynamical indicators	
	Country	dist.	Country	dist.	Country	dist.	Country	dist.
1	Hungary	0.79	Bulgaria	0.81	Bulgaria	0.81	Bulgaria	0.92
2	Bulgaria	0.77	Poland	0.80	Poland	0.78	Romania	0.83
3	Poland	0.76	Hungary	0.76	Romania	0.74	Hungary	0.83
4	Romania	0.70	Romania	0.72	Hungary	0.74	Poland	0.82
5	Cyprus	0.69	Slovakia	0.69	Latvia	0.70	Slovakia	0.79
6	Malta	0.69	Cyprus	0.69	Slovakia	0.67	Latvia	0.75
7	Italy	0.67	Malta	0.68	Lithuania	0.65	Lithuania	0.74
8	Czech Rep.	0.66	Czech Rep.	0.67	Czech Rep.	0.64	Malta	0.73
9	Slovakia	0.65	Lithuania	0.66	Slovenia	0.63	Czech Rep.	0.72
10	Spain	0.64	Latvia	0.66	Estonia	0.60	Slovenia	0.71
11	Slovenia	0.63	Slovenia	0.65	Malta	0.58	Estonia	0.69
12	Greece	0.63	Greece	0.62	Italy	0.55	Cyprus	0.68
13	Lithuania	0.62	Italy	0.62	Cyprus	0.55	Italy	0.68
14	Latvia	0.62	Estonia	0.60	Greece	0.55	Greece	0.68
15	Portugal	0.61	Spain	0.60	Portugal	0.54	Belgium	0.65
16	Belgium	0.61	Portugal	0.58	Austria	0.51	Spain	0.59
17	Ireland	0.59	Belgium	0.57	Spain	0.50	Ireland	0.59
18	Estonia	0.58	Ireland	0.56	Belgium	0.48	Portugal	0.59
19	France	0.56	Luxembourg	0.53	Ireland	0.45	France	0.57
20	Austria	0.55	Austria	0.52	France	0.44	Luxembourg	0.56
21	UK	0.54	France	0.51	Finland	0.44	UK	0.55
22	Denmark	0.53	UK	0.49	Luxembourg	0.42	Germany	0.54
23	Luxembourg	0.53	Germany	0.47	Denmark	0.41	Austria	0.50
24	Germany	0.52	Denmark	0.46	Germany	0.39	Finland	0.48
25	Netherlands	0.48	Finland	0.45	UK	0.36	Netherlands	0.48
26	Finland	0.47	Netherlands	0.45	Netherlands	0.30	Denmark	0.46
27	Sweden	0.37	Sweden	0.25	Sweden	0.27	Sweden	0.26

Source: Own calculations

The Euclidean distance from point (1, 1, 1, 1, 1, 1, 1, 1, 1) reads:

$$d_E^{k1} = \sqrt{\sum_{i=1}^{D}\left(1 - x_i^k\right)^2}. \quad (7)$$

Table 8 presents results: ranking (with distances from the theoretical "best" point) of EU countries carried out according to Euclidean metrics. As in the case before, the distances are given as a fraction of the maximum possible distance, $\tilde{d}_E^{k1} = d_E^{k1}/\sqrt{D}$.

It can be seen, that the ranking according to the distance from the "best" point is different from that established by the distance from the "worst" point. The simplest joined measure of "goodness" of the country may be obtained by simple averaging these two distances (or, to be precise, $\tilde{d}_E^{k0}$ and $1 - \tilde{d}_E^{k1}$). The results are contained in Table 9.

Table 9 Ranks of UE countries with respect to average Euclidean distance from the "worst" and "best" points

	All indicators		Without GDP dynamics		SDI6 and SDI7 averaged		Without dynamical indicators	
	Country	dist.	Country	dist.	Country	dist.	Country	dist.
1	Hungary	0.29	Poland	0.28	Bulgaria	0.26	Bulgaria	0.12
2	Poland	0.31	Bulgaria	0.29	Poland	0.26	Romania	0.21
3	Bulgaria	0.33	Hungary	0.31	Hungary	0.30	Hungary	0.23
4	Romania	0.40	Romania	0.38	Romania	0.35	Poland	0.24
5	Malta	0.42	Czech Rep.	0.42	Latvia	0.41	Slovakia	0.29
6	Italy	0.42	Slovakia	0.42	Lithuania	0.42	Lithuania	0.33
7	Cyprus	0.42	Malta	0.43	Czech Rep.	0.42	Latvia	0.35
8	Czech Rep.	0.42	Cyprus	0.43	Slovakia	0.42	Greece	0.37
9	Greece	0.43	Slovenia	0.44	Slovenia	0.45	Czech Rep.	0.38
10	Spain	0.43	Greece	0.44	Greece	0.48	Malta	0.39
11	Portugal	0.44	Lithuania	0.44	Portugal	0.49	Slovenia	0.39
12	Slovenia	0.45	Italy	0.46	Italy	0.50	Estonia	0.40
13	Ireland	0.47	Latvia	0.46	Malta	0.50	Cyprus	0.41
14	Slovakia	0.48	Portugal	0.47	Estonia	0.51	Italy	0.42
15	Belgium	0.49	Spain	0.47	Cyprus	0.52	Belgium	0.43
16	Lithuania	0.49	Ireland	0.50	Spain	0.53	Portugal	0.47
17	Austria	0.50	Belgium	0.52	Austria	0.53	Ireland	0.48
18	Latvia	0.51	Estonia	0.52	Ireland	0.56	Spain	0.48
19	France	0.53	Austria	0.53	Belgium	0.57	UK	0.51
20	UK	0.53	France	0.58	Finland	0.61	Germany	0.51
21	Denmark	0.53	UK	0.58	France	0.62	France	0.52
22	Estonia	0.54	Luxembourg	0.59	Denmark	0.62	Austria	0.56
23	Germany	0.56	Denmark	0.59	Germany	0.63	Finland	0.58
24	Luxembourg	0.58	Germany	0.59	UK	0.64	Luxembourg	0.60
25	Netherlands	0.58	Finland	0.60	Luxembourg	0.66	Denmark	0.60
26	Finland	0.58	Netherlands	0.61	Netherlands	0.69	Netherlands	0.61
27	Sweden	0.73	Sweden	0.81	Sweden	0.80	Sweden	0.82

