Comparison of OECD Nations through a Comprehensive Evaluation Index for Low-Carbon Green Growth

Eui Sun Yoo*, Sung Hyun Park, Min Hyung Lee*****

ABSTRACT

This paper compares OECD nations by developing a comprehensive evaluation index that examines the efforts and achievements of countries toward Low-Carbon Green Growth. The input-process-output of a Low-Carbon Society system is in dynamic competition with that of a High-Carbon Society system. The model used in this study of the comprehensive evaluation index for Low-Carbon Green Growth was comprised of Large indices such as Input, Process, and Output. The Input and Output consisted of 'Social-economic' and 'Physical-ecological' Middle indices while the Process was made up of 'Stimulation mechanisms' and 'Participation of stakeholders and Knowledge flow' Middle indices. In order to calculate the comprehensive evaluation index, our model gave a weight to each indicator/index and applied a weighted arithmetic mean. Korea ranked 15th out of 30 OECD nations in the comprehensive evaluation that analyzed Input (14th), Process (18th), and Output (17th). The top five nations were Switzerland, Sweden, Denmark, Germany, and France; while Japan was 8th and the USA 26th.

KEYWORDS: low-carbon green growth, comprehensive evaluation index, OECD nations

1. INTRODUCTION

The global response to climate change is emerging as one of the most pressing international issues of recent times. In the Copenhagen climate change conference (COP 15) in 2009, the world leaders agreed to limit the temperature rise of the globe to two degrees Celsius. However, they failed to

* Associate Research Fellow, Future S&T Strategy Center, Science and Technology Policy Institute; esyoo@stepi.re.kr
** Chairman, Committee for Future Science and Technology, The Korean Academy of Science and Technology; parksh@plaza.snu.ac.kr
*** Director, Future S&T Strategy Center, Science and Technology Policy Institute; mhlee@stepi.re.kr

reach a consensus over setting greenhouse gas reduction targets for both developed and developing nations in the Post-Kyoto regime and deferred discussion until 2010. In the long term, high-energy prices are expected to soar as the demand for oil increases and the peak oil becomes close. Advanced nations have pursued a Low-Carbon Society (LCS) in order to address climate change, energy shift, and realize sustainable development. The Korean government also announced on Independence Day 2008 that Low-Carbon Green Growth would be part of the national agenda and initiated the Green New Deal policy as well as a Five-Year Plan for Green Growth. In this context, this paper developed a 'comprehensive' evaluation index that examined and compared the efforts and achievements of OECD nations toward Low-Carbon Green Growth.

2. SYSTEM SHIFT TO A LOW-CARBON SOCIETY

The LCS system needs to be established while competing with the existing dominant system of the High-Carbon Society (HCS) system (Figure 1). In particular, the conflict of the two systems is high at the initial stage. At the introduction stage, the new system is disadvantageous because it has to take roots on the value chain and infrastructure of the HCS. A wedge role of science & technology, policy, and civil society needs to be in place to make up for the disadvantages of the LCS system.

The input and output of a LCS are different from those of a HCS in many aspects (Figure 2). The process that may determine the speed and size at which input generates output is also different. For example, the LCS and HCS systems are in conflict in terms of resource flow. The current input of resources can be described to produce the HCS (Figure 3) as well as the knowledge flow.

FIGURE 1 Dynamic Relationship between Low-Carbon Society (LCS) and High-Carbon Society (HCS) Systems

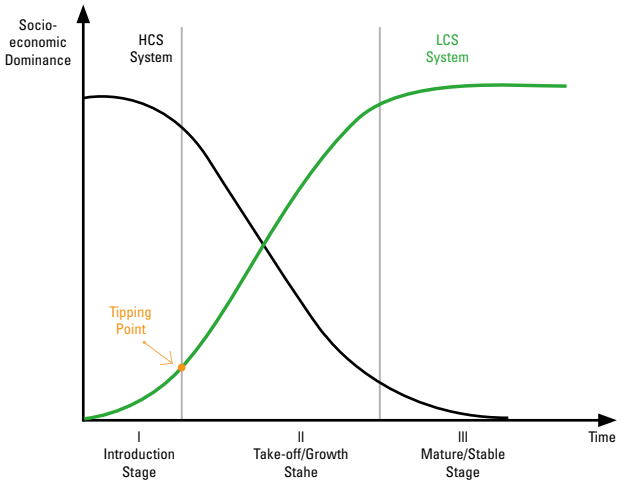


FIGURE 2 Example of the Components of a Low-Carbon Society (LCS) system

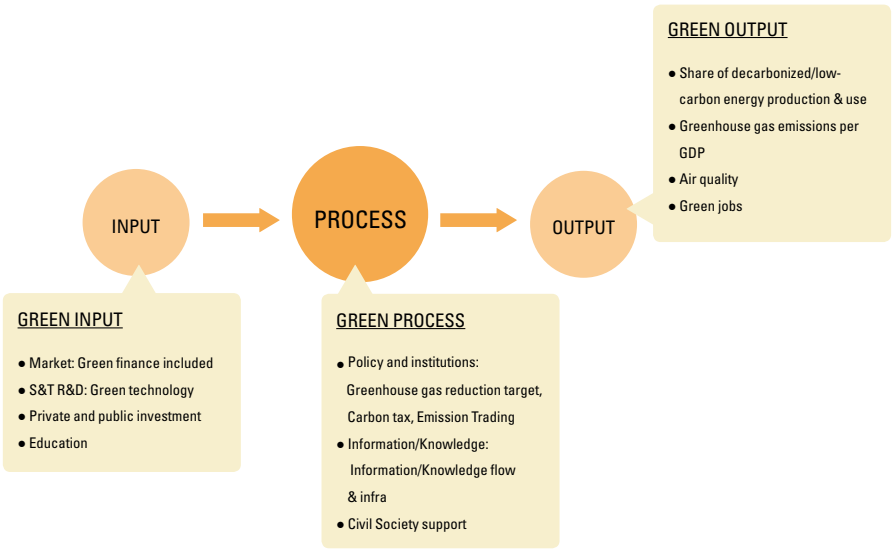
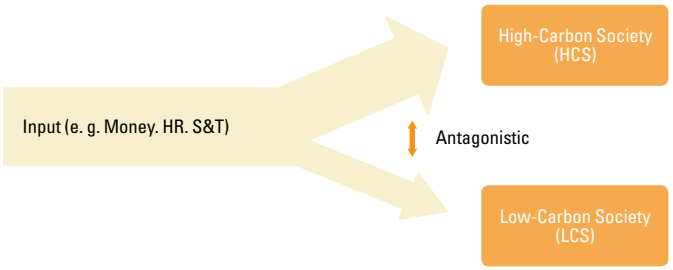


