Chapter 4
GEC Indicator System/Mathematical Model Design & Evaluation Methodology

In order to objectively evaluate the level of GEC and understand all the aspects and internal mechanism of GEC, it is necessary to conduct a comprehensive evaluation, which requires establishment of an indicator system that can objectively and precisely reflect the various aspects of GEC while at the same time referring to the internal structural characteristics of it and can evaluate and analyze it using scientific and logical mathematical evaluation model. Owing to the extensive contents of GEC, such as ecological environment, resource environment, environmental management, environmental influence and environmental coordination, and the unique internal structural characteristics, it is a rather complex task to establish an indicator system and mathematical model for evaluation, analysis and research of the GEC. This study has explored to design a scientific and proactive evaluation indicator system and model with reasonable logics and wide visual field and at the same time fitting into the reality of global environment based on the environmental status and facts of 133 countries of the world and their environmental development objectives.

4.1 Features and Principles of Design

From the perspective of economics, environment is the synthesis of all external conditions supporting economic entities; and GEC is a comprehensive evaluation of the relative competitive advantage of such external conditions. We may use the traditional qualitative description and qualitative evaluation approach to complete the evaluation, but such approach is rather subjective, and, very often, driven by different types of performance examination and benefits; besides, such evaluation results are quite ambiguous, fail to give appropriate and precise evaluation and placement for the environmental competitiveness level of different regions, and of course, no specific and precise policy suggestions with guidance and operability can be proposed based on such evaluation. If adopting quantitative analysis otherwise, we need to use scientific standards, select and determine typical indicators to form an

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evaluation system and use a logical mathematical model to measure and assess the GEC level of the countries; thus GEC can be converted into a concrete standard that can be easily judged and dissected and is operable, from a conceptual and abstract matter into a concrete and representational matter. From the evaluation results obtained, we can timely discover the primary indicators, weak links and other causes that restrict and influence the level of GEC of a nation and hence propose relevant countermeasures for the nation to enhance environmental competitiveness, as decision-making reference.

For quantitative analysis, the most important thing is to design an evaluation indicator system that can objectively and precisely reflect the GEC level of all countries of the world as well as a scientific and logical mathematical model; this is the foundation and key to the comprehensive evaluation, analysis and research of GEC. A scientific GEC indicator system and mathematical model must be designed thorough understanding of the internal mechanism and characteristics of GEC and following certain principles.

4.1.1 Composition and Characteristics of GEC

Environment can be subdivided into natural environment, social environment, economic environment; the environment used in this study refers to natural environment and therefore Global Environmental Competitiveness primarily refers to natural environmental competitiveness. In environmental laws, natural environment refers to the totality of naturally formed substance and energy that have direct or indirect influence over human existence and development, such as atmosphere, water, plant, animal, soil, rock and mineral, etc. These are the material basis for human survival and are normally divided into five natural spheres, the atmosphere, the hydrosphere, the biosphere, the pedosphere and the lithosphere. Natural environment includes ecological environment, biotic environment and resource environment. Biotic environment further includes animal environment and plant environment. As collection of bioenvironmental indicator data is very difficult and very often impossible, the biotic environment part is temporarily taken out from this study and when the data become available, evaluation of this part will be added.

From the definition of environment we can see the wide coverage of the concept; hence, GEC is also a concept with rich contents and broad extension. And therefore, a thorough understanding of the internal mechanism and characteristic of GEC becomes a necessary for construction of a scientific and logical evaluation indicator system; these should be adequately integrated in the indicator system and mathematical model.

1. **GEC has rich contents and covers wide range of aspects.** Comparing to natural environment, GEC covers the entire contents of natural environment, including ecological environment, biotic environment and resource environment and involving various aspects such as air, water, soil, forest, mineral product, energy source, plant, animal, etc.; it is the synthetic manifestation of the competitiveness of all natural environmental factors. Therefore, while constructing the indicator system,

these aspects must be adequately considered and the indicators of various factors should be rationally determined and distributed, so as to form a structurally complete, logically strict and rationally distributed indicator system; in this way, the evaluation system can comprehensively and precisely reflect the real status of global environmental competitiveness.

2. **The GEC factors are mutually influential and interactive.** The ecological, biotic and resource environment under the context of global environmental competitiveness are always mutually influential and interactive in between. Changes in ecological environment will influence biotic and resource environment, while changes in the latter will also influence the former. For example, expansion of natural reserve area (corresponding to ecological environment) will increase the variety of biologic species and improve the status of atmosphere and water resources in the reserve. And deterioration of the atmosphere, water and soil and decrease of biotic life will cause such ecological deterioration problems as desertification of land as well as water loss and soil erosion. The relationship between ecological, biotic and resource environment has decided that the relationship between ecological environmental competitiveness, biotic environmental competitiveness and resource environmental competitiveness are also mutually influential and interactive. Therefore, the relationship between the three should be carefully designed during construction of the indicator system to fully reflect the interactions in between. Of course, the availability of data should also be considered. Take biotic environmental competitiveness for example, there is almost no data and therefore the factors are not included in the indicator system.
3. **GEC is not only determined by environmental system, but also influenced by the economic system and social system.** GEC itself is an indicator reflecting the status of environmental status and hence it is undoubtedly dependent upon environmental system. But environmental problem is never only a matter of environmental issue; it is at the same time a matter of economic issue and social issue. In the entire environment-economy-society system, environmental system is influenced by economic system and social system, and economic system and social system are likewise influenced by environmental system. To be specific, economic system influences environmental system through production activities and environmental system satisfies the resource demand of economic system; social system influences environmental system through human daily life and environmental system satisfies the ecological demand of social system; economic system satisfies the economic demand of social system and social system satisfies the consumption demand of economic system. The relationship between the three is shown in Fig. 4.1.

