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Fossil fuel sustainability index: An application of resource management ☆

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Abstract

A brief review on use of fossil fuel resources and sustainability is given in this paper. A sustainability index for fossil fuels is developed, which aims to determine the most efficient management of fossil fuel resources for the energy system. The study is conducted for 62 countries, in the presence of independence, lifetime and environmental constraints. The effect of these indicators are then integrated into a single index for oil, natural gas, and coal. Two approaches have been taken. The first one employs equally weighing of each index, where the second one weighs the indices by using principle component analysis. It is concluded that Fossil Fuel Sustainability Index (FFSI) values indicate that countries supporting oil as the one and only major player are condemned to suffer due to incompetent energy policies.

Keywords: Fossil fuel; Sustainability index; Energy resource management

1. Introduction

Introduction of the concept of "sustainable development" in the international discussion goes back to the World Conservation Strategy in 1980 (Hueting and Reijnders, 2004). However, the international community has been focusing on the concept since the publication of *Our Common Future*, also known as *Brundtland Report*, produced by the World Commission on Environment and Development (WCED, 1987). The sustainable development is best defined as meeting the needs of the present generations without compromising the ability of future generations to meet their own needs (WCED, 1987).

Sustainable development, balancing economic and social development with environmental protection has recently become a modern paradigm (Herendeen and Wildermuth, 2002; Hueting and Reijnders, 2004; Hammond, 2004c; Spreng, 2005; Giampietro et al., 2006). In the most recent paper entitled "The Climax of Humanity", Musser (2005, p. 44) stated that "*Depending on how we manage the next few decades, we could usher in environmental sustainability—or collapse*". However, although initially the emphasis was strongly on ecology, recently the others also became important (Herendeen and Wildermuth, 2002). A new metadiscipline of sustainability science and engineering is emerging rapidly. This new field also called green engineering and environmental science, integrates industrial, social, and environmental processes in a global context (Mihelcic et al., 2003).

Sustainability, of which conceptions of defining and measuring have broadly been placed in two categories such as "weak sustainability" and "strong sustainability" in previous literature (e.g., Home, 1991; Pearce and Atkinson, 1993; Gutés, 1996; Rennings and Wiggering, 1997), have

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recently been dealt with under different concepts such as "process sustainability" (e.g., Gonzales and Smith, 2003), "engineering sustainability" (e.g., Hammond, 2004a–c), "production sustainability" (e.g., Hueting and Reijnders, 2004; Kjaerheim, 2005), and "environmental sustainability" (e.g., Hueting and Reijnders, 2004), etc.

The measurement of sustainability of natural systems has become of supreme importance recently. Many researchers are trying to characterize the sustainability in terms of a set of indicators. Diaz-Balteiro and Romero (2004, p. 401) noted, "*Despite of potential problems underlying this approach, like hidden nonlinearities, interaction between indicators, dynamic aspects, etc., the 'indicator approach' has acquired paramount importance in the environmental and ecological economics literature*".

The attempts to develop an index to measure sustainability date back to the beginnings of 1990s. Home (1991) derived an index of external sustainability that reflects the probability of future changes in policy expected by private agents over time. Pearce and Atkinson (1993) presented a form of a weak sustainability indicator. More recently, Sands and Podmore (2000) developed the Environmental Sustainability Index (ESI). Pawlowski et al. (2005) used Fisher Information as a basis for an index of sustainability.

Hanley et al. (1999) and Pannell and Glenn (2000) have noted that no one single measure of sustainability is likely to be sufficient and sustainability should be dealt with by monitoring a range of indicators of different types because of its multifaceted nature. For example, Hanley et al. (1999) presented results from a time-series analysis of seven alternative measures of sustainability for Scotland, such as green net national product, genuine savings, ecological footprint, environmental space, net primary productivity, the index of sustainable economic welfare, and the genuine progress indicator. A good summary of the sustainability indicators used by various authors can be found in Hueting and Reijnders (2004). As Ding (2005) and Giampietro et al. (2006) have emphasized recently, science for sustainability policy requires the handling of multi-criteria, multi-dimensional, and multi-scale analyses.

The concept of sustainability is usually dealt with the supply side of the energy systems although such authors as Spreng (2005) gave more emphasis on sustainability of energy consumption. It is, therefore, important to consider whether the production of energy by fossil fuel combustion is sustainable since they consists most of the energy consumed in almost all modern countries. For instance, The UK Government, which is committed by their 2003 Energy White Paper to developing a sustainable energy economy in the 21st Century, should reduce primary energy consumption to between 45% and 75% to be able to reach the target of reducing emissions to 60% of their existing figure by 2050 (Hammond, 2004b).

Sustainability of energy production has three basic dimensions such as, dependency on foreign sources, depletion of domestic sources, and environmental degradation. Deutch (2005) recently argued that energy independence is usually meant ending reliance on imported oil. Studying USA, Japan, Germany, and France Deutch (2005, p. 20) stated, "*The amount of petroleum imported by the United States and other countries is so enormous that operating without it over the next several decades will be impossible for any advanced industrialized economy*". Therefore, he concluded that "*Energy independence is a distant dream for all of these countries*" (p. 20).

