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Research Article

RENEWABLE ENERGY PERFORMANCE OF OECD COUNTRIES: A WINDOW ANALYSIS APPLICATION

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ABSTRACT

Global warming and climate change are two of the most popular and urgent issues to be solved in recent years for all countries in the world. Many international agreements and protocols have been signed to solve these two problems. The main goal of this act is to stop global warming and climate change by reducing the use of fossil fuels. The aim of this study is to evaluate the OECD countries' renewable energy performances and make proposals to guide future energy policies.
In the study, 35 countries in the OECD were taken as decision-making units. Per capita national income to demonstrate the renewable energy performance of OECD countries in 2010-2015 is included as input; electricity production quantities obtained by renewable energy sources as output variables. In the review, Window Analysis (WA) based on Data Envelopment Analysis (DEA) was used which is a powerful methodology used to determine the relative performance of Decision Making Units (DMUs).
As a result of the study, the top five countries with the highest renewable energy performance in 2010-2015 were Iceland, Finland, Portugal, Spain and Czech Republic respectively. The five countries with the lowest renewable energy performance are Mexico, Israel, Korea, Luxembourg and Switzerland. Turkey is taking 19th place in the relative renewable energy performance ranking among OECD countries. Increasing trend has been observed in Turkey's performance. Nevertheless, in order to be able to move to efficient position it is necessary to increase the renewable energy production by more than four-fold, almost five-fold.
Keywords: Data envelopment analysis, window analysis, renewable energy, OECD, performance.

1. INTRODUCTION

The use of non-renewable energy sources is seen as the main cause of climate change and global warming. There have been several gathering on this issue and the strategy and conclusion reports published at the end of these meetings also support this situation. One of the goals set out in the outcome document agreed by 195 nations in the COP21 meeting held in Paris with the title of “United Nations Climate Change in 2015” is to keep the global warming at 2 ° C below 20 ° C, if possible at 1.5 ° C". At the meeting held in the EU Council in 2014, "The Framework of Climate and Energy Policies for 2030" was officially recognized. Within this framework, it was aimed to increase the share of renewable energy in total energy consumption to 27%, to reduce

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greenhouse gas emissions by 40% compared to 1990 emissions, by 2030. The way to prevent greenhouse gas emissions and thus global warming is to increase the use of renewable energy sources. For this reason, the countries of the world have developed various renewable energy strategies such as increasing the capacity and production of renewable energy and mitigation environmental impacts. Developed strategies , the applicability and success of the strategies are the content of many studies. While some strategies give good results, some strategies can give bad results. Analyzes at this stage are of great importance. The data envelopment analysis (DEA) is one of the most suitable techniques that can be applied in this case.

DEA is a technique often used in recent years for performance measurement in energy and environmental issues. The summary table of the method, scope and input-output variables of the studies on energy performance in the literature is given below.

Table 1. Renewable Energy Studies in the Literature

Authors	**Method**	**Scope**	**Input**	**Output**	**Period**
Kim et al. [1]	DEA-CCR	Korea	Investment	Power generation Patent The unit cost	2007-2011
Menegaki [2]	DEA Malmquist	EU countries	Rate of renewable energy sources in electricity generation % Energy consumption CO_2 emissions Employment rate Capital	GDP	1997-2010
Lins et al. [3]	DEA	Brasil	CO_2 emissions Business potential Production potential	Investment cost O&M + CC cost	2007
Wang [4]	Multi-criteria DEA	109 countries	CO_2 emission intensity Energy intensity	Share of renewable energy in electricity generation (%)	2005-2010
Woo et al. [5]	DEA Malmquist	OECD countries	Labor Capital Renewable energy supply	CO_2 emission GDP Electricity generated by renewable energy	2004-2011
Xie et al. [6]	Idle DEA Malmquist	OECD and BRICS countries	Labor Installed capacity Fuel and nuclear input	Power generation CO_2 emissions	1996-2010
Zhou et al. [7]	DEA Bootstrap Malmquist	18 countries	Labor Capital Energy consumption	GDP CO_2 emission	1997-2004
Lyu and Shi [8]	DEA Malmquist		R&D Investment, Stock Market, Venture Capital and Private Equity, Project Financing	Renewable Energy Generation	2008-2015
Meleddu and Pulina [9]	DEA Post-DEA	Italy	R&D expenses Other expenses Radiation protection expenses Electric power consumption	Photovoltaic power Renewable energy	2003-2010
Sözen and Karık [10]	DEA Malmquist	OECD and BRICS countries	Electricity capacity Primary energy supply Final energy consumption Energy production Electricity consumption Labor force/population Net capital account	Hydro capacity Geothermal capacity Solar photovoltaic capacity Wind capacity	2009-2013
Halkos and Tzeremes [11]	DEA	25 European countries	total labor force, capital stock Primary energy consumption (renewables)	GDP	2010
Chien and Hu [12]	DEA	OECD and non-OECD economies	Labor, Capital stock Energy consumption	GDP	2001-2002