In this system, of course, everything goes on surrounding humans; it is humans that impose the influences on environment through various economic and social instruments. Therefore, the influence of economic system and social system on environmental system must be adequately considered and reflected in the indicator system. For instance, adding two sub-index, EMC (including two pillars, resource utilization and environmental safety) and ECC (including two pillars, coordination

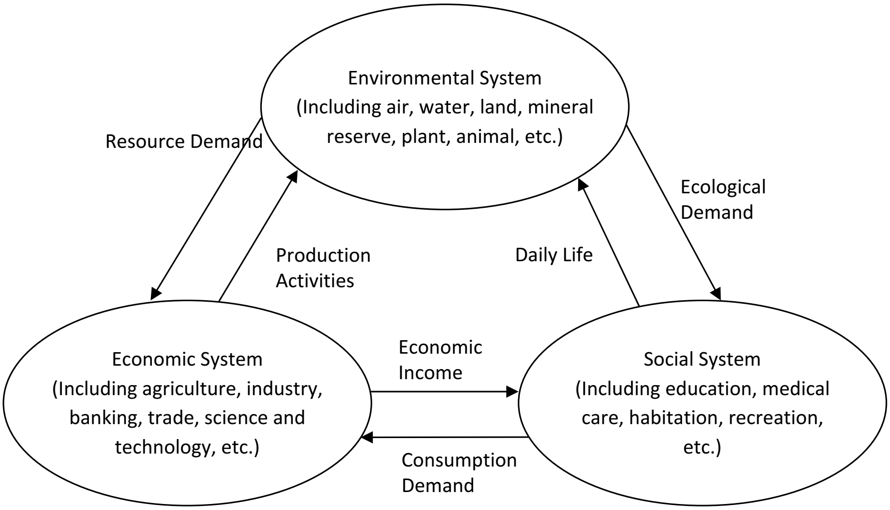

Fig. 4.1 Environment-economy-society system

between population and environment, and coordination between economy and environment), is to adequately reflect the influence of human economic activities and social activities on environment.

4.1.2 Principles of Constructing GEC Indicator System and Mathematical Model

Environment is a complex system with multiple intricately related factors that decide and influence GEC; a comprehensive and systematic analysis of these factors is never simple and should be done within an equally complex evaluation system. A relatively complete framework system requires as many as possible indicators to be screened according to the correlation between the factors and the representative indicators can be obtained after removal of irrelevant ones. This process is based on certain principles. The indicators selected must be typical and representative, as part of a unified entirety and must be mutually related; they should not be a simple combination of non-related indicators. The particularity, complexity and scientific requirements of evaluation of GEC should also be considered in the mathematical model. In summary, below are the principles to be followed while designing the indicator system and mathematical model:

1. **Principle of combining system and layering**
   Environmental system, as a system with the ecological environment, biotic environment and resource environment as dominant factors, has complex inter relationship; the subsystems are mutually influential and interactive. Therefore,

the GEC indicator system and mathematical model must be an organic entirety that can comprehensively and precisely describe and reflect the level and characteristic of the entire environmental system and should follow the principle of being systematic. From the perspective of system theory, environmental system as a macro system may be further divided into many subsystems in multiple layers, which together determines the level of environmental competitiveness and connects the evaluation target with the indicators as organic entirety. From the perspective of methodology, human observation and cognition of complex problem can hardly be thorough once and for all; very often, we need to systematically decompose the problem into multiple layers and subsystems, step by step from global to local, from abstract to concrete, and from appearance to essence; this is a process of using layered cascade method in analysis, following the principle of layering. It is the continuation of the principle of system, requiring the indicator system to divide the indicators into distinct layers according to the structure of the macro system; and, the indicators of the lower layer should represent the meaning of the upper layer as much as possible, in order to avoid overlapping among the various indicators. In the hierarchical structure, each evaluation indicator shows its affiliation to different layers of indicators and the interactions in between. The higher the layer, the more comprehensive the indicator will be; and the lower the layer, the more concrete the indicator will be. Upper-layer indicators are the summarization of the lower-layer indicators and guide the establishment of the lower indicators; lower-layer indicators are the breakdown of the upper-layer indicators; hence an orderly systematic hierarchical structure is formed for convenient operation and utilization. In summary, an indicator system reflecting the environmental competitiveness of the environmental system must be systematic and hierarchical.

2. **Principle of combining completeness and independence**
   The constructed GEC indicator system and mathematical model as an organic whole should reflect not only the entire characteristics and comprehensive status of the environmental system in all countries from different angles and in an all-round way, but also the key information of the system; the indicators should be concise and relatively independent and indicators in the same layer should be able to represent one of the aspects of the layered system, trying to avoid overlapping or inclusive causal relations; the entirety should be expressed in as less indicators as possible.
3. **Principle of combining universality and comparability**
   The indicators of GEC evaluation system should be able to understood and accepted by most people and universally applicable; they should consider the differences of the countries or regions around the globe and straightforwardly manifest the environmental competitiveness status of the countries or regions of the world. While considering the universality of the indicators, comparability should not be neglected. Which is to say, the selected indicators must be comparable indicators showing universality and at the same time with definite meaning as well as scope of statistics and scope in each country, as a way to guarantee the comparability in time and space. They can be compared with respective past and

future and also with the corresponding indicators of other countries, so as to make sure that GEC can be evaluated in comprehensive and proper way; consequently, the evaluation results can be better used to compare and analyzed GEC in time and space and finally to find out the factors that actually influence global environmental competitiveness.