FIGURE 3 Antagonistic Relationship Between a High-Carbon Society (HCS) and Low-Carbon Society (LCS) with the Competition for Resource Input



Note)HR: Human Resources, S&T: Science & Technology

If the current resource flow shifts to the LCS system, the domain of LCS expands and the socio-economic dominance will grow whereas the domain and dominance of HCS decreases (Figure 4). Even though the LCS system was introduced at the same period, the faster this transformation develops in a country, the faster the country will secure competitiveness in the LCS paradigm.

FIGURE 4 Expansion of a Low-Carbon Society (LCS) System that was in Embryo in a High-Carbon Society (HCS) System

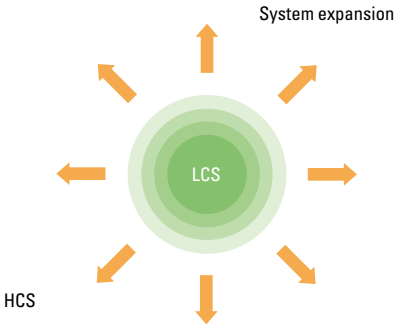
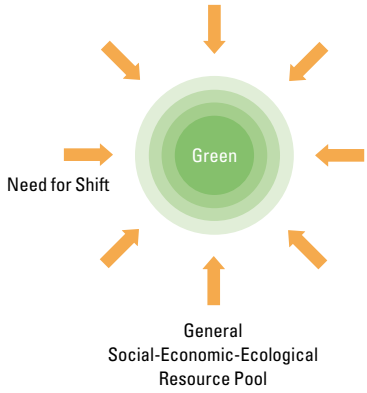


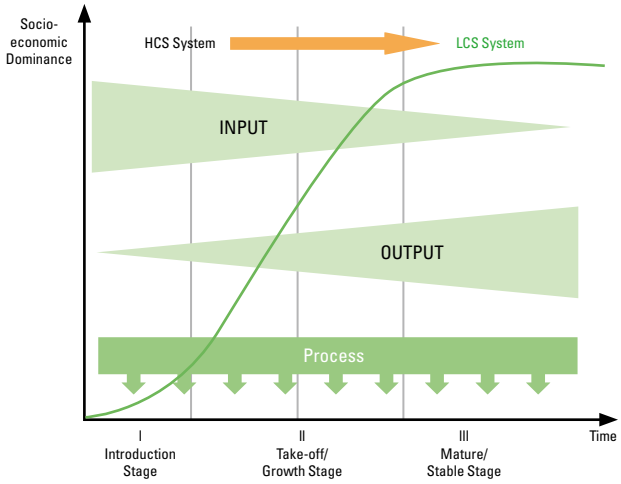
FIGURE 5 Greening of General Social/Economic/ Ecological Resources



Although there are several factors that can be classified as either 'Low-Carbon Green' or 'High-Carbon Black' factors, many factors remain 'General' factors that belong to both categories (e.g. R&D, education). The greening of these General factors is another key to the implementation of a successful system shift (Figure 5).

The input and process are vital at the introduction stage of LCS system (Figure 6). As the system transform through the stable and mature stage, the relative importance of input decreases while the importance of output increases since (at this stage) the output rises with the accumulated effect of input.

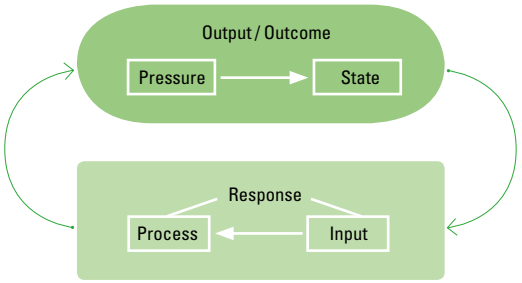
FIGURE 6 Change in the Relative Importance of Input and Output According to the Low-Carbon Society (LCS) Development Stage



3. DEVELOPMENT OF A COMPREHENSIVE EVALUATION INDEX FOR LOW-CARBON GREEN GROWTH TO COMPARE THE OECD NATIONS

This paper set six basic directions to develop a comprehensive evaluation index for Low-Carbon Green Growth. First was to make a framework under which input and output for Low-Carbon Green Growth remain in mutual correspondence as much as possible and the process serves as leverage to promote correspondence. Components in the framework were connected under a circulation structure (Figure 7). Existing research on the environmental or sustainable development index by international organizations often have a circulation structure, for example, the UN environment indices keep the Pressure-State-Response structure. The Input-Process index of this paper correlate with the UN's Response index, while the Output index correlate with the UN's Pressure-State index.