Fossil fuel depletion in a global scope is inevitable, and but can only be delayed upon technological advances and sustainable utilization policies. Gutés (1996) discussed the links between growth theory with exhaustible resources and the concept of weak sustainability as an indicator of sustainable development. Hammond (2000 and 2004a) argued, "fossil fuel depletion" and "pollutant emissions and global warming" are the two important things to be considered for "sustainable energy systems". Therefore, one of the conditions for sustainable development is "*Finite materials including fossil fuels should not be extracted at a faster rate than they can be redeposit in the Earth's crust*" (Hammond, 2004a, p. 616).

Therefore, the authors developed a sustainability index for fossil fuels, which aims to determine the most efficient management of fosil resources for the energy systems. The details of the methodology are given in the following section. The material used in this study is obtained from BP (2005). It includes the production, consumption, and reserve values of oil, natural gas, and coal for 2004. The data is available only for 62 countries. The other countries, which are out of the scope of this study, have relatively insignificant values of production, consumption and reserves with respect to fossil fuels.

2. Methodology

In this study, the authors considered that three energy-related sustainability indicators are significant for sustainability of each type of fossil fuels, namely oil, natural gas, and coal. These indicators are: (1) RP ratio, (2) PC ratio, and (3) carbon emission ratio. They are equivalents of "depletion of resources", "dependence on outside subsidies", and "disruption of natural cycles" developed for agricultural analysis by Herendeen and Wildermuth (2002).

RP ratio, reserves-to-production ratio, is defined as "*If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that level*" (BP, 2005, p. 4). Therefore, RP ratio is expected to give an idea about how many years the reserves last if the present production rate is kept constant. It is a measure of sustainability of the available reserves.

PC ratio is obtained by dividing the annual production to annual consumption of each type of fossil fuels. The ratio gives an idea about how much of the consumption is met by domestic resources. In other words, it is a measure of dependency on foreign sources.

CE ratio, carbon emission ratio, is obtained by multiplying the amount of consumption of each fossil fuel with corresponding carbon conversion factors as 0.84 for oil, 0.64 for natural gas, and 1.08 for coal. The carbon conversion factors may vary from country to country due to methods and level of technological advancement in exploiting the energy source. However the conversion factors used in this study provide the means to make overall estimates of CO_2 emissions from the consumption of fossil fuels based on carbon content of each fuel from the global energy data in the BP Statistical Review (2005) as it is not practically applicable and essential to use country-based conversion factors where the aim is to acquire means for a comparative evaluation rather than country specific statistical data. We took the reciprocal of the calculated values, as the smaller the carbon emission produced, the stronger the sustainability since CO_2 emissions are the main responsible agent of the environmental fatigue and permanent damage on the health and environmental risk. Hence, this anti-proportionality is expressed by taking the reciprocal where large CO_2 emission values will lead to small values in our case, and vise versa.

The next step is to integrate these indicators into a single index for oil, natural gas, and coal, namely Oil Sustainability Index (OSI), Natural Gas Sustainability Index (GSI), and Coal Sustainability Index (CSI). For this, RP ratios, PC ratios, and CE ratios are first standardized between 0 and 1 by using the minimum and maximum values given in Table 1 in the following formula:

$$\text{Normalized value} = \frac{(\text{Actual value} - \text{Minimum value})}{(\text{Maximum value} - \text{Minimum value})}. \quad (1)$$

Table 2 shows the standardized values of energy indicators. As shown in the table, performance of each dimension is expressed from 0 (poorest performance) to 1 (ideal performance). The maximum values for RP, PC and CE of oil occur in Kuwait, Norway, and Lithuania, respectively.

Then, these indices are integrated into a single composite index called the Fossil Fuel Sustainability Index (FFSI). Two methods are used for this purpose. The first one employs equally weighing of each index by using the following formula:

$$\text{SI(for oil, natural gas, coal)} = 1/3\ \text{RP} + 1/3\ \text{PC} + 1/3\ \text{CE}. \quad (2)$$

The OSI, GSI, and CSI are then integrated into the FFSI by using the percentages of oil, natural gas, and coal in total fossil fuel consumption. The formula (3) is used for this purpose:

$$\text{FFSI} = (\text{Oil\%})\ \text{OSI} + (\text{Natural Gas\%})\ \text{GSI} + (\text{Coal\%})\ \text{CSI}. \quad (3)$$

The second method uses multivariate analysis such principal component analysis (PCA). It is a similar method used for integrating energy-related indicators into the Human Development Index (HDI) forming Modified Human development Index (MDHI) in Ediger and Tatlıdil (in press). The method is in part similar to methodology proposed by Herendeen and Wildermuth (2002) and Diaz-Balteiro and Romero (2004) to solve the problem of "aggregation of the different indicators into an index."

In this method, the weights of each indicator are calculated by using PCA. The correlation matrix of principal variables for oil, natural gas, and coal are given in Table 3. In oil, a positive correlation is observed between RP and PC with a value of 0.612 and the correlation is not significant between the others with small values such as −0.026 and 0.178. On the other hand, in natural gas and coal, none of the correlation coefficients between variables are significant with values −0.072, −0.059, and 0.130 for natural gas and −0.126, −0.032, and 0.017 for coal. This simply means that the PCA application will not give significant results except oil.