Source: Own calculations

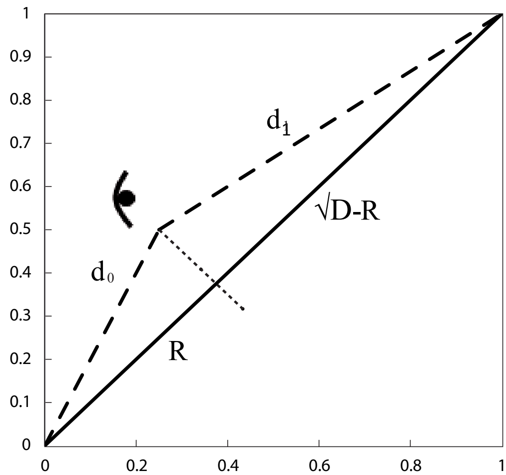
However, dealing with Euclidean metrics probably more "natural" will be averaging not $\tilde{d}_E^{k0}$ and $1 - \tilde{d}_E^{k1}$, but rather, $\left(\tilde{d}_E^{k0}\right)^2$ and $1 - \left(\tilde{d}_E^{k1}\right)^2$. This will be the subject of the following section.

4 MEASURE OF SUSTAINABLE DEVELOPMENT BASED ON DISTANCE ON "WORST-BEST" AXIS

According to the previous section, while evaluating a certain country with respect to the level of its sustainable development two aspects should be taken into regard: its distance from the totally worst state and its distance to ideally best state. In the context of Euclidean metrics it would mean averaging $\left(\tilde{d}_E^{k0}\right)^2$ and $1 - \left(\tilde{d}_E^{k1}\right)^2$. Let us investigate, what such averaging is equivalent to.

Let us take an axis passing points {0} and {1} in D-dimensional space. Let us have in that space any other point, {x}, fulfilling: $0 \le x_1, x_2, \dots, x_D \le 1$. The length of perpendicular projection of vector $\vec{x}$ on the line $\vec{1}$, denoted by R, may be obtained as follows (see Figure 2 for illustration in 2D):

Figure 2 Perpendicular projection of vector $\vec{x}$ on the vector $\vec{1}$ in two dimensions



Source: Own construction

$$(d_E^0)^2 - R^2 = (d_E^1)^2 - \left(\sqrt{D} - R\right)^2, \qquad (8)$$

and

$$R = [D + (d_E^0)^2 - (d_E^1)^2] \,/\, \left[2\sqrt{D}\right]. \qquad (9)$$

Dealing with distances rescaled by the maximum possible distance $\sqrt{D}$ one gets:

$$\tilde{R} = \left[\left(\tilde{d}_E^0\right)^2 + 1 - \left(\tilde{d}_E^1\right)^2\right] / \, 2. \qquad (10)$$

Thus, averaging $\left(\tilde{d}_E^{k0}\right)^2$ and $1 - \left(\tilde{d}_E^{k1}\right)^2$ is strictly the same as projecting the vector determined by points $\{0\}$ and $\{x\}$ on the line going through points $\{0\}$ and $\{1\}$.

Having this geometrical interpretation in mind, let us proceed with ranking countries according to distance from "worst" ideal point on the "worst-best" axis. The results are shown in Table 10.

Table 10 Ranks of UE countries with respect to their distance from the "worst" point on the "worst-best" axis

	All indicators		Without GDP dynamics		SDI6 and SDI7 averaged		Without dynamical indicators	
	Country	dist.	Country	dist.	Country	dist.	Country	dist.
1	Hungary	0.26	Poland	0.24	Bulgaria	0.23	Bulgaria	0.09
2	Poland	0.29	Bulgaria	0.25	Poland	0.24	Romania	0.18
3	Bulgaria	0.29	Hungary	0.29	Hungary	0.28	Hungary	0.20
4	Romania	0.38	Romania	0.36	Romania	0.32	Poland	0.21
5	Malta	0.40	Czech Rep.	0.40	Latvia	0.39	Slovakia	0.25
6	Italy	0.40	Slovakia	0.41	Lithuania	0.40	Lithuania	0.30
7	Cyprus	0.40	Malta	0.42	Slovakia	0.41	Latvia	0.32
8	Czech Rep.	0.41	Cyprus	0.42	Czech Rep.	0.41	Czech Rep.	0.35
9	Greece	0.42	Slovenia	0.42	Slovenia	0.44	Malta	0.36
10	Spain	0.42	Lithuania	0.43	Greece	0.48	Greece	0.36
11	Portugal	0.43	Greece	0.43	Portugal	0.49	Slovenia	0.37
12	Slovenia	0.44	Italy	0.45	Italy	0.50	Estonia	0.38
13	Ireland	0.47	Latvia	0.45	Malta	0.50	Cyprus	0.39
14	Slovakia	0.47	Spain	0.46	Estonia	0.52	Italy	0.40
15	Belgium	0.48	Portugal	0.46	Cyprus	0.52	Belgium	0.42
16	Lithuania	0.49	Ireland	0.50	Spain	0.53	Portugal	0.46
17	Austria	0.50	Belgium	0.52	Austria	0.54	Ireland	0.47
18	Latvia	0.51	Austria	0.53	Ireland	0.56	Spain	0.48
19	France	0.54	Estonia	0.53	Belgium	0.57	UK	0.51
20	UK	0.54	UK	0.59	Finland	0.62	Germany	0.52
21	Denmark	0.54	France	0.59	Denmark	0.63	France	0.52
22	Estonia	0.54	Denmark	0.60	France	0.63	Austria	0.56
23	Germany	0.56	Germany	0.61	Germany	0.64	Finland	0.59
24	Netherlands	0.59	Finland	0.61	UK	0.64	Denmark	0.61
25	Finland	0.59	Luxembourg	0.61	Luxembourg	0.68	Netherlands	0.62
26	Luxembourg	0.59	Netherlands	0.62	Netherlands	0.69	Luxembourg	0.63
27	Sweden	0.77	Sweden	0.85	Sweden	0.84	Sweden	0.86