FIGURE 7 Correlation in the I-P-O Structure of This Paper and the P-S-R Structure of the UN



Note) The symbols of circle represent the I-P-O structure, whereas those of square the P-S-R structure.

Second was to consider the correlation of Green and General Indicators. While dynamic aspects of the comprehensive index were considered in the flow of Input-Process-Output, static aspects were reflected as the correlation of Green and General Indicators. Green factors (e.g. share of renewable energy) that directly contribute to Low-Carbon Green Growth but also general factors (e.g. general science & technology capacity) that indirectly contribute to it or form the foundation of green factors were taken into account. Third was to consider areas that emit high volumes of carbon, as it is important to adequately control high carbon–emitting areas in the establishment of a LCS. This provides an advantage in identifying where strategies and performances for Low-Carbon Green Growth are weak and of revising national policies accordingly. Fourth, the sub-index framework was applied because a direct approach from individual indicators to the comprehensive index is difficult to understand in addition to the difficulty in combining heterogeneous indicators. International comparisons on the sub-index are also considered. Fifth, it was designed that three paths (i.e. energy efficiency, energy shift, and carbon sink) of the response to climate change passed through the entire

index framework. 'Input' represents the efforts to perform the three paths. It was divided into the Social-economic and Physical-ecological inputs. The Social-economic input encompassed education, training, science & technology, and investment that indirectly support the three paths. The Physical-ecological input included materials, energy, and ecological resources closely related or directly implemented into the three paths. 'Output' refers to the product and outcome as the results of 'Input', encompassed 'Social-economic' output (e.g. production, job creation, patents, research papers, and service) and 'Physical-ecological' output (e.g. greenhouse gases, air quality, water quality, marine, and bio-species). 'Process' reflects the policy that facilitates the input-output connection and the activities of a civil society that include 'Stimulation mechanisms', 'Stakeholder participation', and 'Knowledge flow'. Sixth, we examined whether the indicators represent the characteristics of LCS and used data from international authorities to maintain objectivity. We also examined if the data could be further gained on a continuous basis. We minimized the amount of missing data so that might not have significant influence on the ranking of the entire index. We kept the aggregated impact of similar data (e.g. greenhouse gas emissions per capita and per GDP) on the entire index at an appropriate level.

The model of the comprehensive evaluation index for Low-Carbon Green Growth was broken down into the Index Groups of Large, Middle, and Small. The Input Large-Index Group was composed of 25 indicators, while the Process was of 11 indicators, and the Output was of 17 indicators (Table 1).

A scale from 1 to 5 (5: very good, 4: good, 3: normal, 2: bad, 1: very bad) was applied that considered the maximum, minimum, and average value for each indicator. Higher than average is considered high grade while lower than the average is considered low grade. The data was analyzed through use of the standard per GDP, per capita, and per thousand to accurately compare nations. Indicators of which results meant worse with higher amounts were reverse-coded (e.g. greenhouse gas emissions). In order to calculate the comprehensive evaluation index, the model used in this study gave a weight to each indicator/index and applied a weighted arithmetic mean. The respective weight of the Large-Index Group was set at Input: Process: Output=14: 7: 14 (Table 1). As for the weight of indicators, those considered critical for Low-Carbon Green Growth were given the maximum weight of 2 and those with relatively less critical weight were set at less than 2 but with a minimum weight of 0.25.

If there were k indicators in an Index Group and the scale for i^{th} indicator was I_i, the index was calculated by applying W_i as the weight for I_i in the following formula:

$$\text{Index of a Group} = \left(\sum_{i=1}^{k} W_i I_i\right) / \sum_{i=1}^{k} W_i$$

We multiplied the weighted arithmetic mean of the Large Index Groups by 20 times to calculate the comprehensive evaluation index out of a full score of 100. When raw data were not available for a nation, they were considered as missing values and excluded from the calculation for the nation with the weight of zero.

TABLE 1 Basic Structure of the Comprehensive Evaluation Index for Low-Carbon Green Growth With the Weights for Respective Indicators/Indices

Large Index Group (total weight)	Middle Index Group (total weight)	Small Index Group (total weight)	Indicator	Weight
Input (14)	Social economic input (5.5)	social input (1.5)	1. expenditures on public educational institutions per GDP	0.50
			2. public society expense per GDP	0.50
			3. ratio of working-age people supporting seniors	0.50
		science & technology capacity (2.0)	4. researchers per thousand (national totals)	0.25
			5. total R&D personnel nationwide per thousand	0.25
			6. gross domestic expenditure on R&D per GDP	0.50
			7. public R&D budget for environment out of total government R&D budget	0.50
			8. renewable energy RD&D investment	0.50
		green investment (1.0)	9. Pollution Abatement and Control (PAC) expenditure per GDP	1.00
		green input in agriculture and transportation (1.0)	10. share of organic land	0.50
			11. passenger transport density-rail	0.25
			12. passenger transport density-buses	0.25
	Physical ecological input (8.5)	energy input (4.5)	13.energy intensity	2.00
			14. annual energy consumption per capita	0.50
			15. share of energy consumption from renewable sources	1.00
			16. share of electricity production from renewable sources	0.50
			17. total final energy consumption by transport sector	0.50
		material input (3.0)	18. ecological footprint per capita	2.00
			19. apparent consumption of commercial fertilizers per arable land	0.50
			20. daily water consumption per capita	0.25
			21. annual water consumption per GDP and capita	0.25
		ecosystem (1.0)	22. biosphere reserves	0.25
			23. wetlands	0.25
			24. forest	0.25
			25. major protected areas	0.25
		total input weight		14.00
Process (7)	Stimulation mechanisms (4.25)	green laws & institutions (2.25)	26. Kyoto-protocol ratification and GHG(Greenhouse Gas) reduction duty	1.00
			27. legislation for Low-Carbon Green Growth	0.50
			28. strategy for sustainable development	0.25
			29. feed-in Tariff	0.50