The PCA results also confirm this conclusion (Table 4). The highest explained variance occurs as 54.361% for oil's PC1. Other values of explained variances vary between 39.376%, 31.759%, and 28.965% for natural gas, and 37.572%, 33.596%, and 28.832% for coal. This means that loadings from PCA can be used only for oil and PC1 and PC2 will explain 88.164% of variance. For others equal loadings as explained in the formula (2) may be used.

Therefore, the following formulas (4)–(6) are used for oil, where natural gas, and coal indices are calculated by using formula (2). The FFSI is then calculated by using the formula (3).

$$\text{OSI 1} = 0.871\ \text{RP} + 0.907\ \text{PC} + 0.220\ \text{CE}, \quad (4)$$

$$\text{OSI 2} = -0.281\ \text{RP} + 0.035\ \text{PC} + 0.966\ \text{CE}, \quad (5)$$

$$\text{OSI} = (\text{OSI 1} + \text{OSI 2})/2. \quad (6)$$

The final formula OSI equation will then be calculated by weighing factors of 0.295, 0.471, and 0.593 for RP, PC and CE respectively.

Table 1
Goalposts for each indicator

		RP	PC	CE
Oil	Minimum	1.00E+00	4.14E-06	8.96E-04
	Maximum	1.14E+02	1.56E+01	3.36E-01
Gas	Minimum	1.00E+00	8.96E-04	2.68E-03
	Maximum	6.58E+02	3.36E-01	3.13E+01
Coal	Minimum	1.00E+00	2.72E-05	9.68E-04
	Maximum	2.30E+03	6.60E+01	9.26E+02

3. Results and discussions

The results of two methods are given in Table 5 and Fig. 1. The FFSI series can be divided into low, medium or transitional, and high between ranks 1 and 9, 10 and 15,

Table 2
Normalized values of energy indicators (maximum numbers are bold)