4. **Principle of being scientific and operable**
   The screened out indicators and designed mathematical model should be established based on adequate understanding and research on the environmental system. It should be able to objectively reflect the connotations, requirements, intrinsic characteristics and actual status of environmental competitiveness, with logical preciseness and able to survive any questioning or scrutiny by different point of views and argumentation as well as the inspection of facts and history. Moreover, the evaluation of GEC can reveal the essential characteristics and inherent laws of GEC and thus could be guidance for enhancement of GEC.

   In addition to being scientific, the indicator system and mathematical model should also be operable. The selected indicators should be distinct in definition and expressed in terms internationally used to avoid any reciprocal overlapping or repetition of contents. Data should be easily collectable from authoritative and reliable source. For example, the data of biotic environmental competitiveness are basically unavailable and therefore this part is excluded from the indicator system. Besides, the statistics, calculation, comparison and analysis of the indicators and model should be convenient and understandable, in order to guarantee smooth progressing of the evaluation work and sufficient reliability.

5. **Principle of integrating dynamic and static aspects**
   Environmental system is a historical, dynamic, continued and developing system and at the same time static and stable at certain point of time period; it is the unification of being both dynamic and static. On the one hand, GEC evaluation must reflect the dynamic characteristics of environmental system and can adjust and improve the indicator system and model with the development of and changes in the environmental system; in this way, it can continuously and dynamically reflect the changing status of GEC. On the other hand, once established, the indicator system and mathematical model should not be frequently changed and should remain relatively stable within given period of time, to guarantee the effective comparison and analysis of the development process of the system.

6. **Principle of being forward looking and guiding**
   Environmental system is dynamic and so is GEC. One time of evaluation of GEC only represents the status at one point of time in the past of its developing process. To know the latest status, we have to do new evaluation, but as environmental reflection of human activities is always hysteretic even the newest evaluation results might also be hysteretic, which makes it difficult to obtain evaluation results that truly reflect the current status, not to mention the results that can reflect the future status. Therefore, in order to better reflect the actual status of GEC, the design of the indicator system and model should fully consider the development trends and future situation by selecting certain advanced and for-

ward looking indicators that can not only reflect the past and present but also the future status of GEC.

Selection of the forward-looking indicators should follow the principle of being guiding. The selected indicators should be supportive and instructive to decision makers, general public and various entities in the society; they should be able to guide people to act towards the required direction of the forward-looking indicators in areas like resource saving and environment-friendly activities.

4.1.3 Overall Coordination of Relationship Between the Principles

The above six principles are relatively independent and at the same time constitute an interrelated and interactional whole. They should not be dissevered; instead, the relationship between each other should be coordinated in overall perspective and be applied throughout the entire process of evaluation. Only in this way, they can truly offer guidance during construction of the indicator system and model and can be the guarantee for correct and effectively evaluation, analysis and research of GEC.

4.2 Construction of GEC Indicator System

With adequate understanding of the intrinsic composition and characteristics of GEC as well as the principles to be followed, we may start the work of constructing the GEC Evaluation Indicator System.

4.2.1 Methodology

Based on the connotations, intrinsic composition and characteristics of GEC and according to the requirements of global sustainable development, this study has constructed a multi-layer and multi-system GEC Indicator System with classified categories, and divided the indicators into four layers of system layer, module layer, factor layer and foundation layer (corresponding to primary, secondary, tertiary and individual indicators) following the six principles and the rationale behind such top-down hierarchical division is system theory and control theory. The specific flow of thinking is shown in Fig. 4.2.

First the theories about environmental sciences, ecology, environmental economics and sustainable development, the objective, significance and system layering of GEC is made clear according to its connotation, internal mechanism and characteristics and then the representative, pertinent and operable evaluation indicators are selected after careful analysis and comparison as well as consideration of