Large Index Group (total weight)	Middle Index Group (total weight)	Small Index Group (total weight)	Indicator	Weight
	Stimulation mechanisms (4.25)	environmental tax (1.0)	30. revenues from environmentally related taxes per GDP	1.00
		carbon trade (1.0)	31. trading EU emission Allowances (EUAs) & Certified Emission Reductions (CERs)	1.00
	Participation of stakeholders and Knowledge flow (2.75)	green firms (0.75)	32. ISO14001 certified firms per thousand	0.50
			33. Global Reporting Initiative (GRI) sustainability report per million	0.25
		green awareness (1.5)	34. civil awareness of environmental disruption	1.00
			35. education for sustainable development	0.50
		knowledge flow (0.5)	36. broadband subscriber per thousand	0.50
		total of process weight 7.00		
Output (14)	Social economic output (5.0)	GDP (2.0)	37. GDP per capita	2.00
		education level (0.5)	38. high school graduation rate	0.50
		wealth distribution (0.5)	39. GINI index	0.50
		science & technology output (1.0)	40. patents per thousand	1.00
		knowledge intensive service (1.0)	41. share of knowledge-intensive service	1.00
	Physical ecological output (9.0)	waste (1.5)	42. industrial waste per GDP	0.75
			43. municipal waste per capita	0.75
		greenhouse gas (4.0)	44. rank of greenhouse gas emissions	1.00
			45. greenhouse gas emissions per capita	1.00
			46. greenhouse gas emissions per GDP	2.00
		air qualit (1.0)	47. emissions of Sulfur Oxides (SOx) per GDP	0.25
			48. emissions of NOx (Nitrogen Oxides) per GDP	0.25
			49. emissions of Sulfur Oxides (SOx) per capita	0.25
			50. emissions of Nitrogen Oxides (NOx) per capita	0.25
		water quality (1.0)	51. Biological Oxygen Demand (BOD) of selected rivers	1.00
		bio-diversity (1.5)	52. birds species known	0.75
			53. bird species critically endangered	0.75
		total of output weight		14.00

Korea ranked 14 out of 30 OECD nations in the entire Input (Table 2), where Korea was 4th in the Social-economic input but was at 21st in the Physical-ecological input. Under the Social-economic input, Korea was 2nd in the science & technology capacity, 6th in the green investment, and 3rd in the green input in agriculture and transport. However, Korea was 29th in the social input, under which it

TABLE 2 The Rank of Korea in the Comprehensive Evaluation for Low-Carbon Green Growth (rank/ total nations)

Large Index Group (total weight)	Middle Index Group (total weight)	Small Index Group (total weight)	Indicator
Input (14/30)	Social input economic (4/30)	social input (29/30)	1. expenditures on public educational institutions per GDP (19/28)
			2. public society expense per GDP (29/29)
			3. ratio of working-age people supporting seniors (26/28)
		science & technology capacity (2/30)	4. researchers per thousand (national totals) (9/30)
			5. total R&D personnel nationwide per thousand (5/28)
			6. gross domestic expenditure on R&D per GDP (4/30)
			7. public R&D budget for environment out of total government R&D budget (2/27)
			8. renewable energy RD&D investment (4/23)
		green investment (6/25)	9. Pollution Abatement and Control (PAC) expenditure per GDP (6/25)
		green input in agriculture and transportation (3/30)	10. share of organic land (20/30)
			11. passenger transport density-rail (4/30)
			12. passenger transport density-buses (6/30)
	Physical ecological input (21/30)	energy input (25/30)	13.energy intensity (23/30)
			14. annual energy consumption per capita (20/30)
			15. share of energy consumption from renewable sources (30/30)
			16. share of electricity production from renewable sources (30/30)
			17. total final energy consumption by transport sector (10/30)
		material input (6/29)	18. ecological footprint per capita (5/27)
			19. apparent consumption of commercial fertilizers per arable land (16/29)
			20. daily water consumption per capita(15/25)
			21. annual water consumption per GDP and capita(17/25)
		ecosystem (21/30)	22. biosphere reserves(17/24)
			23. wetlands(27/30)
			24. forest(4/30)
			25. major protected areas(26/30)
Process (18/30)	Stimulation mechanisms (24/30)	green laws & institutions (23/30)	26. Kyoto-protocol ratification and GHG(Greenhouse Gas) reduction duty*
			27. legislation for Low-Carbon Green Growth*
			28. strategy for sustainable development*
			29. feed-in Tariff
		environmental tax (11/28)	30. revenues from environmentally related taxes per GDP(11/28)
		carbon trade (30/30)	31. trading EUAs(EU emission Allowances) & CERs(Certified Emission Reductions)(30/30)
	Participation of Stakeholders and knowledge flow (7/30)	green firms (7/30)	32. ISO14001 certified firms per thousand(9/21)
			33. GRI(Global Reporting Initiative) sustainability report per million(17/30)
		green awareness (5/30)	34. civil awareness of environmental disruption(27/29)
			35. education for sustainable development*
		knowledge flow (3/29)	36. broadband subscriber per thousand(3/29)