In this study, the Win dow Analysis (WA) method was used to show the trend and stability of renewable energy performance of OECD countries.

WA is a time-based version of the DEA, a nonparametric mathematical programming based technique. When performing section analysis with DEA, a dynamic image is obtained by using the moving average logics in the time series analysis with WA. Thus, the stability and trend of the performance in the period during the study is done can be observed.

As a result of the analysis, the positions of OECD countries in renewable energy performance have been determined, the trend in performance over the years in question has also been revealed. Suggestions have been made for inefficient countries to be efficient.

2. RENEWABLE ENERGY

Energy is an indispensable consumption tool. With each passing day technology, industry and population increase, energy demand is also increasing. Energy by usage is divided into two categories: renewable and non-renewable. Figure 1 shows the predicted remaining lifetimes of non-renewable energy type fossil fuel reserves. The coal that has the most life expectancy is expected to be exhausted after 114 years. In addition, fossil fuels have serious damages to the environment. Due to these problems, the world countries have recently moved towards renewable energy sources.

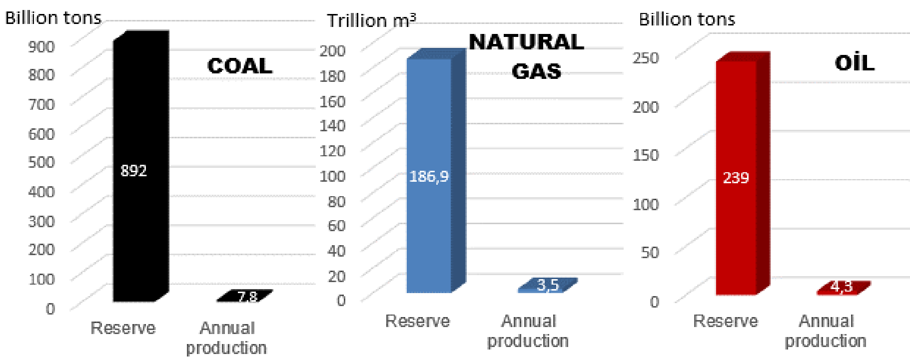

Figure 1. Residual life of fossil fuel reserves [13]

Renewable energy is produced from natural resources that can be renewed continuously and never consumed [14]. Renewable energy sources are mainly solar, hydraulic, wind, geothermal, bioenergy, wave and hydrogen. Figure 2 shows the ratios of renewable energy sources used in electricity generation. By using renewable energy sources, 5512 TWh of electricity were produced in 2015, of which 3893 TWh from hydraulics, 826 TWh from wind, 456 TWh from bioenergy, 256 Twh from sun, 82 TWH from geothermal and wave sources were derived [15]. However, the share of this production in total production is still not high enough.

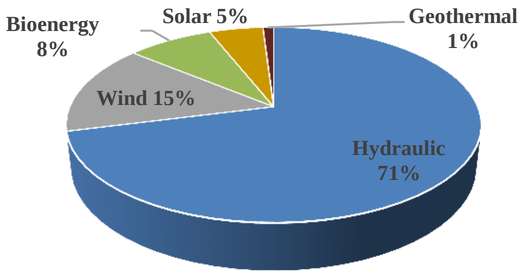

Figure 2. Usage rates of renewable energy sources in electricity generation

The share of resources in primary energy generation in the OECD countries in 2015 is given in Figure 3. Although the fossil fuels will soon be exhausted and the enormous damage that they give to the environment, they still take the first four places of energy production, oil, natural gas, coal and nuclear energy, respectively.