Source: Own calculations

5 MEASURE OF SUSTAINABLE DEVELOPMENT BASED ON DISTANCE ON "BAD-GOOD" AXIS

All methods of ranking described in the previous sections have the same restriction: one has to determine, which variable is favorable and which one is not, for sustainable development. If we have variables that *define* sustainable development then there is no problem with that question. However, often it may be not so clear. The method used in this section to rank countries according to their level of sustainable development is based on the a priori experts' knowledge. This knowledge, however, relates not to the favorable or unfavorable character of certain variables, but to the overall result. Namely, it is enough to know, which country may be regarded as a one that deserves to be called "the best" or at least "good", and which one is retarded with respect to sustainable development, that is, "the worst" or at least – "bad". Such two countries will establish a certain axis – "bad-good" axis. The coordinates of the remaining countries will be projected on this axis and the distances from the "bad" country will be calculated. However, it may occur, that applying this procedure some country or countries will turn out to be worse that the "bad" one, in the sense, that its distance to the "good" country will be larger than the "bad-good" countries distance. The country which distance from the "good" one will be the largest will be treated as "the worst" one. On the other hand, the country, which distance from the "bad" country will be the largest, will be called "the best" one (Ostasiewicz, 1986). In this section we will "forget" for a moment our knowledge about indicators, use "experts'" method to obtain ranking of the countries and then compare it with results got in the previous section, while embodying the awareness of indicators' character.

Table 11 Dependence of ordering of countries on units in which variables were measured, while using variables with units

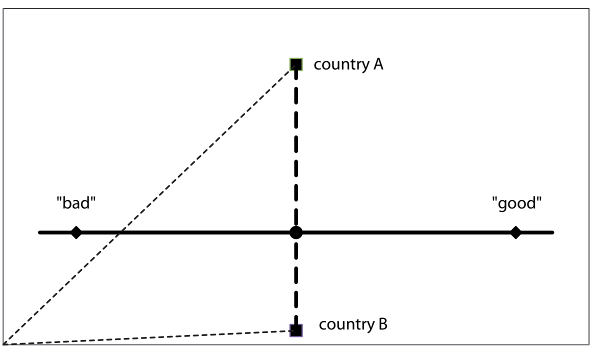
Rank	SDI2 in EUR / kg units	SDI2 in eurocents / tone units	SDI2 solely
1	Bulgaria	Bulgaria	Bulgaria
2	Romania	Romania	Romania
3	Poland	Estonia	Estonia
4	Hungary	Latvia	Latvia
5	Lithuania	Poland	Poland
6	Slovakia	Czech Rep.	Czech Rep.
7	Latvia	Lithuania	Lithuania
8	Belgium	Slovenia	Slovenia
9	Czech Rep.	Slovakia	Slovakia
10	Luxembourg	Hungary	Hungary
11	Italy	Portugal	Portugal
12	Estonia	Cyprus	Cyprus
13	UK	Ireland	Ireland
14	Germany	Finland	Finland
15	France	Spain	Spain
16	Holand	Greece	Greece
17	Greece	Denmark	Denmark
18	Slovenia	Austria	Austria
19	Ireland	Belgium	Belgium
20	Malta	Italy	Italy
21	Denmark	Germany	Germany
22	Austria	Sweden	Sweden
23	Portugal	France	France
24	Spain	Malta	Malta
25	Finland	United Kingdom	United Kingdom
26	Sweden	Netherlands	Netherlands
27	Cyprus	Luxembourg	Luxembourg

Source: Own calculations

Using this method we have to use normalized data instead of raw data, as in the latter case the results would depend on the units used to measure a certain quantity. Indeed, let us see the difference in rankings of countries while measuring SDI2 in EUR / kg or eurocent / tone. The results in Table 11 show, that the rankings are quite different. It is worth noticing that the second one is identical to the ranking of countries according to the SDI2 solely (see Table 3). Thus, taking units 10^5 times smaller acted as if putting 10^5 weight on this variable, causing the whole data being dominated by it. On the other hand, the decision, which variables have been treated as favorable and which one as unfavorable does not matter here, as it does not change the ranking.

The question, how to rescale variables in the context of this method is not a simple one. Let us assume, that there not exist such a country, that is better than all the others in respect of all variables; and that there not exist such a country, that is worse than all the others in respect of all variables. If they existed, it would be the case described in previous section, with this advantage, that points {0} and {1} would not be "ideal" but real ones. Still, such case is strongly improbable, thus, let us proceed with excluding it in this section. If we rescale variables like in Table 2, taking as minimum and maximum the least and the largest values amongst data, the vector $\vec{x}_G - \vec{x}_B$ will consists from different values as its components. Let us assume, that there exist such a variable that its value for "good" country is strictly the same as its value for "bad" country. In such case this variable falls out of the analysis and the countries with favorable value of this particular variable are undervalued. Figure 3 pictures a 2D example. Countries A and B are projected to the same point, although their properties in the dimension, in which coordinates of "bad" and "good" countries are these same, are apparently different. What follows, such a rescaling still put weight on particular variables; the weight is the larger, the larger is the difference of values of this variable for "good" and "bad" countries.