No	Country	Oil			Gas			Coal		
		RP	PC	CE	RP	PC	CE	RP	PC	CE
1	Algeria	0.1396	0.4968	0.2316	0.0828	0.2244	0.0025	0.0000	0.0000	0.0012
2	Argentina	0.0773	0.1297	0.1314	0.0190	0.0688	0.0014	0.0000	0.0000	0.0014
3	Australia	0.1724	0.0379	0.0619	0.1048	0.0833	0.0022	0.0933	0.0555	0.0000
4	Austria	0.0000	0.0000	0.1803	0.0000	0.0000	0.0058	0.0000	0.0000	0.0003
5	Azerbaijan	0.5262	0.2239	0.5544	0.4615	0.0317	0.0064	0.0000	0.0003	0.0200
6	Bangladesh	0.0000	0.0000	0.5942	0.0487	0.0581	0.0041	0.0000	0.0000	0.0025
7	Belarus	0.0000	0.0000	0.3316	0.0000	0.0000	0.0029	0.0000	0.0002	0.0100
8	Belgium and Luxembourg	0.0000	0.0000	0.0631	0.0000	0.0000	0.0033	0.0000	0.0000	0.0002
9	Brazil	0.1680	0.0582	0.0271	0.0434	0.0342	0.0029	**1.0000**	0.0021	0.0001
10	Bulgaria	0.0000	0.0000	0.5423	0.0000	0.0000	0.0178	0.0360	0.0093	0.0001
11	Canada	0.1236	0.0949	0.0225	0.0119	0.1187	0.0005	0.0430	0.0173	0.0000
12	Chile	0.0000	0.0000	0.2316	0.0000	0.0000	0.0067	0.0000	0.0000	0.0004
13	China	0.1102	0.0362	0.0054	0.0817	0.0607	0.0013	0.0250	0.0157	0.0000
14	China Hong Kong SAR	0.0000	0.0000	0.1612	0.0000	0.0000	0.0249	0.0000	0.0000	0.0002
15	Colombia	0.0587	0.1732	0.2455	0.0248	0.0581	0.0087	0.0519	0.2009	0.0004
16	Czech Republic	0.0000	0.0000	0.2612	0.0000	0.0000	0.0062	0.0387	0.0175	0.0000
17	Denmark	0.0729	0.1356	0.2728	0.0126	0.1007	0.0101	0.0000	0.0000	0.0002
18	Ecuador	0.2204	0.2779	0.3952	0.0000	0.0012	**1.0000**	0.0000	0.0152	**1.0000**
19	Egypt	0.1138	0.0839	0.0912	0.1036	0.0608	0.0021	0.0000	0.0000	0.0014
20	Finland	0.0000	0.0000	0.2338	0.0000	0.0000	0.0127	0.0000	0.0000	0.0002
21	France	0.0000	0.0000	0.0240	0.0000	0.0000	0.0012	0.0068	0.0006	0.0001
22	Germany	0.0000	0.0000	0.0176	0.0169	0.0110	0.0006	0.0137	0.0097	0.0000
23	Greece	0.0000	0.0000	0.1227	0.0000	0.0000	0.0226	0.0236	0.0155	0.0001
24	Hungary	0.0000	0.0000	0.3952	0.0000	0.0000	0.0042	0.1040	0.0146	0.0003
25	India	0.1564	0.0204	0.0183	0.0461	0.0533	0.0016	0.0994	0.0140	0.0000
26	Indonesia	0.0933	0.0645	0.0432	0.0516	0.1265	0.0016	0.0159	0.0556	0.0000
27	Iran	0.7796	0.1770	0.0315	0.4878	0.0570	0.0006	0.0000	0.0000	0.0009
28	Italy	0.1627	0.0039	0.0253	0.0180	0.0103	0.0007	0.0000	0.0000	0.0001
29	Japan	0.0000	0.0000	0.0077	0.0000	0.0000	0.0007	0.1162	0.0001	0.0000
30	Kazakhstan	0.7342	0.4038	0.2584	0.2451	0.0704	0.0036	0.1564	0.0245	0.0000
31	Kuwait	**1.0000**	0.5601	0.1803	0.2494	0.0581	0.0057	0.0000	0.0152	**1.0000**
32	Lithuania	0.0000	0.0000	**1.0000**	0.0000	0.0000	0.0178	0.0000	0.0002	0.0100
33	Malaysia	0.1058	0.1107	0.1049	0.0680	0.0942	0.0016	0.0000	0.0000	0.0002
34	Mexico	0.0853	0.1434	0.0267	0.0157	0.0448	0.0011	0.0581	0.0072	0.0001
35	Netherlands	0.0000	0.0000	0.0516	0.0315	0.0919	0.0012	0.0000	0.0000	0.0001
36	New Zealand	0.0000	0.0000	0.3554	0.0000	0.0581	0.0155	0.0496	0.0253	0.0006
37	Norway	0.0649	**1.0000**	0.2584	0.0447	**1.0000**	0.0121	0.0000	0.0000	0.0017
38	Pakistan	0.0000	0.0000	0.1714	0.0508	0.0525	0.0021	0.4421	0.0062	0.0003
39	Philippines	0.0000	0.0000	0.1560	0.0000	0.0000	0.0226	0.0000	0.0000	0.0002
40	Poland	0.0000	0.0000	0.1150	0.0386	0.0190	0.0041	0.0374	0.0183	0.0000
41	Portugal	0.0000	0.0000	0.1570	0.0000	0.0000	0.0178	0.0000	0.0000	0.0003
42	Qatar	0.3644	0.8712	0.7569	**1.0000**	0.1507	0.0036	0.0000	0.0152	**1.0000**
43	Republic of Ireland	0.0000	0.0000	0.2855	0.0000	0.0000	0.0138	0.0000	0.0000	0.0006
44	Romania	0.0871	0.0362	0.2455	0.0324	0.0409	0.0029	0.0064	0.0145	0.0001
45	Russian Federation	0.1804	0.2287	0.0168	0.1225	0.0851	0.0001	0.2437	0.0183	0.0000
46	Saudi Arabia	0.5938	0.4071	0.0288	0.1602	0.0581	0.0008	0.0000	0.0152	**1.0000**
47	Singapore	0.0000	0.0000	0.0631	0.0000	0.0000	0.0071	0.0000	0.0152	**1.0000**
48	Slovakia	0.0000	0.0000	0.7135	0.0000	0.0000	0.0081	0.0000	0.0000	0.0002
49	South Korea	0.0000	0.0000	0.0212	0.0000	0.0000	0.0017	0.0105	0.0004	0.0000
50	Spain	0.0000	0.0000	0.0296	0.0000	0.0000	0.0019	0.0108	0.0048	0.0000
51	Sweden	0.0000	0.0000	0.1612	0.0000	0.0001	0.0713	0.0000	0.0000	0.0004
52	Switzerland	0.0000	0.0000	0.2062	0.0000	0.0000	0.0184	0.0000	0.0002	0.0100
53	Taiwan	0.0000	0.0000	0.0577	0.0000	0.0000	0.0054	0.0000	0.0000	0.0000
54	Thailand	0.0471	0.0132	0.0548	0.0306	0.0408	0.0018	0.0288	0.0086	0.0001
55	Turkey	0.0000	0.0000	0.0757	0.0000	0.0000	0.0024	0.0375	0.0067	0.0000
56	Turkmenistan	0.0569	0.1314	0.5089	0.0793	0.2056	0.0035	0.0000	0.0152	**1.0000**
57	Ukraine	0.0000	0.0000	0.1414	0.0907	0.0151	0.0007	0.1839	0.0161	0.0000
58	United Arab Emirates	0.9093	0.5166	0.1580	0.2012	0.0672	0.0013	0.0000	0.0152	**1.0000**
59	United Kingdom	0.0444	0.0757	0.0283	0.0078	0.0568	0.0005	0.0034	0.0061	0.0000
60	USA	0.0898	0.0225	0.0000	0.0134	0.0488	0.0000	0.1060	0.0152	0.0000
61	Uzbekistan	0.0853	0.0703	0.4151	0.0491	0.0658	0.0010	0.0000	0.0000	0.0008
62	Venezuela	0.6204	0.3739	0.0926	0.2260	0.0581	0.0019	0.0227	**1.0000**	0.0100

and 16 and 62 in Method 1 and between 1 and 10, 11 and 16, and 17 and 62 in Method 2, respectively. In the High FFSI group, Qatar, Norway, Kuwait, Equator, Azerbaijan, Iran, Venezuela, Saudi Arabia, United Arab Emirates exist in both methods. Lithuania exists in the second method but not in the first method.