Large Index Group (total weight)	Middle Index Group (total weight)	Small Index Group (total weight)	Indicator
Output (17/30)	Social economic output (17/30)	GDP(23/30)	37. GDP per capita(23/30)
		education level(4/30)	38. high school graduation rate(4/30)
		wealth distribution(17/30)	39. GINI index(17/30)
		science & technology output (7/30)	40. patents per thousand(7/30)
		knowledge intensive service (21/30)	41. share of knowledge-intensive service(21/30)
	Physical ecological output (19/30)	waste (3/30)	42. industrial waste per GDP(14/24)
			43. municipal waste per capita(5/30)
		greenhouse gas (25/30)	44. rank of greenhouse gas emissions(25/30)
			45. greenhouse gas emissions per capita(19/30)
			46. greenhouse gas emissions per GDP(24/30)
		air quality (14/30)	47. emissions of SOx(Sulphur Oxides) per GDP(14/30)
			48. emissions of NOx(Nitrogen Oxides) per GDP(20/30)
			49. emissions of SOx(Sulphur Oxides) per capita(12/30)
			50. emissions of NOx(Nitrogen Oxides) per capita(19/30)
		water quality(20/30)	51. BOD(Biological Oxygen Demand) of selected rivers(20/30)
		bio-diversity (6/30)	52. birds species known(8/28)
			53. bird species critically endangered(10/30)

**: no ranks for categorical (3 point benchmark), binary (2 point benchmark)*

TABLE 3 Comparison Results of OECD Nations in the Comprehensive Evaluation Index for Low-Carbon Green Growth

OECD nations	Input (40%)		Process (20%)		Output (40%)		Comprehensive evaluation index	
	weighted average	rank	weighted average	rank	weighted average	rank	evaluation index (a full score=100)	rank
Canada	2.429	22	2.679	21	2.857	20	53.000	23
Mexico	2.679	15	1.571	30	2.804	23	50.143	25
USA	2.310	27	2.571	24	2.661	26	50.055	26
Japan	3.000	9	3.000	14	3.411	8	63.286	8
Korea	2.714	14	2.786	18	3.036	17	57.143	15
Australia	2.214	29	2.571	24	2.839	21	50.714	24
N. Zealand	2.673	16	2.321	26	3.375	9	57.667	14
Austria	3.321	2	3.393	6	3.143	14	65.286	6
Belgium	2.327	25	2.679	21	3.107	15	54.190	21
Czech Rep.	2.125	30	3.071	12	2.571	28	49.857	29
Denmark	3.101	6	3.821	1	3.464	6	67.810	3
Finland	3.000	9	3.000	14	3.232	12	61.857	12
France	3.089	7	3.214	11	3.500	5	65.571	5
Germany	3.411	1	3.583	2	3.054	16	66.048	4
Greece	2.605	19	2.714	19	2.911	19	54.984	18
Hungary	2.518	21	2.929	16	2.821	22	54.429	20
Iceland	2.555	20	1.615	29	3.446	7	54.474	19
Ireland	2.346	23	2.929	16	3.321	10	57.055	16
Italy	3.018	8	3.500	4	2.982	18	62.000	11
Luxemburg	2.325	26	3.571	3	3.750	2	62.886	10
Netherlands	2.839	11	3.500	4	3.321	10	63.286	8
Norway	3.113	5	2.607	23	3.589	4	64.048	7
Poland	2.345	24	2.286	27	1.946	30	43.476	30
Portugal	2.839	11	3.036	13	2.339	29	53.571	22
Slovak Rep.	2.274	28	2.714	19	2.625	27	50.048	27
Spain	2.654	17	3.286	9	2.768	24	56.516	17
Sweden	3.321	2	3.286	9	3.607	3	68.571	2
Switzerland	3.161	4	3.375	7	3.929	1	70.214	1
Turkey	2.625	18	1.857	28	2.696	25	50.000	28
UK	2.839	11	3.357	8	3.161	13	61.429	13

evaluation index = 20[(averaged input weight*0.4+ averaged process*0.2+ averaged output *0.4)/ (0.4+0.2+0.4)]*

was 19th in the expenditure on public education institutions per GDP, 29th in the public society expense per GDP, and 26th in the ratio of working-age people supporting seniors. Under the Physical-ecological input, Korea was 6th in the material input such as ecological footprint per capita, whereas it was 25th in the energy input and 21st in the ecosystem . Under the energy input, Korea ranked 30th (the lowest) in the renewable energy consumption and power generation. In addition, under the ecosystem it ranked poorly at 27th in the wetlands and 26th in the major nature reserves. The top five nations in the entire Input were Germany, Sweden, Australia (joint second place), Switzerland, and Norway (Table 3). In the entire Process, Korea was placed 18th among the 30 Nations (Table 2, [Appendix 2]). Under the Process, Korea was 24th in the Stimulation mechanisms. In detail, it was 11th in the environmental tax, but 23rd in the green laws and institutions and 30th in the carbon trade. Korea was 7th in the Participation of stakeholders and Knowledge flow, owing to 7th place in the green firms and 5th in the green awareness. The top five countries in the entire Process were Denmark, Germany, Luxemburg, Netherlands, and Italy (both 4th) (Table 3). The rank of the entire Output for Korea was 17th out of the 30 nations (Table 2, [Appendix 2]). Korea was 17th in the Social-economic output encompassing GDP, the science & technology output, and the knowledge-intensive service. It placed 19th in the Physical-ecological output, under which it was 3rd in the waste, and 6th in the biodiversity while showing poor records in the greenhouse gas (25th) and the water quality (20th). The top five countries in the entire Output were Switzerland, Luxemburg, Sweden, Norway, and France (Table 3). In the comprehensive evaluation that reflected all Input, Process, and Output, Korea remained in the middle as 15th (Table 3). The top five nations in the comprehensive evaluation were Switzerland, Sweden, Denmark, Germany, and France (with Japan at 8th and the United States at 26th). It seems that Europe (in particular northern Europe) showed the highest evaluations because they had made efforts earlier in energy efficiency improvement, renewable energy introduction, and environmental protection.