Figure 3 Falling out of analysis these variables, which values for "bad" and "good" countries are equal



Source: Own construction

The opposite idea of rescaling: taking value of "bad" country as minimum and value of "good" country as maximum (all components of the vector $\vec{x}_G - \vec{x}_B$ will be equal to 1), arises strictly opposite problem. There arises weights, which are the larger the smaller difference of values of a certain variable between "good" and "bad" country.

Still another problem arises when we have to choose a "good" country and a "bad" one. Even if we can trust our expert that he / she will choose properly, and even if "good" country will be the best one, and "bad" will be the worst one, there still may occur serious misleading biases, if the best country is not better than the worst country in respect of all variables. Let us assume, that "good" country is better than the "bad" one in respect of all but one variable. Thus, vector $\vec{x}_G - \vec{x}_B$ will point at the desirable direction in respect of all but this one dimension. What follows, the country which strong point resides in the favorable value of this particular variable will be treated very "unjust", as its strongest in fact point will become its strongest weakness; and the more favorable value of this variable the worse rank this country will get.

In order to deal with all mentioned above difficulties let us rank countries with both kinds of rescaling and with two different set of variables. The scaling performed by taking the least value amongst data as minimum and the largest as a maximum will be abbreviated in what follows as Scaling1 (S1), and the scaling performed by taking the value of "bad" country as the minimum and the value of "good" country as a maximum by Scaling2 (S2). Whole set of variables will be denoted by Variables1 (V1) and set of variables without these of relative character by Variables2 (V2). Such choice of the second set of variables is dictated by the last problem mentioned in the previous paragraphs, that is, the problem with finding such a pair of countries that the "good" one is better in respect of all variables than the "bad" one. If we presume, that the growth of GDP is favorable and dynamics of greenhouse gases emissions and use of energy relative to GDP are unfavorable, it occurs, that even Sweden, that wins all rankings performed above, has less favorable values of SDI1 and SDI6 than Bulgaria, which often appears as the worst country in EU.

S1V1 case

First, let us examine ranking of countries imposed by projecting all nine coordinates on "bad-good" axis, with variables scaled by the first described above method. Despite the fact, that "the best" Sweden is not "better" than three the worst (due to rankings in previous sections) countries (Bulgaria, Poland, Hungary) in respect to all variables, there exist six pairs of countries that fulfil this condition. These are: Estonia and Bulgaria (Bu-E), Lithuania and Bulgaria (Bu-Li), Sweden and Denmark (D-S), Germany and Hungary (H-G), France and Italy (I-Fr) and Finland and Portugal (P-F). (There exists also the seventh one, Sweden and Portugal, where Sweden is better or equal to Portugal in respect of all variables: we exclude this pair from our analysis because of impossibility to rescale the case in the S2 way, what we will be prompted to do for comparison of results). Thus we obtain six rankings with distances of particular countries from the first ("worst") one. Spearman rank correlations between different rankings are placed in Table 12 below diagonal, while Pearson correlation coefficients also in the same table, above diagonal. One can see, that these values are quite large, no less than 0.47 (Spearman) and 0.66 (Pearson correlation).

Table 12 Spearman rank (below diagonal, normal font) and Pearson (above diagonal, italics) correlations between orderings obtained by different choices of "bad" and "good" countries (S1V1case)

	Bu-E	Bu-Li	D-S	H-G	I-Fr	P-F
Bu-E	**1**	*0.816861*	*0.86919*	*0.922976*	*0.886461*	*0.743297*
Bu-Li	0.575702	**1**	*0.718511*	*0.659511*	*0.797197*	*0.869104*
D-S	0.849206	0.593407	**1**	*0.862284*	*0.917956*	*0.840779*
H-G	0.893773	0.466422	0.737485	**1**	*0.916693*	*0.722551*
I-Fr	0.815629	0.767399	0.794872	0.842491	**1**	*0.924664*
P-F	0.582418	0.899878	0.69475	0.535409	0.998462	**1**

Source: Own calculations

However, if we take axis determined by countries, which are at first glance in clear relation worse-better, but some indicators of "better" country has less favorable values than those of "worse" country, the coefficient may obtain such small values as 0.10 (0.05) of Pearson (Spearman) correlations, while comparing rankings appointed by axis "Romania-Belgium" and "Portugal-Finland", or 0.39 (0.38) of Pearson (Spearman) correlations, comparing rankings of "Bulgaria-Luxembourg" and "Denmark-Sweden" axes.

Then, let us compare rankings obtained here with the one determined by projecting coordinates of countries on the "worst-best" axis (passing and points, see Table 10, first column). Correlations between the latter and six different rankings obtained by different pairs of "bad" and "good" countries, are contained in Table 13. The last row containes correlations between "worst-best" ranking and averaged results of six rankings obtained in this section. As weights put on particular variables depend on differences between "good" and "bad" country, thus they depend on the choice of these countries. One may expect, that averaging over some number of rankings will lead toward convergence of ranking countries. Indeed, correlation between averaged results and "worst-best" ranking have greater values than the greatest of individual correlations.

Table 13 Correlations between "worst-best" ordering and six orderings obtained by different choices of "bad" and "good" countries (S1V1 case)

Results from "worst-best" axis method with	Pearson correlation	Spearman correlation
Bu-E	0.867508	0.760684
Bu-Li	0.865563	0.84127
D-S	0.891673	0.799145
H-G	0.866789	0.752747
I-Fr	0.963081	0.935897
P-F	0.930545	0.888278
averaged	0.966085	0.943223

Source: Own calculations

S2V1 case

Now, let us examine, whether the second kind or rescaling variables will change obtained results. It may be seen at a first glance, that these results are much more diversified, while taking different pairs of countries. Table 14 shows Pearson and Spearman correlations between each pair, and some of them are even negative. Spearman rank correlations between six different rankings and ranking determined by ideal "worst-best" axis can also obtained as small vales as 0.1. However, Spearman correlation between averaged ranks and "worst-best" ranks has much larger value, 0.90 (see Table 15). It seems, that discrepancies of rankings cancel out one another, tending to the ranking of "worst-best" axis. Still, this correlation is worse that correlation with "worst-best" ranking obtained with the former method of scaling.