Table 3
Correlation matrix of principal variables for oil, natural gas, and coal

	RP	PC	CE
Oil			
RP	1.000	0.612	−0.026
PC	0.612	1.000	0.178
CE	−0.026	0.178	1.000
Gas			
RP	1.000	0.130	−0.072
PC	0.130	1.000	−0.059
CE	−0.072	−0.059	1.000
Coal			
RP	1.000	−0.017	−0.126
PC	−0.017	1.000	−0.032
CE	−0.126	−0.032	1.000

Table 4
Principal component analysis results

Eigenvalues for oil	1.631	1.014	0.355
Explained variance, %	54.361	33.803	11.835
Component loadings	PC 1	PC 2	PC 3
RP	0.871	−0.281	*
PC	0.907	0.035	*
CE	0.220	0.966	*
Eigenvalues for natural gas	1.178	0.953	0.869
Explained variance, %	39.376	31.759	28.965
Component loadings	PC 1	PC 2	PC 3
RP	0.691	0.253	*
PC	0.671	0.382	*
CE	−0.500	0.862	*
Eigenvalues for coal	1.127	1.008	0.865
Explained variance, %	37.572	33.596	28.832
Component loadings	PC 1	PC 2	PC 3
RP	0.739	−0.237	*
PC	0.090	0.969	*
CE	−0.757	−0.115	*

*Eigenvalues are less than 1.

Table 5
FFSI calculated by two methods

Method 1 (equal weighing)			Method 2 (PCA)		
Rank	Country	FFSI	Rank	Country	FFSI
1	Qatar	0.4393	1	Norway	0.5330
2	Norway	0.3972	2	Qatar	0.4984
3	Kuwait	0.3953	3	Kuwait	0.4477
4	Ecuador	0.2981	4	Ecuador	0.4295
5	Azerbaijan	0.2644	5	Azerbaijan	0.3212
6	Iran	0.2513	6	Lithuania	0.2777
7	Venezuela	0.2316	7	Venezuela	0.2579
8	Saudi Arabia	0.2298	8	Saudi Arabia	0.2534
9	United Arab Emirates	0.2234	9	Iran	0.2526
10	Algeria	0.1656	10	United Arab Emirates	0.2469
11	Lithuania	0.1575	11	Algeria	0.2087
12	Kazakhstan	0.1493	12	Turkmenistan	0.1702
13	Turkmenistan	0.1316	13	Kazakhstan	0.1672
14	Colombia	0.1086	14	Colombia	0.1552
15	Brazil	0.1010	15	New Zealand	0.1333
16	Denmark	0.0903	16	Denmark	0.1332
17	Russian Federation	0.0881	17	Bangladesh	0.1164
18	New Zealand	0.0794	18	Bulgaria	0.1099
19	Bangladesh	0.0771	19	Slovakia	0.1085
20	Egypt	0.0763	20	Brazil	0.1074
21	Malaysia	0.0701	21	Republic of Ireland	0.1056
22	Australia	0.0661	22	Switzerland	0.1003
23	Bulgaria	0.0655	23	Russian Federation	0.0944
24	Slovakia	0.0615	24	Egypt	0.0926
25	Mexico	0.0606	25	Malaysia	0.0853
26	Republic of Ireland	0.0599	26	Sweden	0.0804
27	Argentina	0.0584	27	Hungary	0.0768
28	Canada	0.0576	28	Argentina	0.0755
29	Switzerland	0.0569	29	Finland	0.0755
30	Indonesia	0.0561	30	Mexico	0.0752
31	Uzbekistan	0.0554	31	Chile	0.0722
32	Pakistan	0.0519	32	Australia	0.0711
33	Romania	0.0503	33	Romania	0.0696
34	Ukraine	0.0474	34	Uzbekistan	0.0687
35	India	0.0467	35	Pakistan	0.0677
36	Hungary	0.0460	36	Portugal	0.0660
37	Sweden	0.0456	37	Indonesia	0.0645
38	Finland	0.0428	38	Canada	0.0643
39	Chile	0.0409	39	Philippines	0.0643
40	Portugal	0.0374	40	China Hong Kong SAR	0.0619
41	Italy	0.0369	41	Belarus	0.0616
42	Philippines	0.0365	42	Austria	0.0576
43	China Hong Kong SAR	0.0351	43	Ukraine	0.0527
44	Belarus	0.0349	44	Greece	0.0506
45	USA	0.0336	45	Czech Republic	0.0493
46	Austria	0.0327	46	India	0.0472
47	Czech Republic	0.0323	47	Thailand	0.0383
48	Thailand	0.0305	48	Italy	0.0373
49	Greece	0.0303	49	United Kingdom	0.0354
50	United Kingdom	0.0291	50	USA	0.0334
51	Netherlands	0.0256	51	Netherlands	0.0322
52	Poland	0.0235	52	Singapore	0.0320
53	China	0.0233	53	Poland	0.0305
54	Singapore	0.0181	54	Belgium & Luxembourg	0.0245
55	Turkey	0.0155	55	Turkey	0.0239
56	Belgium & Luxembourg	0.0139	56	China	0.0238
57	Japan	0.0124	57	Taiwan	0.0164
58	Taiwan	0.0093	58	Japan	0.0136
59	Germany	0.0074	59	Spain	0.0121
60	Spain	0.0072	60	France	0.0094
61	France	0.0054	61	Germany	0.0094
62	South Korea	0.0051	62	South Korea	0.0082