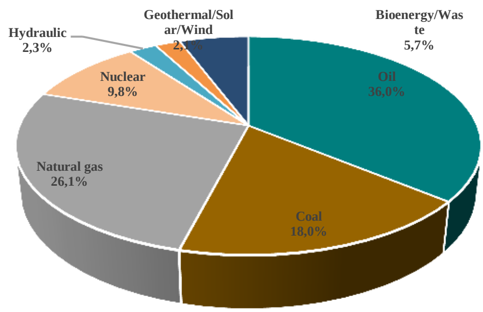

Figure 3. Distribution of primary energy consumption by sources [16]

When the new energy scenario of the international energy agency is taken into account, it is envisaged that the energy resources in the world electricity generation will change as in Figure 4 [17]. According to the study done; coal and natural gas will have an important share in energy production in the coming years. It is expected that the share of renewable energy sources will increase considerably while the share of petroleum in production is expected to decrease.

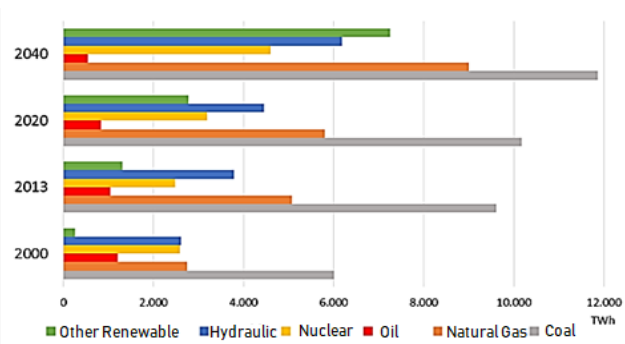

Figure 4. Foreseen changes in the share of energy resources in electricity generation (2000-2040)

3. METHODOLOGY AND DATA

3.1. Data Envelopment Analysis (DEA)

DEA is a nonparametric technique developed by Charnes, Cooper and Rhodes (CCR) [18] and it is known that DEA is based on Farrell's productivity measurement approach. While Farrell's original idea relates to an input and an output, Charnes, Cooper and Rhodes' DEA method is concerned with the case where organizations (DMUs) use multiple inputs to produce more than one output at the same time. A DMU is defined as units whose relative activities, such as business, institution, firm, company, which produce similar outputs with the help of similar inputs, are to be examined and their performance is evaluated.

DEA is a powerful new methodology for organizing and analyzing data and determining best practice boundaries. DEA's basic idea is to identify the most efficiency DMU among all DMUs. The most efficient DMU is called 'Pareto-optimal' and is considered as the standard for comparison for all other DMUs.

As a result of the calculations made, an efficiency value between 0 and 1 is obtained for each DMU. DMUs whose efficiency value is equal to 1 are referred as efficiency DMUs and set the efficiency limit. DMUs with an efficiency value between 0 and 1 are expressed as inefficient DMUs and the efficiency values express the distance to the efficiency boundary. The deviation of inefficient DMUs from the value of 1 gives the inefficiency measures of these units [19].

DEA models can be classified according to two criteria; scale effect and model orientation type. The first criterion sets assumptions (Constant return on scale (CRS) or variable return on scale (VRS)) about the scale effects that are accepted in the model. Mathematical models of scale effect are as follows:

- Constant return model [18]

This model, which is called the CCR model in literature, was proposed by Charnes, Cooper and Rhodes in 1978. Based on the constant return assumption, an increase or decrease in input or outputs cause the same proportional increase or decrease in the outputs or inputs respectively.
The output-focused CCR model is given below:

$$E_k = \max\beta - \varepsilon\sum_{i=1}^{m} S_i^- + \varepsilon\sum_{r=1}^{p} S_r^+$$
$$\sum_{j=1}^{n} X_{ij}\lambda_j + S_i^- - X_{ik} = 0 \qquad i = 1, \dots, m$$
$$\sum_{j=1}^{n} Y_{rj}\lambda_j - S_i^+ - \beta Y_{rk} = 0$$
$$\lambda_j \geq 0 \qquad S_i^- \geq 0 \qquad S_r^+ \geq 0$$
$$j = 1, \dots, n \qquad r = 1, \dots, p \qquad i = 1, \dots, m$$

- Variable return model [20]

The model, referred to as the BCC model, was proposed by Banker, Charnes, and Cooper in 1984. According to the variable return assumption, an increase or decrease in the input or output does not result in the same proportional increase or decrease in the output or inputs, respectively. The ratio may be greater or smaller than 1. The BCC model is obtained by adding the following constraint to the CCR model.

$$\sum_{j=1}^{m} \lambda_j = 1$$

In the second criterion, the model orientation is divided into input-oriented and output-oriented. In the input-oriented model the goal is to minimize the inputs, while in the output-oriented model, the goal is to maximize the output.