Table 14 Spearman rank (below diagonal, normal font) and Pearson (above diagonal, italics) correlations between orderings obtained by different choices of "bad" and "good" countries (S2V1case)

	Bu-E	Bu-Li	D-S	H-G	I-Fr	P-F
Bu-E	**1**	*0.230366*	*0.748422*	*0.543692*	*0.447433*	*0.303369*
Bu-Li	0.076313	**1**	*0.576669*	*–0.11878*	*0.936355*	*0.963217*
D-S	0.745421	0.483516	**1**	*0.62824*	*0.760821*	*0.643899*
H-G	0.557387	–0.28083	0.541514	**1**	*0.057643*	*–0.08958*
I-Fr	0.409035	0.887057	0.765568	0.051282	**1**	*0.975404*
P-F	0.125153	0.971306	0.551893	–0.20024	0.92735	**1**

Source: Own calculations

Table 15 Correlations between "worst-best" ordering and six orderings obtained by different choices of "bad" and "good" countries (S2V1 case)

Results from "worst-best" axis method with	Bu-E	Bu-Li	D-S	H-G	I-Fr	P-F	Averaged
Spearman correlation	0.5159	0.8126	0.8083	0.1044	0.9512	0.8449	0.8987

Source: Own calculations

S1S2 comparison

As it was stated above, S1 scaling puts the larger weight on a certain variable the larger difference of values of this variable between "good" and "bad" country. On the other hand, S2 scaling put the larger weight the smaller difference between values of a variable. Averaging over some set of rankings and distances is expected to result in canceling out overestimation and underestimation of the influence of a given variable. Indeed, as was shown in previous paragraphs, such averaged results both in S1 and in S2 cases better correlate with ideal "worst-best" axis results. Now let us check whether averaging not over some set of results within S1 / S2 scaling but rather over S1 and S2 results will lead to rankings that will be in better agreement with "worst-best" axis results. Table 16 presents Pearson and Spearman correlations for rankings obtained by averaging (geometric mean) distances resulting from S1 and S2 scaling. One can see, that these correlations are indeed larger than correlations obtained within both S1 and S2 scaling.

Table 16 Correlations between "worst-best" ordering and six orderings obtained by different choices of "bad" and "good" countries (geometric mean of S1 and S2 scaling, V1 case)

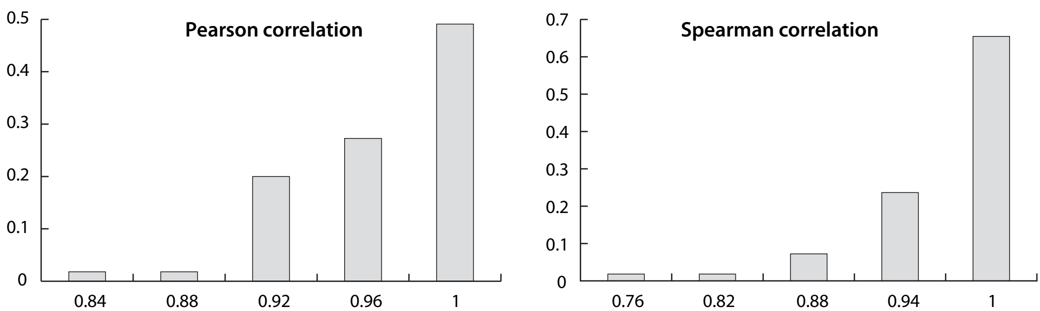
Results from "worst-best" axis method with	Pearson correlation	Spearman correlation
Bu-E	0.887909	0.885226
Bu-Li	0.973164	0.964591
D-S	0.931021	0.937118
H-G	0.840714	0.882784
I-Fr	0.988949	0.977411
P-F	0.989428	0.976190

Source: Own calculations

S1V2 case

Let us proceed to the case of reduced set of variables, that is, without relative ones. Here we use the first method of scaling, which has proved to be more self-consistent and converging toward "worst-best" axis method. Again, we will use these pairs of countries, which are in the same relation worse-better in regard to all non-relative six variables. Such pairs are much more numerous than in the case of all nine variables, as there are 55 of them (59, including those pairs, for which some variables have the same value). They will not be listed here. Nor will we put here correlations between individual pairs of them. Pearson and Spearman correlations between different pairs and "worst-best" result are pictured in Figure 4. As for Pearson correlation the minimum value equals 0.801, maximum value 0.998, with average value equal to 0.947. Minimum value of Spearman rank correlation is 0.700, the maximum value 0.995, and the average value equal to 0.940.

Figure 4 Pearson and Spearman correlations between individual "bad-good" orderings and "worst-best" one



Source: Own construction

If we average all 55 results for all different pairs of "bad" and "good" countries, the Pearson and Spearman correlations will be equal to 0.997 and 0.992 respectively. This is a bit worse result than the best one of set of correlations for individual countries but much better than the average one (see Table 17).

Table 17 Correlations for individual and averaged orderings, S1V2 case

		Pearson	Spearman
Individual results	Worst	0.801	0.700
	Best	0.998	0.995
	Average	0.947	0.940
Averaged result		0.998	0.992