4. FURTHER CHALLENGES

Korea needs to set up a strategy to improve deficient areas that are directly related to Low-Carbon Green Growth but rated poorly in the comprehensive evaluation index. There exists a need for Korea to establish a strategy to improve the undeveloped Physical-ecological Input and Process, when considering that Korea is in the introduction stage of the paradigm of LCS. In addition, research should be intensified to identify and address impediments between green Inputs and Processes.

Korea needs to draw up a green shift strategy of the general social-economic factors (e.g. science & technology capacity) which are the background and have potential to support the Low-Carbon Green Growth. It is also necessary to establish an improvement strategy for poor factors (e.g. social welfare capacity) out of the general social-economic factors, because the poor social-economic factors can drag the Low-Carbon Green Growth.

A time-series analysis of the comprehensive evaluation is required. The analysis can evaluate the past and present trends for Low-Carbon Green Growth, which can be fed back for policy-making. For example, we can examine the growth rate of each indicator/index from 1990 or 2005 to the present and compare nations. In addition, the accumulated results of indices until the current year can be examined for comparison.

Efforts to make the comprehensive evaluation index 'more green' are necessary. For instance, 'per GDP' applied to the cross-nation comparison is a standard that reflects the existing High-Carbon Society paradigm; in addition, alternative research to develop 'Green GDP' is desirable.

The local statistics are also necessary to develop the comprehensive evaluation index from the national to the local level. Data for the important indicators in measuring and evaluating local Low-Carbon Green Growth need to be accumulated in the local statistics. The examples are the data for the renewable energy R&D investment per Gross Regional Domestic Product (GRDP), the green education expenditure per GRDP, and human resources in green technology R&D.

References

GFN (Global Footprint Network). "Footprint for Nations." (2008). http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_for_nations/ (accessed September 1, 2009).

Green Growth Committee of Korea. *"Green Law Status."* 2009.

GRI (Global Reporting Initiative). *"GRI Sustainability Report."* 2008.

IEA (International Energy Agency). *"Key World Energy Statistics."* 2007.

IFOAM (International Federation of Organic Agriculture Movements) and FiBL (Research Institute of Organic Agriculture FiBL). *"The World of Organic Agriculture: Statistics and Emerging Trends 2007."* 2007.

IMD (International Marketing Development of Switzerland). *"World Competitiveness Yearbook 2008."* 2008.

KEMCO (Korea Energy Management Corporation). *"Kyoto Protocol Status of Ratification."* 2005.

National Statistical Office. *"International Statistics Yearbook 2007."* 2007.

OECD. *"OECD Environmental Data Compendium 2008."* (2008a), http://www.oecd.org/document/49/0,3343,en_2649_34283_39011377_1_1_1_1,00.html (accessed September 1, 2009).

_____. *"OECD in Figures 2008."* (2008b), http://www.oecd.org/document/32/0,3343,en_2649_34489_41722336_1_1_1_1,00.html (accessed September 1, 2009).

_____. *"OECD Factbook 2009."* (2009a), http://titania.sourceoecd.org/vl=28207563/cl=18/nw=1/rpsv/factbook/ (accessed September 1, 2009).

_____. *"OECD Science, Technology & Industry Scoreboard 2007."* 2008c.

_____. *"OECD Statistics."* OECD. Stat Extracts, (2009b), http://stats.oecd.org/Index.aspx (accessed September 1, 2009).

Peglau, R. (Federal Environmental Agency/Germany). *"Worldwide Number of ISO 14001"*, (2007) , http://www.ecology.or.jp/isoworld/english/analy14k.htm (accessed September 1, 2009).

PointCarbon. *"Carbon 2009: Emission Trading Coming Home."* 2009.

REN21. *"Renewables 2007 Global Status Report."* (2007), http://www.ren21.net/pdf/RE2007_Global_Status_Report.pdf (accessed September 1, 2009).

UNCSD. National Strategies for Sustainable Development, (2009), http://www.un.org/esa/dsd/index.shtml (accessed September 1, 2009).

UNESCO. Education for Sustainable Development, (2009), http://www.unesco.org/en/esd/ (accessed September 1, 2009).