3.2. Window Analysis

In DEA, DMUs are observed and analyzed once. However, DMUs may be monitored multiple times in performance analyses to have knowledge of efficiency changes. At this point, window analysis is used. WA was developed in 1985 by Charnes, Clark, Cooper and Golany [21]. WA is a time-dependent version of DEA and based on moving average method. In WA, the data of a DMU at different times are included in the analysis as the data of a different DMU. It is a useful tool to see the change, stability, and trend of performance over time.

While the result tables of DEA analysis are called static tables, WA tables can be called dynamic tables [22].

In WA, there are the concepts of DMU number, periods and window size. Duration refers to the number of times a DMU has been observed and window size refers to the number of periods to be compared. Window size should not be larger than the period.

Inferences can be made on the basis of rows and columns of table created after WA. Conclusions can be made about the performance trends of DMUs on the row-based, and the determination of DMU's performance on the column-based.

3.3. Input, Output and Decision Units

In the study, 35 countries belonging to the Organization for Economic Development and Cooperation (OECD) were taken as DMUs. Per capita national income to demonstrate the renewable energy performance of OECD countries in 2010-2015 is included as input; electricity production quantities obtained by solar, wind, hydraulic, bioenergy and geothermal energy are included to work as output variables. Data obtained from the International Renewable Energy Agency (IRENA) website. All inputs and outputs have been converted per person.

4. FINDINGS AND RESULTS

In the study, WA was made to demonstrate the renewable energy performance of OECD countries between 2010-2015. Solutions were obtained using the Efficiency Measurement System (EMS 1.3.0) package program [23]. The average, standard deviation, and range values for the performance scores of the countries and the performance ranking based on these statistics are given in Table 2. % of the performance scores are given here. For example, the 2010 performance score for Canada is 45.62, and is actually 0.4562.

The top five countries with the highest renewable energy performance in 2010-2015 are Iceland, Finland, Portugal, Spain, and Czech Republic, respectively. The average performance scores of these countries were 97.98, 97.43, 96.93, 95.40, and 91.62, standard deviations were 3.02, 4.01, 5.26, 7.26, and 15.27 and range values were calculated as 9.33, 12.21, 16.31, 23.17, and 51.91.

The five countries with the lowest renewable energy performance are Mexico, Israel, Korea, Luxembourg, and Switzerland. The performance scores average of Mexico is 9.5. If this country increases its output by about 90% (in all the years), it may be an efficiency country in terms of renewable energy performance.

Turkey is taking 19th place in the relative renewable energy performance ranking among OECD countries with the 21.01 average, 3.74 standard deviation, and 15.16 range statistics. An increasing trend in Turkey's performance was observed (Table 2). Nevertheless, in order to be able to move to efficient position, it is necessary to increase the renewable energy production by more than four-fold, almost five-fold.

The country with the highest standard deviation and the highest performance score range is Greece (Std deviation = 28.9, Range = 73.96). This is an indication that the country's performance is heterogeneous. Greece, which had a very low performance score in 2010, significantly increased its performance by 2015. The reason for this change can be seen as the economic crisis that erupted in late 2009.

The desired condition for the performance of the DMU is that the average is as high as possible, and the standard deviation and variation range is small. It can be said that the performance of DMUs with small standard deviation and range is stable. For example, Luxembourg ranks 32nd out of 35 countries with an average of 11.81 performance score, although it has a 1.84 standard deviation and a 6.39 range. In this case, it can be deduced that Luxembourg's performance is stable but not good.