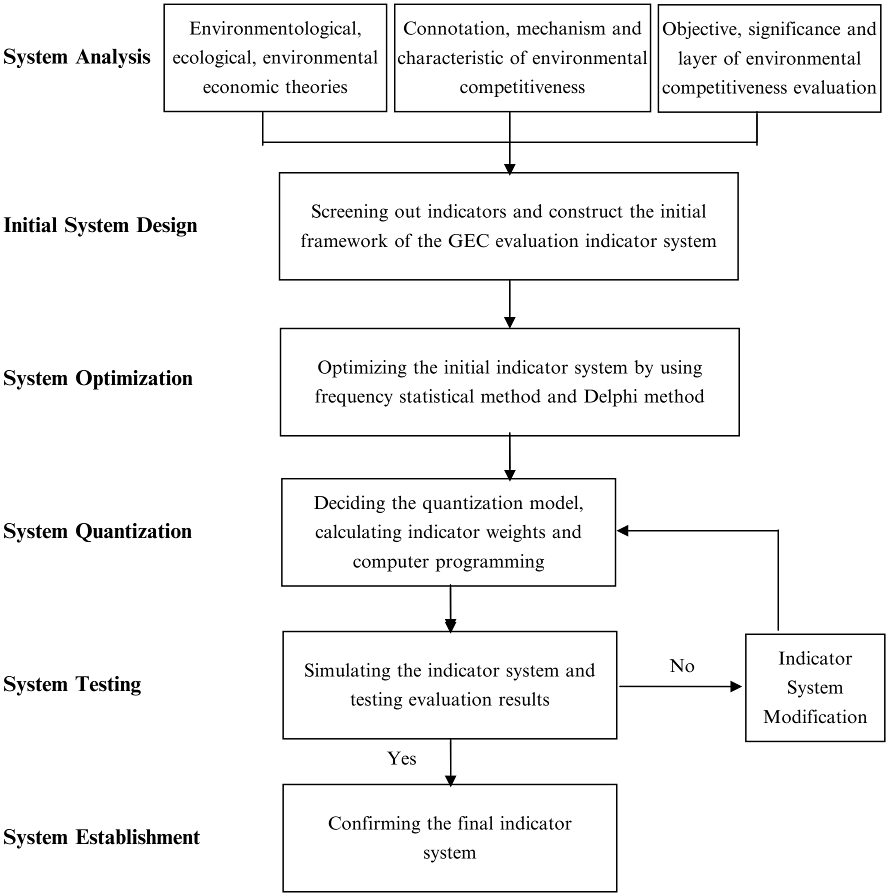

Fig. 4.2 GEC evaluation indicator system construction flow

the availability of data; thus the analytical framework and layered indicators for GEC evaluation are constructed and the meaning as well as measuring method for each indicator are also defined.

Second, by using frequency statistical method and Delphi method, the evaluation indicator system is further optimized to ensure the scientific and authoritative property of the indicators. To be specific, a statistical frequency counting is first done regarding the research reports and papers about sustainable development evaluation, ecological environmental quality evaluation and environmental competitiveness evaluation and then selects the indicators with high frequency of usage, such as Proportion of land area covered by forest, water resources per capita, Arable land per capita, etc. These indicators can reflect regional environment-friendliness and mostly data are available; thus these are good for indicators to measure the environment friendliness in evaluation. On top of this, Research team invited over 50 experts from environmental protection authority, social sciences academy, governmental development research center and the university domestic and overseas, meanwhile, we asked the environmental experts in the field of economy for advice who participated in "International workshop on Green Economic Transformation and Environmental Competitiveness Indicators" which held by UNEP, Chinese Academy for Environmental Planning, Division of Environmental Strategy, PRCEE, Fujian normal university to form an expert panel and the panel use Delphi method to do additions and deletions and improvement on the indicator system after discussions in meetings; an indicator weight survey form is also designed for all layers as showed in Table 4.1.

Third, a quantized mathematical model is decided according to the indicator system established in the previous step and the specific weight of each indicator is calculated; at the same time, quantization method and quantity calculation method for specific indicator as well as the detailed procedures are also defined; then a computer program is compiled.

Finally, input the regional indicator data to simulate the system and test the results. If the test results are justifiable, then the final GEC evaluation indicator system will be confirmed; if unjustifiable, the research team will further modify the indicator system and do system simulation again after modification.

4.2.2 Selection of Indicators in System Layer and Module Layer

There is only one indicator in the system layer of GEC evaluation indicator system (index), i.e., Global Environmental Competitiveness (GEC, A1). This is a comprehensive and systematic index to evaluate global environmental competitiveness, covering the various aspects of an environmental system as general outline and reflects the overall level of environmental competitiveness of a country; it is also the general objective of evaluation for the indicator system.

Below the system layer is module layer, in which indicators are actually the sub modules of an environmental system reflecting respective support to the environmental system. As per the composition, mechanism and characteristics of GEC, the module indicators are designed from the five key component parts of GEC, namely REC, EEC, ECC, EMC and EHC, as five sub-index which constitute the major aspects and framework of GEC, as shown in Fig. 4.3.

1. **Resource Environmental Competitiveness (REC, B1).** Resource is the most fundamental condition for human existence and development and also the basic element for socioeconomic activities. Utilization of resources will not only influence the balance of resource supply, but also affect the balance of environmental system and might further cause deterioration of the foundation for human existence and development due to environmental damage and pollution out of overuse and disuse of resources. REC reflects a region's strength in resource material basis; it is the basal indicator to measure the strength of GEC.

Table 4.1 List of experts to attend "International workshop on "Green Economic Transformation and Environmental Competitiveness Indicators""

NO:	Name	Institution	Nationality
1	André Schneider	Former COO, World Economic Forum	Swiss
2	Andrea Bassi	CEO of KnowlEdge Srl and an Extraordinary Professor at Stellenbosch University	Italian
3	Caroline Eugene	Ministry of Sustainable Development, Energy, Science and Technology	Saint Lucian
4	Dowarkasing Mokshanand	Project Director, 'Sustainable Mauritius'	Citizen of Mauritius
5	German Dario Benitez Forte	Fiscal advisor at the Ministry of Economics and Finance, Uruguay	Uruguay
6	Hoseok Kim	Global Green Growth Institute	Korea
7	Laszlo Pinter	International Institute for Sustainable Development and Central European University	Canadian & Hungarian
8	Lino Briguglio	Professor of Economics, University of Malta	Maltese
9	Novrizal Tahar	Environmental Economic Planning Division, Ministry of Environment of Indonesia	Indonesia
10	Oliver Greenfield	Convener, Green Economy Coalition	British
11	Richard Scotney	Consultant, UNEP	British
12	Roberto Crotti	World Economic Forum	Italian
13	Seong yoon CHOI	Global Green Growth Institute	Korea
14	Sheng Fulai	Head of Research Unit, UNEP	Chinese
15	Zhou Xin	Institute for Global Environmental Strategies (IGES), Japan	Japanese
16	Chen BoPing	World Wide Fund for Nature (WWF)	Chinese
17	Chen Shaofeng	Institute of Policy and Management, Chinese Academy of Sciences (CAS)	Chinese
18	Cheng Qian	International Labour Organisation (ILO)	Chinese
19	Dong Zhanfeng	Chinese Academy for Environmental Planning	Chinese
20	Ji Zhu	President, Beijing Academy of Smart Economy	Chinese
21	Jiang Hongqiang	Chinese Academy for Environmental Planning	Chinese
22	Jiang Nanqing	UNEP China Office	Chinese
23	Jin Zhouying	Senior Researcher, Institute of Quanti-Economics and Techno-Economics, Chinese Academy of Social Sciences (CASS)	Chinese
24	Li Xiaoxi	Director, Institute of Economics and Resources Management, Beijing Normal University	Chinese
25	Liu Yimeng	Institute of Economics and Resources Management, Beijing Normal University	Chinese
26	Wang Jingyi	Institute of Scientific & Technical Information of China	Chinese
27	Wang Jinnan	Director, Chinese Academy for Environmental Planning	Chinese
28	Wang Yi	Deputy Director-General, Institute of Policy and Management, Chinese Academy of Sciences	Chinese
29	Wu Qiong	Chinese Academy for Environmental Planning	Chinese
30	Wu Yitong	Volunteer	Chinese