Appendix 1 - Source of indicators with data-applied year

Large index	Indicator	Source	Quoted year
Input	1. expenditure on public educational institutions per GDP	OECD(2008b)	2005
	2. public society expense per GDP	OECD(2009b)	2005
	3. ratio of working-age people supporting seniors	National Statistical Office(2007)	2005
	4. researchers per thousand (national totals)	OECD(2008b)	2006
	5. total R&D personnel nationwide per thousand	IMD(2008)	2006
	6. gross domestic expenditure on R&D per GDP	OECD(2008b)	2006
	7. public R&D budget for environment out of total government R&D budget	OECD(2008b)	2006
	8. renewable energy RD&D investment	IEA(2007)	2007
	9. PAC(Pollution Abatement and Control) expenditure per GDP	OECD(2008a)	2003
	10. share of organic land	IFOAM and FiBL(2007)	2007
	11. passenger transport density-rail	OECD(2008a)	2005
	12. passenger transport density-buses		
	13. en ergy intensity	IEA(2007)	2006
	14. annual energy consumption per capita	OECD(2009b)	2007
	15. share of energy consumption from renewable sources	IEA(2007)	2007
	16. share of electricity production from renewable sources	IEA(2007)	2007
	17. total final energy consumption by transport sector	OECD(2008a)	2004
	18. ecological footprint per capita	GFN(2008)	2005
	19. apparent consumption of commercial fertilizers per arable land	OECD(2008a)	2005
	20. daily water consumption per capita	OECD(2009b)	2006
	21. annual water consumption per GDP and capita		
	22. biosphere reserves	OECD(2008a)	2008
	23. wetlands		2008
	24. forest		2005
	25. major protected areas		2007
Process	26. Kyoto-protocol ratification and GHG(Greenhouse Gas) reduction duty	KEMCO(2005)	2005
	27. legislation for Low-Carbon Green Growth	Green Growth Committee of Korea(2009)	2009
	28. strategy for sustainable development	UNCSD(2009)	2009
	29. feed-in Tariff	REN21(2007)	2007
	30. revenues from environmentally related taxes per GDP	OECD(2008a)	2004
	31. trading EUAs(EU emission Allowances) & CERs(Certified Emission Reductions)	PointCarbon(2009)	2009
	32. ISO14001 certified firms per thousand	Peglau(2007)	2007
	33. GRI(Global Reporting Initiative) sustainability report per million	GRI(2008)	2008
	34. civil awareness of environmental disruption	IMD(2008)	2008
	35. education for sustainable development	UNESCO(2009)	2009
	36. broadband subscriber per thousand	IMD(2008)	2006
Output	37. GDP per capita	OECD(2008b)	2007
	38. high school graduation rate		2006
	39. GINI index	OECD(2009a)	2004
	40. patents per thousand	OECD(2009a)	2009
	41. share of knowledge-intensive service	OECD(2008c)	2004

Large index	Indicator	Source	Quoted year
Output	42. industrial waste per GDP	OECD(2008b)	2006
	43. municipal waste per capita		
	44. rank of greenhouse gas emissions		
	45. greenhouse gas emissions per capita		
	46. greenhouse gas emissions per GDP		
	47. emissions of SOx(Sulphur Oxides) per GDP	OECD(2008a)	2005
	48. emissions of NOx(Nitrogen Oxides) per GDP		
	49. emissions of SOx(Sulphur Oxides) per capita		
	50. emissions of NOx(Nitrogen Oxides) per capita		
	51. BOD(Biological Oxygen Demand) of selected rivers		2002~04
	52. birds species known		2006
	53. bird species critically endangered		2006

Appendix 2 - Detailed comparison of OECD nations through the comprehensive evaluation index for Low-Carbon Green Growth

OECD nations	Input (weight value 14)							Weighted arithmetic mean	rank
	Social economic input (weight 5.5)				Physical ecological input (weight 8.5)				
	social input	science & tech nology capacity	green invest ment	green input in agriculture and transpor tation	energy input	material input	ecosystem		
Canada	3.000	2.375	3	1.50	2.89	1.50	2.75	2.429	22
Mexico	3.000	1.000	2	2.50	2.89	3.33	3.50	2.679	15
USA	2.667	3.143	.	2.75	2.44	1.00	3.00	2.310	27
Japan	2.000	3.625	2	3.00	3.00	3.67	2.25	3.000	9
Korea	2.333	3.250	3	3.25	1.89	3.83	1.75	2.714	14
Australia	3.000	2.500	1	1.75	2.33	1.92	2.50	2.214	29
N. Zealand	3.333	1.833	3	1.25	3.44	2.33	2.00	2.673	16
Austria	3.667	1.750	4	3.25	3.89	3.50	2.25	3.321	2
Belgium	3.667	1.500	2	1.25	2.11	3.33	1.33	2.327	25
Czech Rep.	2.500	1.375	2	2.50	1.22	3.67	2.25	2.125	30
Denmark	4.000	1.875	5	2.00	3.56	3.00	1.67	3.101	6
Finland	3.667	2.500	2	2.50	3.11	3.50	2.50	3.000	9
France	3.667	2.625	3	3.00	3.22	3.42	1.75	3.089	7
Germany	3.333	2.750	5	4.00	3.22	3.50	3.25	3.411	1
Greece	2.667	1.833	.	1.50	2.89	3.40	1.50	2.605	19
Hungary	3.333	2.375	3	1.75	1.56	4.00	1.75	2.518	21
Iceland	4.000	2.600	2	1.00	1.57	4.50	1.00	2.555	20
Ireland	3.000	1.500	.	1.00	2.67	2.83	1.50	2.346	23
Italy	3.000	1.750	3	4.75	3.22	3.17	2.50	3.018	8
Luxemburg	3.500	2.000	.	1.50	2.33	.	2.00	2.325	26
Netherlands	3.000	1.625	4	1.75	2.67	4.08	2.00	2.839	11
Norway	3.333	1.625	3	2.00	3.89	3.50	2.33	3.113	5
Poland	3.667	1.167	3	1.50	1.56	3.75	2.25	2.345	24
Portugal	3.000	1.375	2	2.75	3.22	3.83	1.75	2.839	11
Slovak Rep.	2.667	1.167	1	2.00	1.67	4.33	2.00	2.274	28
Spain	3.000	1.750	.	2.50	2.78	2.75	3.25	2.654	17
Sweden	4.500	2.250	2	2.50	3.89	3.58	2.50	3.321	2
Switzerland	3.333	1.750	3	3.25	3.78	3.50	2.00	3.161	4
Turkey	3.500	1.000	4	2.00	2.22	4.00	1.50	2.625	18
UK	3.333	2.000	2	2.75	3.00	3.25	2.75	2.839	11

*Weighted arithmetic mean = (sum of social economic input*5.5+ sum of physical ecological input*8.5)/14*