Table 2. Window Analysis Performance Score Statistics

Rank	Country	Average	Standard deviation	Range
1	Iceland	97,98	3,02	9,33
2	Finland	97,43	4,01	12,21
3	Portugal	96,93	5,26	16,31
4	Spain	95,40	7,26	23,17
5	Czech Republic	91,62	15,27	51,91
6	Estonia	90,89	9,36	24,95
7	Germany	78,77	9,14	29,78
8	Sweden	73,54	7,32	28,59
9	Denmark	73,49	5,52	15,65
10	Greece	70,19	28,90	73,96
11	Italy	67,44	18,53	65,50
12	Slovakia	53,67	11,15	40,91
13	Chile	53,65	11,34	44,16
14	Canada	49,47	7,02	22,65
15	Belgium	47,53	8,50	27,74
16	Poland	47,11	9,59	31,99
17	Austria	45,32	4,42	16,58
18	Slovenia	41,83	11,18	32,89
19	Latvia	41,16	13,21	38,65
20	New Zealand	38,09	4,62	13,68
21	Norway	37,96	5,96	22,04
22	Ireland	97,98	3,02	9,33
23	Hungary	35,54	4,64	13,19
24	UK	26,11	7,38	24,45
25	Japan	24,90	12,24	36,23
26	USA	24,16	1,71	5,66
27	Holland	24,13	2,03	7,21
28	Australia	21,66	4,88	14,58
29	Turkey	21,01	3,74	15,16
30	France	19,36	3,46	11,90
31	Switzerland	14,90	2,42	7,48
32	Luxembourg	11,81	1,84	6,39
33	Korea	11,71	3,41	10,55
34	Israel	11,02	3,57	12,34
35	Mexico	9,50	2,65	8,85

Between 2010 and 2015, the mean, standard deviation and range statistics based on the performance scores of all OECD countries over the years were obtained as 48.07, 29.76 and 96.40, respectively (Appendix-1). It can be said that the OECD countries' renewable energy performance scores change in a wide range and their average is very low.

Based on years in this period, OECD countries' renewable energy performance averages have an ever-increasing trend: ((%) 40.04, 42.70, 47.82, 49.98, 50.80, 58.10) (Appendix-1).

If the results are to be evaluated in terms of Turkey; Turkey's renewable energy performance is below the average of OECD countries (Figure 5).

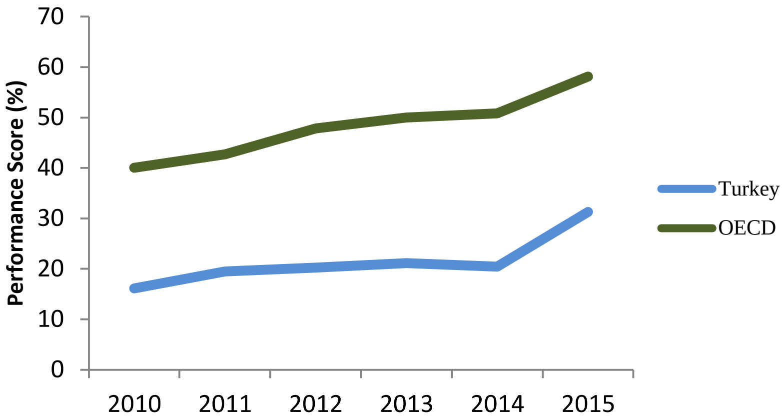

Figure 5. Renewable energy performance scores average of OECD and Turkey (2010-2015)

In Figure 6, 2 best and 2 worst performing countries and Turkey's performance scores are shown. The performance scores of the two top performing countries (Iceland and Finland) are close to 100, while the worst performers are Mexico and Israel with a performance score of about 10. Mexico's performance seems to be on the rise.

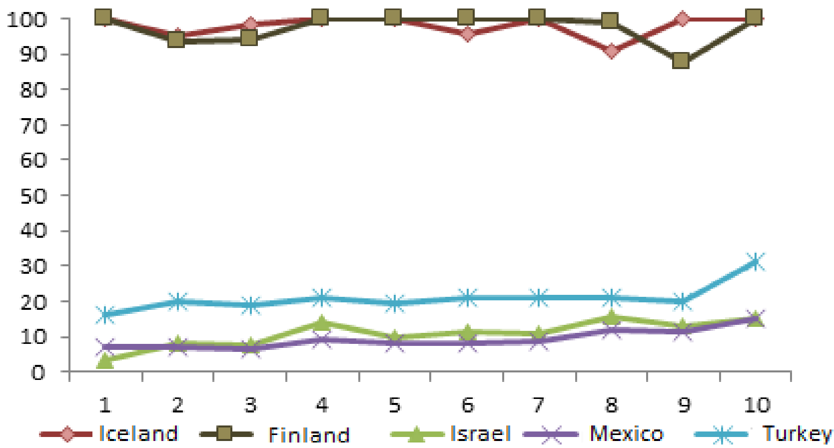

Figure 6. 2 best and 2 worst performing countries and Turkey's performance scores

In figure 7, 6 countries with different characteristics in performance are given. Although the range of performance scores of Greece is quite wide, it can be said that the performance has changed positively because of the increasing trend in performance. It seems that the US has gone bad in performance because performance scores are both low and declining trends. The UK, Mexico, and Japan performance scores are low, but these countries show an increasing trend. It can be deduced that Sweden's performance is not stable.