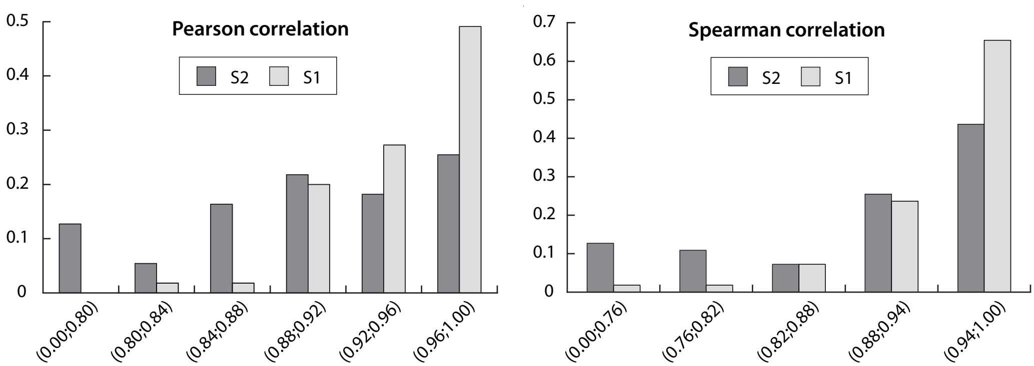
Source: Own calculations

The procedure of averaging seems to be a converging one. We have divided all results into randomly chosen 27 and 28-elements sets, and averaged distances within each set. The Pearson correlations equal to 0.997 and 0.996. Moreover, averaging distances of six worst results (those, for which Pearson correlation was less than 0.9) we got correlation equal to 0.948. Thus, averaging of rankings obtained by different choices of "bad" and "good" countries one gets ranking that converges to the ranking obtained by fixing ideal "worst-best" axis. The importance of this phenomenon lies in the fact, that using method of designing "bad" and "good" country one has not to know which variable is in fact favorable and which one is not. Contrary, this knowledge is essential while settling ideal "worst" and "best" point.

S2V2 case

Although we have already seen, that S2 scaling behaves much worse than S1 one (in the sense of self-converging) we investigate here this case for comparison purpose and to show the possibility of averaging S1 and S2 scaling. Indeed, both Spearman and Pearson correlations have worse values for S2 case (as compared with S1 case, see Figure 5).

Figure 5 Pearson and Spearman correlations between individual "bad-good" orderings and "worst-best" one for S2 and S1 cases



Source: Own construction

The averaged value of Pearson correlations between S2 rankings and ideal "worst-best" case for the whole set of 55 values equals to 0.892 (compare the value 0.947 for S1 case – 6% worse). However, after averaging results the Pearson correlation rises to 0.987 (as compared with 0.998 in S1 case – 1% worse).

Thus, averaging causes lessening the advantage of S1 scaling from 6 to 1 percent of correlation value. As for Spearman correlation, average value of 55 correlations equals to 0.880 (6% worse that the value 0.940 of S1 case), but after averaging it rises to 0.982, what means diminishing the advantage of S1 scaling to 1% of 0.992 value in S1 case. The best, worst, averaged correlations and correlations after averaging are collected for S2V2 case in Table 18.

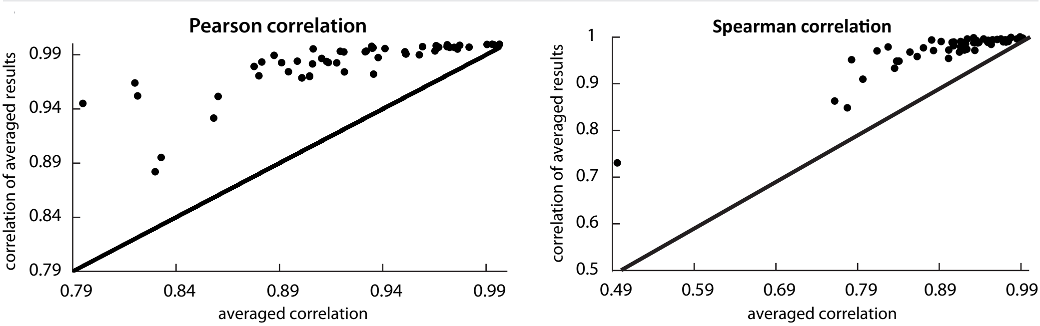
Table 18 Correlations for individual and averaged orderings, S2V2 case

		Pearson	Spearman
Individual results	Worst	0.500	0.261
	Best	0.995	0.990
	Average	0.892	0.880
Averaged result		0.987	0.982

Source: Own calculations

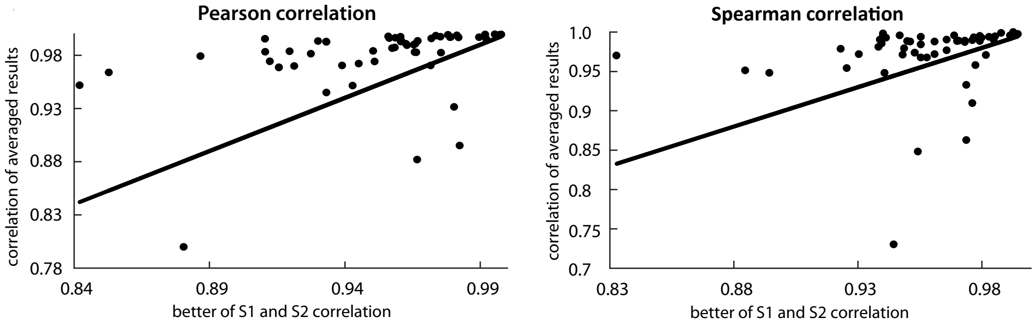
Although averaging results causes convergence of S2 results toward ideal "worst-best" results, they are still worse than S1 results. Let us argue that there is another potential benefit of using S2 scaling method. While having many pairs of "bad" and "good" countries the most efficient strategy to establish the ranking seems to be averaging rankings resulting from S1 scaling method. However, if our "expert" is not able to suggest numerous enough set of such pairs, the method cannot be applied. It seems, that in such case the use of both S1 and S2 scaling may be helpful. Let us compare the following results: For a given choice of "bad" and "good" country let us calculate correlations of S1 scaling result with ideal "worst-best" one; S2 scaling result with ideal "worst-best" one; averaged value of the two mentioned above and correlation of averaged S1-S2 result (taking geometric mean of each pair of distances) with ideal "worst-best" one. Figures 6 and 7 show obtained results. Figure 6 presents dependences of averaged S1 and S2 correlations versus correlations of averaged results. It occurs, that all points lie above solid $y = x$ line, that is, all correlations for averaged results are better than averaged value of the two, calculated according to S1 and S2 scaling. However, it is not so profitable, as it may occur, as the smaller value of S1 and S2 correlations lowers the averaged correlation. Thus, we check how the correlations of averaged results are related to the better of two S1 and S2 values of correlations. This is pictured in Figure 7. One can see, that most of points lie above $y = x$ line. Thus, in most cases, taking into regard both of S1 and S2 scaling improve results (as if claiming to obtain ideal "worst-best" ranking). However, in about 10%, averaging results causes their receding from "worst-best" ranking.