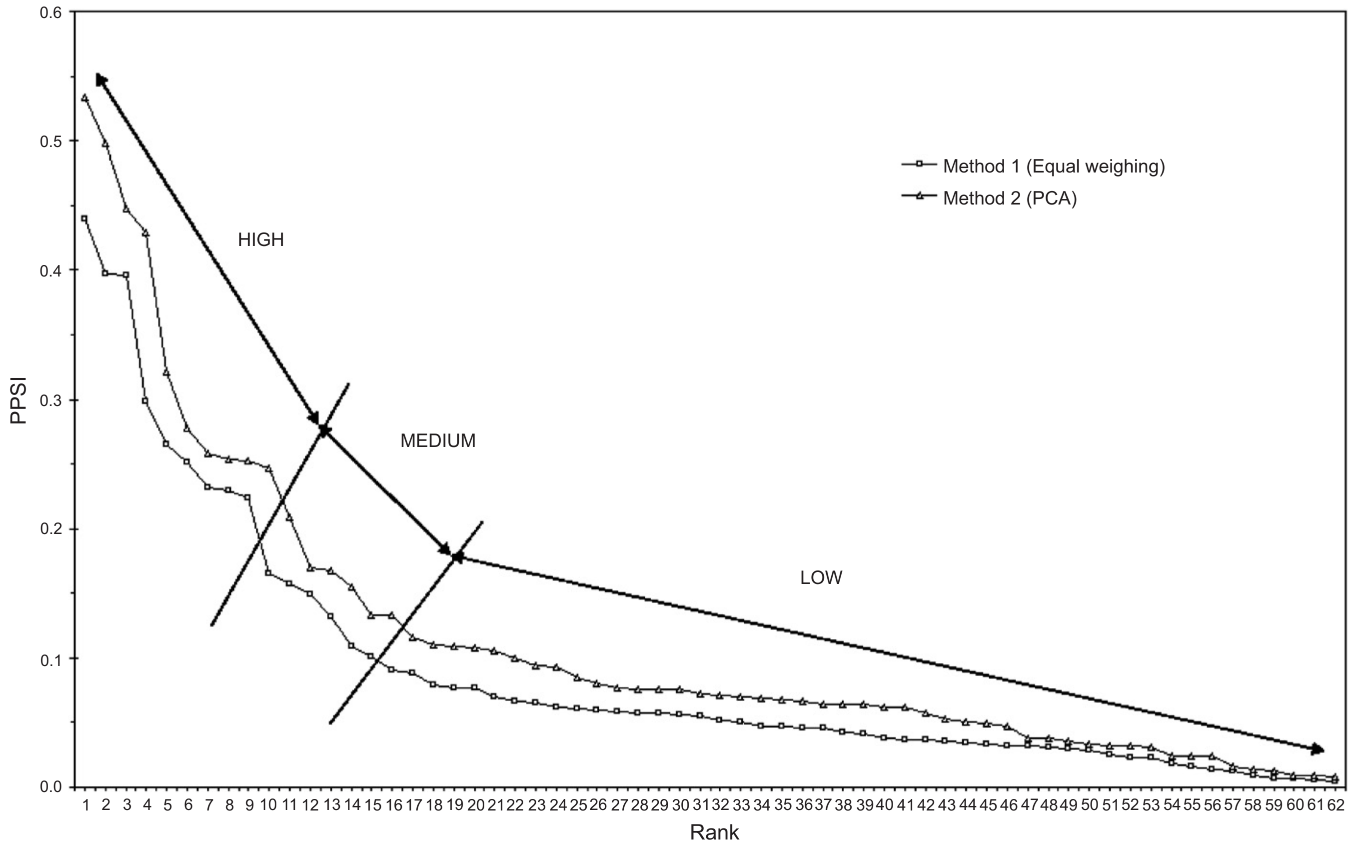

Fig. 1. Fossil Fuel Sustainability Index calculated from Methods 1 and 2.

The Medium or Transitional group includes Algeria, Lithuania, Kazakhstan, Turkmenistan, Colombia, and Brazil in the Method 1 and Algeria, Turkmenistan, Kazakhstan, Columbia, New Zealand, and Denmark in the Method 2. Rest of the countries is located in the Low FFSI group.