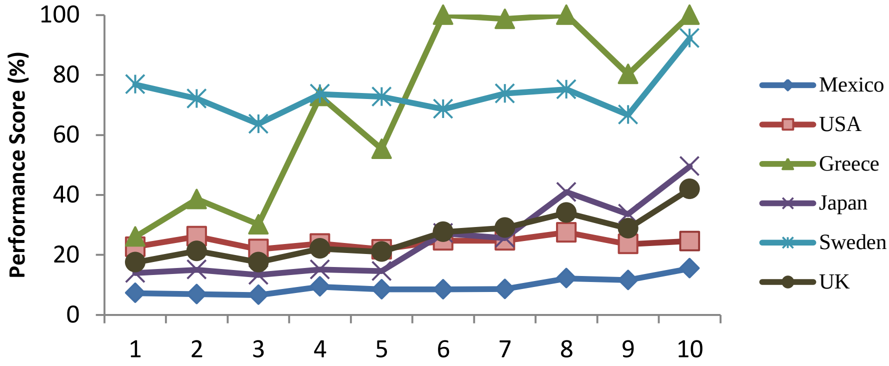

Figure 7. US, Japan, UK, Sweden, Mexico and Greece performance scores

5. CONCLUSION

In all these findings, the performance of renewable energy across OECD countries has increased every year. However, this increase is not enough when the average performance of OECD countries in 2015 (58.10) is insufficient. It is necessary to increase the amount of renewable energy produced by about 42% in order for the countries to be efficiency in their performance. When the performance scores of all countries and years were taken into consideration, range calculated as 96.4. This shows that there are huge differences between the performance of OECD countries. That is, while an OECD country has 100% performance, the performance of another OECD country is around 5%. It is desirable that these performances be in the minimum range in an organization. For this reason, countries should develop strategies appropriate to their geographical, social and economic characteristics and increase their investments in renewable energy resources for maximum performance in the minimum range.

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Appendix-1.

	2010	2011	2012	2013	2014	2015		Average	Standard Deviation	Range	Rank
Australia	16,05	19,29						21,66	4,88	14,58	28
		15,25	19,52								
			17,69	22,59							
				22,59	29,83						
					24,03	29,76					
Austria	44,33	40,68						45,32	4,42	16,58	17
		36,72	45,6								
			44,69	46,43							
				48,55	49,61						
					43,26	53,3					
Belgium	31,53	42,01						47,53	8,50	27,74	15
		35,4	52,99								
			50,19	53,6							
				52,85	53,52						
					43,95	59,27					
Canada	45,62	44,94						49,47	7,02	22,65	14
		42,92	43,9								
			42,86	48,4							
				49,69	57,67						
					53,16	65,51					
Chile	34,16	49,73						53,65	11,34	44,16	13
		49,32	47,67								
			47,61	52,52							
				53,17	67,04						
					57	78,32					
Czech Rep.	48,09	100						91,62	15,27	51,91	5
		92,39	100								
			98,2	100							
				92,29	100						
					85,21	100					
Denmark	76,64	82,36						73,49	5,52	15,65	9
		67,15	73,45								
			68,46	69,49							
				70,72	76,14						
					67,69	82,8					
Estonia	100	95,59						90,89	9,36	24,95	6
		79,78	100								
			100	75,05							
				85,43	93,21						
					80,07	99,75					
Finland	100	93,49						97,43	4,01	12,21	2
		94,18	100								
			100	100							
				100	98,88						
					87,79	100					
France	13,92	17,32						19,36	3,46	11,90	30