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Table 4.1 (continued)

NO:	Name	Institution	Nationality
31	Yang Weishan	Chinese Academy for Environmental Planning	Chinese
32	Yu Hai	Director, Division of Environmental Strategy, PRCEE	Chinese
33	Zhang Huanbo	Research Associate, China Center for International Economic Exchanges (CCIEE)	Chinese
34	Zhang Wei	Chinese Academy for Environmental Planning	Chinese
35	Zhang Xuehua	Environmental Impact Assessment Specialist, UNEP	Chinese
36	Zhang Yongliang	Policy Research Center for Environment and Economy, Ministry of Environmental Protection, P.R. China	Chinese
37	Liao Fulin	Vice-chancellor of Fujian Normal University	Chinese

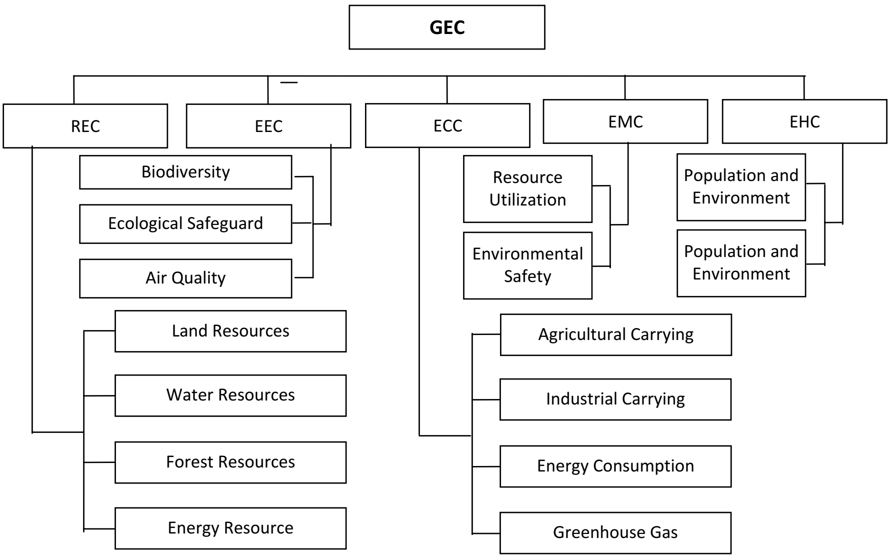

Fig. 4.3 Pillars of GEC evaluation indicator

2. **Ecological Environmental Competitiveness (EEC, B2)** Ecological environment refers to the entirety of various ecosystems that are composed of biotic communities and, mainly or completely, abiotic natural factors, and that indirectly and potentially impact human existence and development in the long run; it is the key part of natural environment. EEC mainly reflects the effect of both nature and humans themselves on ecological environment; it is an important label to indicate GEC strength.
3. **Environmental Carrying Competitiveness (ECC, B3).** Environmental Carrying refers to the effects of human activities (economic and social activities)

on environment and the changes in environment cause by such activities, such as environmental quality worsening due to natural environmental pollution and damage during human production and life process, including low-efficiency and uncontrolled exploitation of natural resources, discharge of waste water, waste gas and waste solids into the natural world without strict treatment, etc. EBC reflects the impact of human activities on natural environment in a region, or environment's ability to respond to and restore itself against human activity; it is an important indicator to show GEC strength.

4. **Environmental Management Competitiveness (EMC, B4).** Environmental management refers to a comprehensive action of human by using various means of planning, organizing, coordinating, control and supervision for the purpose of anticipated environmental objectives, mainly positive effects applied on natural environment, such as environmental pollution governance. Environmental management can timely discover and correct the problems in environmental system running, making environment operate normally and improving environmental status. EMC reflects a region's intensity in natural environment governance and supervision; it is a key indicator to measure GEC.
5. **Environmental Harmony Competitiveness (EHC, B5).** Environmental harmony refers to the degree of harmony between the existence and development of humans and the environment, mainly including two aspects, namely coordinated development of population and environment, and coordinated development of economy and environment. EHC reflects the degree of coordination between human activities and natural environment in a region and also an important indicator to measure GEC strength.

4.2.3 Selection of Indicators in Factor Layer

Indicators in factor layer are the major factors that influence the sub-index and therefore are decided by the contents and features of each submodule. As per the connotations, composition and characteristics of the five sub-index; the factors are further subdivided to 16 pillars. Establishment of indicators in the system layer, the module layer and the factor layer has formed the main framework of GEC, as shown in Fig. 4.3.

1. **Pillars under REC.** Resource environment mainly includes four factors, land, water, forest and energy; therefore Land Resources (C11), Water Resources (C12), Forest Resources (C13) and Energy Resources (C14) as the pillars of GEC. Land, water, forest and energy are the most fundamental resources for human existence and development and also the basic elements for consumption required by the social and economic activities of human; they are the carrier of the entire human production and life and the environment constituted by these factors are the place where human society exist and where human interference

and damage are most serious. Today, the resource environmental pollution and damage has become one of the key issues faced by the world. Land resources, water resources, forest resources and energy resources reflect the resource support to production and life from the angles of different type of resources in a region; they are the fundamental components of REC.