Figure 6 Correlations of averaged S1 and S2 results versus averaged value of correlations for S1 and S2 case



Source: Own construction

Figure 7 Correlations of averaged S1 and S2 results versus averaged value of correlations for S1 and S2 case



Source: Own construction

6 DISCUSSION

In previous sections we have used a few methods of ranking EU countries according to their level of sustainable development. Let us compare results of three of them, namely: averaged rank method (AR), Manhattan distance from the ideal worst point method (MD) and a distance on "worst-best" axis method (ED).

From Tables 19–22 it may be seen, that methods MD and ED gives exactly the same results for three cases, excluding the case of averaging variables SDI6 and SDI7. Spearman correlations between AR ranking and the two others equal to 0.944 (all variables); 0.943 (all but the first variable); 0.960 and 0.962 (averaged variables SDI6 and SDI7); 0.966 (without a variables). Thus the last set of variables ensures the most consistent results while using various methods of ranking.

Table 19 Ranks of countries with respect to all variables

	Ranks according to		
	AR	MD	ED
Austria	21	17	17
Belgium	19	15	15
Bulgaria	3	3	3
Cyprus	9.5	7	7
Czech Rep.	11	8	8
Denmark	20	21	21
Estonia	22	22	22
Finland	26	25	25
France	24	19	19
Germany	25	23	23
Greece	7	9	9
Hungary	1	1	1
Ireland	13	13	13
Italy	4	6	6
Latvia	16	18	18
Lithuania	15	16	16
Luxembourg	17.5	26	26
Malta	6	5	5
Netherlands	23	24	24
Poland	2	2	2
Portugal	8	11	11
Romania	5	4	4
Slovakia	14	14	14
Slovenia	12	12	12
Spain	9.5	10	10
Sweden	27	27	27
UK	17.5	20	20

Source: Own calculations

Table 20 Ranks of countries with respect to all variables but the first one

	Ranks according to		
	AR	MD	ED
Austria	21	18	18
Belgium	19	17	17
Bulgaria	3	2	2
Cyprus	11	8	8
Czech Rep.	7,5	5	5
Denmark	22	22	22
Estonia	18	19	19
Finland	24	24	24
France	25	21	21
Germany	26	23	23
Greece	5	11	11
Hungary	2	3	3
Ireland	15	16	16
Italy	13	12	12
Latvia	12	13	13
Lithuania	10	10	10
Luxembourg	17	25	25
Malta	6	7	7
Netherlands	23	26	26
Poland	1	1	1
Portugal	14	15	15
Romania	4	4	4
Slovakia	9	6	6
Slovenia	7,5	9	9
Spain	16	14	14
Sweden	27	27	27
UK	20	20	20

Source: Own calculations

Table 21 Ranks of countries with respect to all variables but the first one, SDI6 and SDI7 averaged

	Ranks according to		
	AR	MD	ED
Austria	19	17	17
Belgium	20	19	19
Bulgaria	2	1	1
Cyprus	14	14	15
Czech Rep.	8	5	8
Denmark	22	20	21
Estonia	17	16	14
Finland	24	22	20
France	25	21	22
Germany	26	24	23
Greece	10	10	10
Hungary	3	3	3
Ireland	15.5	18	18
Italy	12	12	12
Latvia	5	8	5
Lithuania	6	7	6
Luxembourg	18	25	25
Malta	13	11	13
Netherlands	23	26	26
Poland	1	2	2
Portugal	11	13	11
Romania	4	4	4
Slovakia	7	6	7
Slovenia	9	9	9
Spain	15.5	15	16
Sweden	27	27	27
UK	21	23	24

Source: Own calculations

Table 22 Ranks of countries with respect to variables without dynamical ones

	Ranks according to		
	AR	MD	ED
Austria	19	17	17
Belgium	20	19	19
Bulgaria	2	1	1
Cyprus	14	14	15
Czech Rep.	8	5	8
Denmark	22	20	21
Estonia	17	16	14
Finland	24	22	20
France	25	21	22
Germany	26	24	23
Greece	10	10	10
Hungary	3	3	3
Ireland	15.5	18	18
Italy	12	12	12
Latvia	5	8	5
Lithuania	6	7	6
Luxembourg	18	25	25
Malta	13	11	13
Netherlands	23	26	26
Poland	1	2	2
Portugal	11	13	11
Romania	4	4	4
Slovakia	7	6	7
Slovenia	9	9	9
Spain	15.5	15	16
Sweden	27	27	27
UK	21	23	24

Source: Own calculations

Now, let us appoint "absolute winners" and "absolute losers", defined as these countries, which are in the first / last five countries in rankings based on all methods used and all sets of variables included. The very first of absolute winners is Sweden, as it is the best country according to all methods of ranking. Besides Sweden, also Netherlands are among first five in all possible rankings. As for the worst ones, four countries: Hungary, Poland, Bulgaria and Romania appear repeatedly among worst five. Table 23 shows the differences between averaged ranks and averaged (and normalized) values for set of best (Sweden, Netherlands) and worst (Hungary, Poland, Bulgaria, Romania) countries. It occurs, that for SDI1 and SDI6 these differences are negative, that is, suggesting advantage of the second set of countries. It may be concluded, that these two variables are probably not the best indicators of sustainable development. Note, that both of them have relative character. The third relative variable, SDI8, is characterized by a comparatively small advantage of best over worst countries. However, removing it from analysis would be a controversial step, as its logical consequence would be removal also SDI7 variable, characterized by even smaller advantage. Yet, SDI7 denotes the share of renewable energy in energy consumption, and it seems to be one of essential indicators of sustainable development. As for Czech Republic, it ranks from 17th to 22nd. It is always better then four above mentioned worst countries and is in the midst of ranking for co-called post-communist countries. According to ranking excluding relative variables, which seems most preferably one, Czech Republic has 17th to 19th rank, according to various methods.