		14,04	20,81								
			19,21	20,13							
				20,3	22,9						
					19,1	25,82					
Germany	63,32	80,49						78,77	9,14	29,78	7
		64,83	85,41								
			77,24	81,22							
				81,45	88,37						
					72,28	93,1					
Greece	26,04	38,56						70,19	28,90	73,96	10
		30,17	72,87								
			55,34	100							
				98,62	100						
					80,25	100					
Hungary	43,73	34,41						35,54	4,64	13,19	23
		30,54	30,87								
			30,76	32,25							
				36,51	40,32						
					34,1	41,88					
Iceland	100	95,12						97,98	3,02	9,33	1
		98,24	100								
			100	95,78							
				100	90,67						
					100	100					
Ireland	33	47,25						37,29	3,91	14,25	22
		38,4	37,46								
			33,43	35,73							
				35,73	37,75						
					34,4	39,73					
Israel	3,6	8,45						11,02	3,57	12,34	34
		7,8	14,28								
			10	11,42							
				10,81	15,94						
					12,83	15,02					
Italy	25,08	55,23						67,44	18,53	65,50	11
		48,72	90,58								
			71,12	81,79							
				77,01	79,83						
					65,85	79,22					
Japan	13,92	15,08						24,90	12,24	36,23	25
		13,31	15,11								
			14,6	27,24							
				25,6	40,92						
					33,64	49,54					
Korea Rep.	8,98	9,61						11,71	3,41	10,55	33
		8,61	9,95								
			8,43	11,38							
				10,84	16,44						
					13,9	18,98					
Latvia	24,66	23,65						41,16	13,21	38,65	19
		22,57	38,72								

			38,7	47,73							
				50,18	56,65						
					47,52	61,22					
Luxembourg	10,79	10,15						11,81	1,84	6,39	32
		8,93	11,09								
			10,37	12,92							
				12,68	14,02						
					11,78	15,32					
Mexico	7,26	6,92						9,50	2,65	8,85	35
		6,63	9,41								
			8,49	8,48							
				8,6	12,17						
					11,59	15,48					
Netherland	25,43	26,58						24,13	2,03	7,21	27
		21,98	24,46								
			23,97	22,63							
				24,77	23,9						
					20,18	27,39					
NewZealand	46,38	44,35						38,09	4,62	13,68	20
		41,33	39,23								
			36,47	33,43							
				34,17	34,3						
					32,7	38,49					
Norway	34,04	31,79						37,96	5,96	22,04	21
		33,24	38,33								
			37,46	34,53							
				35,77	40,48						
					40,1	53,83					
Poland	33,29	39,61						47,11	9,59	31,99	16
		33,55	48,09								
			47,89	44,18							
				50,82	58,33						
					50,06	65,28					
Portugal	100	100						96,93	5,26	16,31	3
		83,69	100								
			91,89	100							
				100	100						
					93,7	100					
Slovakia	23,9	53,3						53,67	11,15	40,91	12
		47,52	54,86								
			53,45	61,2							
				57,38	64,57						
					55,71	64,81					
Slovenia	22,15	27,94						41,83	11,18	32,89	18
		26,66	44,23								
			43,39	50,69							
				48,52	55,04						
					48,13	51,55					
Spain	99,42	100						95,40	7,26	23,17	4
		76,83	100								
			91,88	100							

				100	98,13						
					88,52	99,23					
Sweden	76,84	72,07						73,54	7,32	28,59	8
		63,65	73,63								
			72,7	68,61							
				73,79	75,18						
					66,7	92,24					
Switzerland	12,74	11,25						14,90	2,42	7,48	31
		11,34	14,63								
			14,49	16,01							
				15,66	17,93						
					16,26	18,73					
Turkey	16,13	20,24						21,01	3,74	15,16	29
		18,76	21,24								
			19,27	21,01							
				21,28	20,98						
					19,91	31,29					
UK	17,52	21,31						26,11	7,38	24,45	24
		17,55	22,12								
			21,03	27,65							
				29,04	34,07						
					28,8	41,97					
USA	22,7	26,14						24,16	1,71	5,66	26
		21,87	23,76								
			21,83	24,77							
				24,75	27,49						
					23,58	24,67			General		
								Average	Std. Dev.	Range	
Average	40,04	42,70	47,82	49,98	50,80	58,10		48,07	29,76	96,40	
Std. Dev.	29,90	28,70	30,36	29,87	27,93	29,68					
Range	96,40	93,37	91,57	91,52	88,41	84,98					