2. **Pillars Indicators under EEC.** EEC mainly reflects the competitiveness in biodiversity and ecological safeguard and air quality are selected as the factor indicators under EEC. Biodiversity refers to the steady ecological complex composed of various live organism (animal, plant and microorganism) incorporated in regular pattern. It reflects the abundance of biotic resources and also the intricate relations between biotic lives as well as between environments; it even reflects the degree of human influence on ecological system. Ecological Safeguard reflects the effects of ecological recovery and reconstruction in a region; it has big impact on ecological environmental competitiveness. Air Quality reflects the degree of air contamination; It is judged on the basis of pollutant concentration in the air, it is an important part of EEC.
3. **Pillars under ECC.** Environmental Carrying mainly reflects the scale and scope of human activities; such economic activity need to consume natural resources on the one hand and has certain influence on the ecological environment on the other. The capacity of environment to support and carry human activity decides the sustainability of good environment. Therefore, four pillars are selected under ECC, agricultural carrying, industrial carrying, energy consumption, greenhouse gas. Agricultural production is the key source of food and other consumer goods and such activities inevitably requires development and protection of land resources; it is one of the most direct factors that influence ecological environment. Industrial production is the most important part of economic activity and the major aspect that consumes resources and damages environment. The production level and industrial structure in all countries are different and therefore environmental bearing capacity also shows big difference; hence varied influence on EBC. Energy is the motive power of economic activity. At present, the industrial development pattern relying on consumption of fossil energy not only requires exploitation and consumption of large quantity of energy, but also emits greenhouse gases that have a strong impact on climate environment. The ecological disasters caused by climate change and the impact on human activity have attracted worldwide attention. Greenhouse gasses emission increase is the leading cause for climate change; emission control not only reflects the economic structure of a country, but also reflects a country's efforts in response to climate change.
4. **Pillars under EMC.** Environmental management mainly involves rational utilization of resources and protection of ecological environment, the factor indictors under this aspect are environmental governance, environmental protection and resource utilization. Modern economic operation can't do without exploitation, allocation and use of natural resources. Some resources are renewable, but many more resources are non-renewable. Excessive exploitation of renewable resources would cause non-renewability. Therefore, any country

need to ensure that resource utilization is rational and controlled and continue optimizing resource allocation to increase utilization efficiency. Human activity keeps discharge different kinds of waste into the external environment, including the byproducts and waste of industrial and agricultural production and also the disposables generated during people's daily life. Establishment of waste discharge regulation and supervision are the preconditions to guarantee no pollution or damage to the environment on which human existence and development lie and also an important aspect to measure a country's environmental management capacity.

5. **Pillars under EHC.** Environmental harmony mainly involves two aspects, the harmony between human and environment and the harmony between economy and environment, which become the two factor indicators under EHC. Harmony between population and environment refers to scientific planning of population development to promote moderate population growth and rational distribution as well as coordinated development of both population and environment, while taking environmental bearing capacity into consideration. Population and environment harmony competitiveness reflects the degree of harmony between population development and environmental protection in a region; it is an important indicator to evaluate EHC. Harmony between economy and environment refers to adequate consideration of environmental protection while guaranteeing necessary economic development, adopting low-pollution and environment-friendly way of production and life as much as possible, so that the influence of economic growth on environmental quality can be controlled within the range of bearing capacity and that economy and environment can reach balance. Economy and environment coordination competitiveness reflects the degree of harmony between economic development and environmental protection in a region; it is also an important part of EHC.

4.2.4 Selection of Indicators in Foundation Layer and Description

Foundation layer is composed of individual indicators with direct measuring capacity, directly showing the measurement of indicators in factor layer; it is the most basic layer and operation layer of GEC indicator system. The evaluation of the entire indicator system is actually carried out in this layer. As per the defined scope of pillars, there are 60 designed individual indicators, as shown in Table 4.2.

GEC Evaluation Indicator System is composed of four layers, system layer, module layer, factor layer and foundation layer, which corresponds to 1 index, 5 sub-index, 16 pillars and 60 individual indicators; among these, the index, sub-index and pillars are indirect synthetic indicators, while individual indicators are direct objective indicators that are measurable and therefore will use the data

Table 4.2 GEC individual indicators system

Sub-index (5)	Weight	Pillars (16)	Weight	Individual indicators (60)	Weight
Resource environment competitiveness	0.2	Land resources	0.2	Land area per capita	0.40
				Percentage of arable land to total land area	0.30
				Arable land per capita	0.30
		Water resources	0.3	Surface water	0.25
				Annual precipitation	0.25
				Groundwater	0.25
				Total internal renewable water resources	0.25
		Forest resources	0.2	Growing stock in forest and other wooded land	0.30
				Proportion of land area covered by forest	0.40
				Forest area per capita	0.30
		Energy resources	0.3	Fossil energy	0.30
				Energy production	0.35
				Proportion of combustible renewables and waste to total energy consumption	0.20
				Net energy imports of the energy consumption	0.15
Ecological environment competitiveness	0.2	Biodiversity	0.3	Threatened fish species	0.20
				Threatened mammal species	0.20
				Threatened plant species	0.20
				GEF benefits index for biodiversity	0.40
		Ecological safeguard	0.3	Terrestrial protected areas	0.60
				Marine protected areas	0.40
		Air quality	0.4	Inhalable particles (PM10)	0.20
				Particulate matter (PM2.5)	0.20
				Index of Indoor air pollution	0.30
				Nitrogen oxides emission	0.15
				Sulfur dioxide emission	0.15