Table 23 Differences between averaged ranks and averaged values for set of best and worst countries

Difference between averaged:	SDI1	SDI2	SDI3	SDI4	SDI5	SDI6	SDI7	SDI8	SDI9
Ranks	–5.00	19.50	23.50	14.00	17.00	–7.50	2.00	8.25	22.00
Values	–0.24	00.45	00.59	00.57	00.60	–0.15	0.30	0.33	00.91

Source: Own calculations

SUMMARY AND CONCLUSIONS

In this paper we were trying to rank European Union countries according to the level of their sustainable development. The task in not straightforward, as there exist many indicators of sustainable development, each of which may have units completely different from the others, and different impact (weight) on the generally perceived sustainable development. We have chosen here nine main indicators, representing different groups of indicators, for which data for 2007 year was available. We have decided also not to make a differs among various indicators as regarding their impact on SD, thus to take all of them with equal weight. We have normalized these variables, taking the range of variability of each one as the range of it.

Using different methods we have ranking countries of EU. The simplest method relies on joint (or averaged) ranks in respect to all indicators. Another method ranks countries according to their distances from ideal "worst" and "best" points. The advantage of Manhattan distance is that ranking established by distances of the countries from the worst point is the same as the ranking obtained by counting distances of the countries to the best point. That is not, however, in the case of Euclidean distance. As ranking determined by distance from worst point may be different from ranking with regard to distance to the best point, we have decided to average this two distances. It appears, that such procedure is equivalent to calculating the distance from the worst point of the perpendicular projection on the axis designed by worst and best points.

Although some of SD indicators may be questionable, it seems easy to establish worst and best points in this case, as by definition sustainable development indicators should indicate the level of sustainable development. However, in cases when we cannot appoint ideal points (for example, if we do not know, which variable is favorable and which one is not) we can use a "good-bad" point method. Using data, we have shown, that averaging over a few such axes we get results converging to "worst-best" method. Moreover, we have shown, that in most cases one can obtain good results with averaging over two kinds of scaling methods, what may be helpful if we have not many "good-bad" axis at hand.

All rankings appointed Sweden as an absolute "winner", as this country occurs as the best one no matter which method of ranking is used. Also, Netherland are always one of the best five countries. On the other hand, four countries, namely, Hungary, Poland, Bulgaria and Romania appears repeatedly as one of the worst five countries (in varying order). Czech Republic is always within third best quarter.

References

ARROW K., J., BOLIN, B., COSTANZA, R., DASGUPTA, P., FOLKE, C., HOLLING, C. S., et al. Economic Growth, Carrying Capacity and the Environment. *Science*, 268, 1995, pp. 520–521.

BELL, S., MORSE, S. *Sustainability Indicators: Measuring the Immeasurable?* UK: TJ International Ltd., 2008.

COUNCIL OF THE EUROPEAN UNION. *Review of the EU Sustainable Development Strategy (EUSDS) – Renewed Strategy,* 10917 / 06.

EBERT, U., WELSH, H. Meaningful Environmental Indices: a Social Choice Approach. *Journal of Environmental Economics and Management,* 47, 2004, pp. 270–283.

ESTY, D. C., LEVY, M., SREBOTNJAK, T., SHERBININ, A. 2005 *Environmental Sustainability Index: Benchmarking National Environmental Stewardship* [online]. New Haven, CT: Yale Center for Environmental Law & Policy, 2005. <http://www.yale.edu/esi>.

EU. *Monitoring Report of the EU Sustainable Development Strategy. Sustainable Development in the European Union* [online]. Brussels: Eurostat, 2011. [cit. 12.6.2012]. <http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/indicators>.

GALBRAITH, J. K. *The Affluent Society*. Boston: Houghton Mifflin Company, 1958.

HAK, T., MOLDAN, B., DAHL, A. (eds.). *Sustainability Indicators: A Scientific Assessment*, SCOPE, Vol. 67, Island Press, 2007.

HOSSEINI, H. M., KANEKO, S. Dynamic Sustainability Assessment of Countries at the Macro Level: A Principal Component Analysis. *Ecological Indicators*, 11, 2011, pp. 811–823.

KING, C., GUNTON, J., FREEBAIRN, D., COUTTS, J., WEBB, I. The Sustainability Indicator Industry: Where to from Here? A Focus Group Study to Explore the Potential of Farmer Participation in the Development of Indicators. *Australian Journal of Experimental Agriculture,* 40, 2000, pp. 631–642.

OSTASIEWICZ, W. *Zastosowanie zbiorów rozmytych w ekonomii* (The Use of Fuzzy Sets in Economics). Warszawa: PWN, 1986.

PHILLIS, Y. A., GRIGOROUDIS, E., KOUIKOGLOU, V. S. Sustainability Ranking and Improvement of Countries. *Ecological Economics,* 70, 2011, pp. 542–553.

SEN, A. Real National Income. *Review of Economic Studies,* 43, 1976, pp. 19–39.

VAN DE KERK, G., MANUEL, A. A Comprehensive Index for a Sustainable Society: the SSI — the Sustainable Society Index. *Ecological Economics,* 66, 2008, pp. 228–242.

WCED. Report of the World Commission on Environment and Development to the General Assembly of the United Nations. *Our Common Future,* 1987.