Process

OECD nations	Process (weight 7)						Weighted arithmetic mean	rank
	Stimulation mechanisms (weight 4.25)			Participation of stakeholders and Knowledge flow (weight 2.75)				
	green laws & institutions	environ-mental tax	carbon trade	green firms	green awareness	knowledge flow		
Canada	3.67	2	2	2.00	2.33	3	2.679	21
Mexico	1.89	2	1	1.00	1.67	1	1.571	30
USA	2.78	1	5	1.00	2.33	3	2.571	24
Japan	4.56	2	2	2.33	2.33	3	3.000	14
Korea	3.22	3	1	2.33	3.00	4	2.786	18
Australia	2.33	2	3	2.33	3.00	3	2.571	24
N. Zealand	2.78	2	1	2.00	3.00	2	2.321	26
Austria	4.56	3	1	2.00	4.33	3	3.393	6
Belgium	3.67	3	1	2.00	2.33	3	2.679	21
Czech Rep.	5.00	3	1	2.33	2.33	2	3.071	12
Denmark	4.56	5	1	2.67	4.33	4	3.821	1
Finland	3.67	4	1	3.00	2.33	4	3.000	14
France	5.00	3	2	1.67	2.33	3	3.214	11
Germany	5.00	.	1	1.67	4.33	3	3.583	2
Greece	4.56	3	1	1.00	2.33	1	2.714	19
Hungary	4.56	3	1	2.33	2.33	2	2.929	16
Iceland	1.89	3	1	1.00	1.00	.	1.615	29
Ireland	4.56	3	1	1.00	3.00	2	2.929	16
Italy	4.56	4	2	2.33	3.67	2	3.500	4
Luxemburg	4.56	4	1	5.00	3.00	3	3.571	3
Netherlands	5.00	4	2	2.33	2.33	4	3.500	4
Norway	1.89	4	2	2.00	3.00	4	2.607	23
Poland	4.11	2	1	1.00	1.67	1	2.286	27
Portugal	4.56	4	1	2.00	2.33	2	3.036	13
Slovak Rep.	4.56	3	1	1.00	2.33	1	2.714	19
Spain	5.00	3	2	3.00	2.33	2	3.286	9
Sweden	4.11	3	1	4.33	3.00	4	3.286	9
Switzerland	4.11	.	2	3.33	3.00	4	3.375	7
Turkey	1.00	5	1	1.00	2.33	1	1.857	28
UK	4.11	3	5	1.67	2.33	3	3.357	8

*Weighted arithmetic mean = (sum of stimulant mechanism*4.25 +sum of participation of stakeholder and knowledge flow*2.75)/7*

Output

OECD nations	Output (weight 14)										Weighted arithmetic mean	rank
	Social economic input (weight 5)					Physical ecological input (weight 9)						
	GDP	education level	wealth distribution	science & technology output	knowledge intensive service	waste	greenhouse gas	air quality	water quality	bio diversity		
Canada	3	3	3	3	2	4.0	2.50	1.00	3	4.0	2.857	20
Mexico	2	2	1	1	1	5.0	3.25	2.75	1	5.0	2.804	23
USA	3	4	1	4	3	1.0	2.50	1.75	4	3.0	2.661	26
Japan	3	5	2	5	2	3.5	3.50	4.25	4	2.5	3.411	8
Korea	2	5	3	4	2	4.0	2.50	3.50	3	4.0	3.036	17
Australia	3	4	3	2	3	3.0	2.25	1.00	4	4.5	2.839	21
N.Zealand	2	4	2	2	2	3.5	4.00	2.50	5	5.0	3.375	9
Austria	3	3	5	4	2	3.0	3.50	4.25	3	1.5	3.143	14
Belgium	3	3	4	3	3	3.5	3.50	3.75	2	2.0	3.107	15
Czech Rep.	2	4	5	1	1	4.5	3.00	2.50	2	1.5	2.571	28
Denmark	3	4	5	4	2	3.0	3.75	4.00	4	3.0	3.464	6
Finland	3	5	4	5	1	2.5	3.50	3.50	3	3.0	3.232	12
France	3	3	3	4	3	3.0	4.00	4.25	3	3.5	3.500	5
Germany	3	5	3	5	2	3.5	3.00	4.25	2	1.5	3.054	16
Greece	2	5	2	1	1	4.0	3.50	2.25	3	4.0	2.911	19
Hungary	2	4	3	1	2	4.0	3.00	3.50	3	3.0	2.821	22
Iceland	3	5	4	2	2	4.0	4.75	2.00	3	2.5	3.446	7
Ireland	3	4	2	2	3	2.0	3.75	3.75	4	4.5	3.321	10
Italy	2	4	1	2	2	3.5	3.50	4.25	4	2.5	2.982	18
Luxemburg	5	4	5	4	5	2.5	3.50	4.00	2	3.5	3.750	2
Netherlands	3	3	4	5	3	2.5	3.50	4.50	3	2.5	3.321	10
Norway	4	5	4	3	1	2.5	4.75	3.50	3	3.0	3.589	4
Poland	2	4	1	1	1	3.0	1.75	2.50	1	2.5	1.946	30
Portugal	2	3	1	1	2	3.5	2.50	3.25	3	1.5	2.339	29
Slovak Rep.	2	4	5	1	1	3.0	2.75	3.25	3	3.0	2.625	27
Spain	3	4	2	1	1	3.0	3.50	2.25	4	2.0	2.768	24
Sweden	3	4	5	5	2	2.0	4.50	4.50	3	3.0	3.607	3
Switzerland	3	4	4	5	4	1.0	4.75	5.00	3	5.0	3.929	1
Turkey	2	3	1	1	2	4.0	3.00	2.75	2	4.0	2.696	25
UK	3	4	2	3	3	3.5	3.00	3.75	3	3.5	3.161	13

*Weighted arithmetic mean = (sum of social economic output*5+ sum of physical ecological output*9)/14*