As seen in Fig. 1 both rank series are highly similar to each other. Actually, they correlate well with other with a correlation coefficient of 0.993. However, some differences occur between the ranks of two series (Fig. 2). No rank change occurs in 11 countries, namely, Azerbaijan, Colombia, Denmark, Ecuador, Kuwait, Netherlands, Romania, Saudi Arabia, South Korea, Turkey, and Venezuela. The highest rank decreases occur in Ukraine (−9), Australia (−10), Canada (−10), and India (−11) and the highest rank increases occur in Finland (+9), Hungary (+9), and Sweden (+11). As seen from the figure, highest number of changes occurs in the middle of both series. Despite these changes in rankings, the change in groups occurs only in four countries, namely; Lithuania, Brazil, Denmark and New Zealand. The rest 58 countries lie in the same group for both Methods 1 and 2 whether their ranking changes or not. Therefore, it can be concluded that both series can be used for interpretation of the FFSI.

Examining the High FFSI countries (Qatar, Norway, Kuwait, Equator, Azerbaijan, Iran, Venezuela, Saudi Arabia, and United Arab Emirates), it is concluded that oil plays a role more important than the other fossil fuels in FFSI because of its share is more than the others. The percentages vary between 11.63% and 99.20% for oil, 0.79% and 86.05% for natural gas, and 0–73.57% for coal. The averages of oil, natural gas, and coal are 47.52±19.92%, 35.18±21.96%, and 18.41±18.90%, respectively. Ranking of high FFSI countries in various indicators of oil are given in Table 6.

Most of the countries are not sustainable as far as fossil fuel management is concerned. Since oil dominant energy policy is ruling amongst the countries even though most of them do not have significant indigenous oil reserves where the excess consumption amount has to be exported from e.g. OPEC. Lack of oil reserves has a drastical effect on the FFSI model generated, for RP and PC values are directly related with size of the reserves. Nevertheless, fossil fuel-rich countries are also penalized due to large consumption values which are proportional to carbon emissions as environmental damages, where reserve-poor countries are penalized somewhat less accordingly. FFSI values indicate that countries supporting oil as the one and only major player for consumption are condemned to suffer due to incompetent energy policies. Henceforth, diversification in energy resources needs to be treated with great subtlety.

A truly sustainable development may be achieved with the diversification and use of local energy sources considering the impact of each energy system on the