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Table 4.2 (continued)

Sub-index (5)	Weight	Pillars (16)	Weight	Individual indicators (60)	Weight
Environment carrying competitiveness	0.2	Agricultural carrying	0.3	Cereal yield per unit of arable land	0.40
				Fertilizer consumption per unit of arable land	0.30
				Annual freshwater withdrawals for agriculture per unit of arable land	0.30
		Industrial carrying	0.3	Net exports of goods as a percentage of GDP	0.25
				Electric power consumption per unit of value added of industry	0.25
				SO_2 emissions per unit of value added of industry	0.25
				Annual freshwater withdrawals for industry per value added of industry	0.25
		Energy consumption	0.2	Energy consumption per unit of land area	0.25
				Ratio of clean energy consumption	0.25
				Elasticity of energy consumption	0.25
				Elasticity of electric power consumption	0.25
		Greenhouse gas	0.2	Growth rate of CO_2 emissions	0.40
				Growth rate of Methane emissions	0.20
				CO_2 emissions per unit of land area	0.20
				CO_2 emissions per unit of energy consumption	0.20
Environment management competitiveness	0.2	Environmental governance	0.3	Agricultural chemicals regulation	0.20
				Percentage of the rural population with access to an improved water source	0.20
				Percentage of the urban population with access to an improved water source	0.20
		Ecological protection	0.4	Area of plantation and afforestation	0.40
				Biome protect	0.30
				Overfishing of fishing resources	0.30
		Resource utilization	0.3	Utilization rate of water resources	0.20
				Percentage of total internal renewable water resources to total water resources	0.20
				Percentage of agricultural land to total land area	0.20
				Percentage of fossil fuel energy consumption to total energy consumption	0.20

Environment harmony competitiveness	0.2	Population and environment	0.5	Percentage of population with access to Improved sanitation facilities	0.20
				Motor vehicles per 1,000 people	0.20
				Renewable internal freshwater resources per capita	0.15
				SO_2 emissions per capita	0.15
				CO_2 emissions per capita	0.15
				Energy consumption per capita	0.15
		Economy and environment	0.5	Land resource utilization efficiency	0.25
				Sulfur dioxide emissions per unit of GDP	0.25
				Carbon dioxide emissions per unit of GDP	0.25
				Energy consumption per unit of GDP	0.25

released in current statistics system by such international organizations as UN and World Bank to guarantee the comparability of the collected data. As the statistical data about environment are limited and incomplete in current statistical system, which, to some degree, influences the availability of individual indicators data, certain relatively irrelevant individual indicators are already deleted while constructing the indicator system; but as for the few important and indispensible indicators, data will be collected using synthetic or substitute indicator. Such treatment might influence the precision and objectiveness of the evaluation result, but as the number of such indicator is extremely small and they are distributed in the bottom layer carrying small weights, there would be no obvious impact on the final overall evaluation result. The establishment of environmental competitiveness evaluation indicator system will provide a relatively reasonable and objective standard for the evaluation of GEC.

4.3 Construction of GEC Model Based on Modified AHP

After construction of GEC evaluation indicator system, the next step is to construct a GEC mathematical model, which is a step of vital importance during the evaluation process. Once the model is established, the evaluation process only requires input of collected data into the model and result will be obtained. Construction of the model can be done in three steps: first, apply dimensionless treatment to the evaluation indicators; next, determine the weights of indicators; and finally, establish the mathematical model. In the second step, indicator weights will be determined using Delphi – modified analytic hierarchy process.

4.3.1 Dimensionless Treatment to Indicators

As the unit of measurement and dimension of each indicator (individual indicators) are different and very often the numerical values show wide gap, calculation can't be done directly; instead, we must first apply dimensionless treatment to the indicators, changing them into non-dimensional numerical value or point value by indexation for integrated computation. There are multiple non-dimensional methods, and there are four commonly used ones: normalization by aggregation, normalization by standard deviation, normalization by max value and normalization by range. Here we adopt simple and practical efficiency coefficient method to apply this treatment to the indicators.

When an indicator is a positive indicator (having positive influence on the upper-layer indicators), the non-dimensional value of Indicator i will be Xi:

$$Xi = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \times 100$$

When an indicator is a negative indicator (having negative influence on the upper-layer indicators), the non-dimensional value of Indicator i will be Xi:

$$Xi = \frac{x_{\max} - x_i}{x_{\max} - x_{\min}} \times 100$$

In which, Xi represents the obtained non-dimensional value of Indicator i, Non-dimensional Indicator i for short; xi is the original value of the indicator, x_{max} and x_{min} represent the maximum and minimum original values of similar indicators under comparison respectively.

After dimensionless treatment, the value of each indicator will be within the range of 1–100, with consistent polarity.