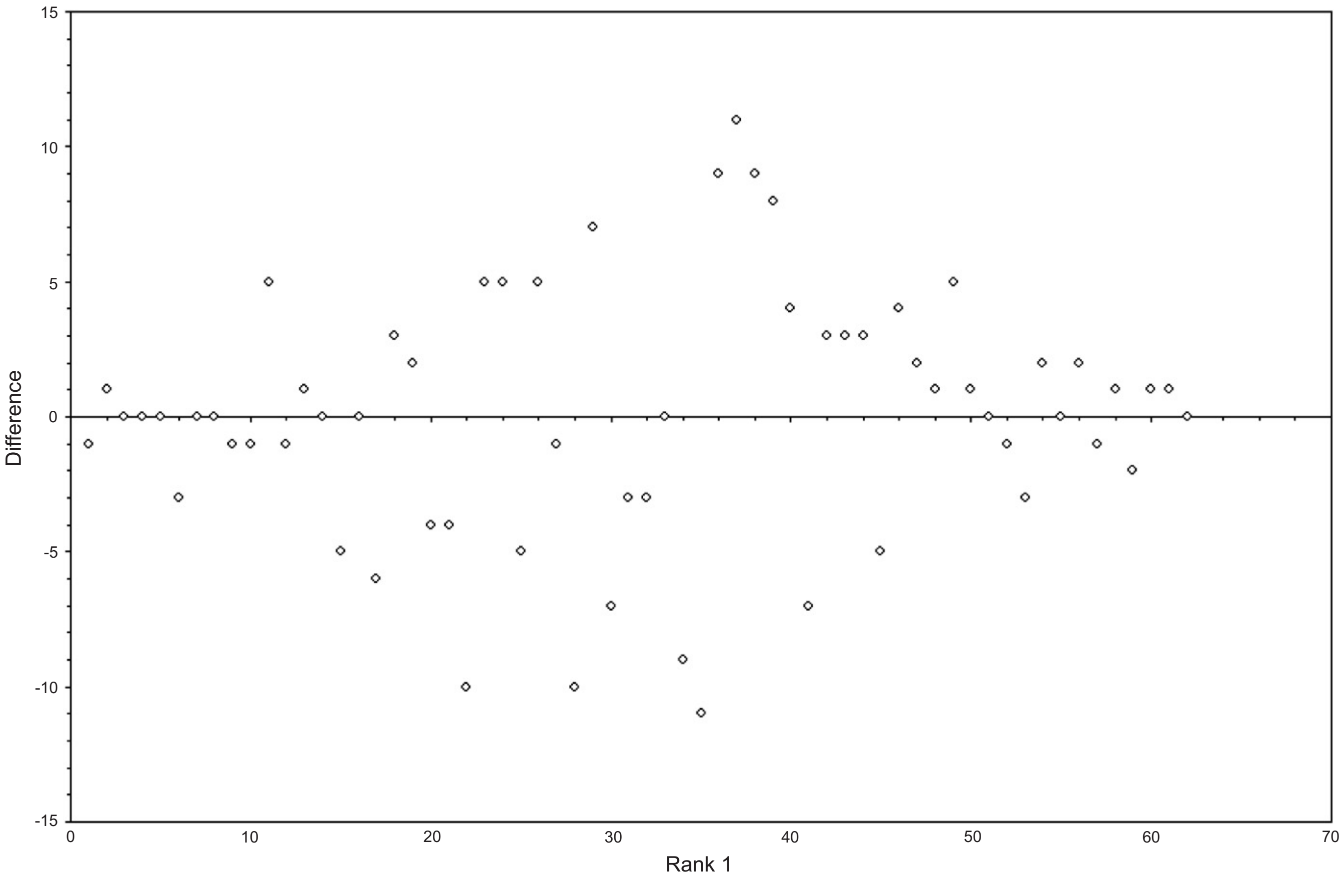

Fig. 2. Rank differences between two methods according to Rank 1.

Table 6
Ranking of high FFSI countries in various indicators of oil

Countries	RP	PC	CE
Qatar	8	2	2
Norway	27	1	17
Kuwait	1	3	25
Ecuador	9	9	9
Azerbaijan	7	11	5
Iran	3	12	47
Venezuela	5	8	37
Saudi Arabia	6	6	49
United Arab Emirates	2	4	29
Lithuania	46	32	1

environment is small and well within the tolerance limit. Diversity is an essential element of security, and sustainability because concentration of dependence onto fewer sources, technologies or types of fuel inherently increases risks and reduces the flexibility to respond.

4. Conclusions and prospective policy alternatives

The major conclusion of this study is that countries supporting oil as the one and only major player for consumption without adequate local reserves are condemned to suffer due to incompetent energy policies. However, although most experts agreed on the fact that a more sustainable energy supply will lead to a more sustainable future, the path toward sustainable energy remains unclear, with several alternatives (Abraham, 2005). One of the paths is developing of sustainable energy; the other is technological advances (e.g., Walter 2002; Voorspools, 2004).

Sustainable energy can be developed only by giving more emphasis on domestic resources in the countries' energy mix. The most abundant unused energy source appears to be coal in most of the countries. For instance, Deutch (2005, p. 22) ask the question "*Why should the United States so quickly abandon a natural resources that it has in such abundance*?", implying coal. Coal is of course one the dirtiest fossil fuel but for all its shortcomings it is a relatively cheap source of electricity.

However, it is also known that the economical viability will be more effective than the resource scarcity in the future energy mix. Deutch (2005), for instance, have argued that less foreign oil does not mean lower prices since the price of oil is based on global supply and demand and events influencing supply and demand in one country affect prices in another. Pasqual and Souto (2003) argued that the exploitation of a non-renewable resource should be accepted as long as part of the return compensates the future generations. This means sustainability can be achieved if there is adequate compensation. However, Deutch (2005) noted that it is questionable whether the customers are willing to pay more for green energy.

Replacing oil with natural gas is also another alternative. McCabe (1998) showed that the timing of extraction of a resource is driven by market and political forces and technology availability. The relationship between production and price of fossil fuel is important for substitution.

In spite of the present disadvantages, renewables are definitely the energy for the future. Renewable energy is basic not only to allow sustainable development but also to reduce poverty. Recently, Goldemberg and Coelho (2004, p. 711) summarized the advantages of renewables as: "*The advantages of renewables are well known, as far as they enhance diversity in energy supply markets*; *secure long-term sustainable energy supplies; reduce local and global atmospheric emissions*; *create new employment opportunities offering possibilities for local manufacturing and enhance security of supply since they do not require imports that characterize the supply of fossil fuels*". However, they also noted that the distinction between traditional (especially biomass) and modern renewables should definitely be made.

The other alternative appears to be nuclear. Nuclear energy offers reliable, safe, cheap, and sustainable electricity, which the world's future economic growth is closely tied to (e.g., Duffy, 2005) and nuclear power is an important means of diversifying energy supply and reducing carbon emissions (Deutch, 2005).

The role of technological change for a sustainable development has recently been discussed in detail by Vollebergh and Kemfert (2005). Bretschger (2005) and Deutch (2005) have argued whether new technologies are effective and efficient enough to act as a remedy for resource scarcity in the long run. However, Voorspools (2004) demonstrated that the efficiency improvement and sustainable conversion technologies cannot provide long-term alternatives. Alcott (2005) discussed whether the technological efficiency gains actually increased the overall consumption of energy together with material and other resources. Pasche (2002) showed that a growing part of income has to be spent for continuing technical progress in order to compensate the pollution effects of growth.

Finally, it should be reminded that the developed countries should act in partnership with developing countries no to repeat the environmental and social legacy of unsustainability of the industrial era. As Byrne et al. (1998) have appropriately argued that the industrial countries have the wealth, technology, and responsibility to solve the problems of climate and social inequity by avoiding globalization of fossil fuel economy.

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