4.3.2 Assessment of Indicator Weight

Indicator weight represents its contribution to the evaluation objective in the indicator system; assessment of the weight of each indicator is a rather difficult procedure of the evaluation process and has vital importance for the results; therefore, the method used must be objective. Generally speaking, the most common way to assess indicator weight is using Delphi – analytic hierarchy process, i.e. first marking of the confirmed evaluation indicators through survey by experts based on and their long years of professional experience after pairwise comparison of the significance of each indicator and then calculation using analytic hierarchy process. Here the Delphi – modified analytic hierarchy process will be used to assess the weights. Modified analytical hierarchy process and the traditional analytical hierarchy process differ mainly in the scaling method for experts' marking while using Delphi method to arrange the evaluation indicators' relative importance judgment matrix. In traditional AHP, 1–9 scaling is adopted. But due to the complexity and fuzziness of indicator, it is difficult for experts to make precise assessment on each indicator into the 9 grades of the 1–9 scale; instead, they may give relatively fuzzy judgment of the indicators' relative importance. For example, Indicator A is more important than Indicator B, but how much more important is not clearly given. The judgment matrix obtained this way is less accurate and needs several times of adjustment. Therefore, the AHP is modified to adopt the scale of 0–2, which is less time-consuming and convenient, and more acceptable to experts (CHENG Jian-quan 2002). 0–2 Scaling is to first form a comparison matrix B, in which b_{ij} is defined as:

$$\mathrm{B} = \left(\mathrm{b}_{ij}\right)_{n\times n}$$

$$b_{ij} = \begin{cases} 2 & \text{When Factor i is more important than Factor j} \\ 1 & \text{When Factor i is equally important as Factor j} \\ 0 & \text{When Factor j is more important than Factor i} \end{cases}.$$

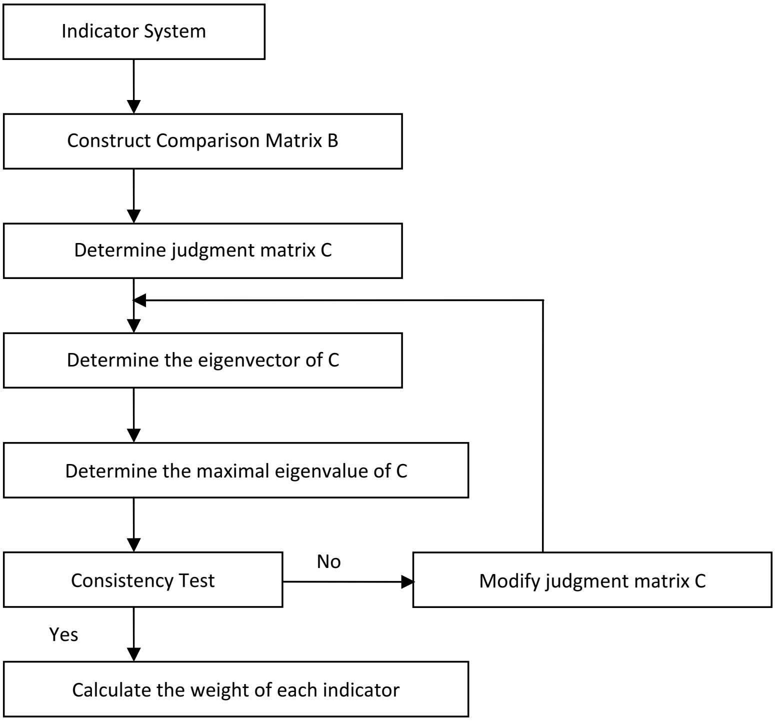

Fig. 4.4 Procedures of modified AHP

Next calculate $r_i = \sum b_{ij}(i = 1, 2, \cdots, n)$, i.e. summation by row, and then obtain the judgment matrix $C = (c_{ij})_{N \times N}$ using the following formula, in which $r_{\max} = Max\{r_i\}$, $r_{\min} = Min\{r_i\}$ and $b_m = r_{\max}/r_{\min}$.

$$c_{ij} = \begin{cases} \left[\left(r_i - r_j\right)/(r_{\max} - r_{\min})\right] \times (b_m - 1) + 1 & r_i \geq r_j \\ \left\{\left[\left(r_j - r_i\right)/\left(r_{\max} - r_{\min}\right)\right] \times \left(b_m - 1\right) + 1\right\}^{-1} & r_i < r_j \end{cases}$$

After establishment of judgment matrix, other procedures shall follow the traditional AHP and finally the weight of each indicator can be obtained. The procedures of modified AHP are shown in Fig. 4.4.

Based on these procedures, we sent the GEC Indicator System Weighting Survey Form for Experts to more than 50 scholars doing related researches in the academic circle and experts from government authorities; all experts are required to fill in the survey form independently and rate of return is 100 %. Through reorganization of the survey forms and deducting the highest and lowest weighting results, the weights of all indicators are obtained from the average of the remaining weighting results followed by test. The finally tested environmental competitiveness indicator weight system is shown in Table 4.2.

4.3.3 Establishment of GEC Model

After weighting of indicators, next step is to construct the GEC model for calculation of the GEC evaluation score of each country. The higher the evaluation score, the stronger the country's environmental competitiveness will be. The GEC model is determined as:

$$Y = \sum_{i=1}^{l}\sum_{j=1}^{m}\sum_{k=1}^{n} x_{ijk} w_{ijk} \tag{4.1}$$

$$Y_i^1 = \sum_{j=1}^{m}\sum_{k=1}^{n} x_{ijk} w_{ijk} \tag{4.2}$$

$$Y_{ij}^2 = \sum_{k=1}^{n} x_{ijk} w_{ijk} \tag{4.3}$$

In which, Y is the GEC comprehensive evaluation score, Y_i^1 is the evaluation score of Module Indicator i, Y_{ij}^2 is the evaluation score of Factor Indicator j, x_{ijk} is the non-dimensional data value of Foundation Indicator k under Factor j in Module i, w_{ijk} is the weight of this Foundation Indicator, l represents the number of Module Indicators in the GEC indicator system, m is the number of Factor Indicators in each Module Layer, and n is the number of Foundation Indicators in each Factor Layer.

With the GEC model, evaluation of a country's environmental competitiveness becomes a simple job, because the weight of each indicator is fixed and the only thing to be done is to input the non-dimensional data value of the Foundation Indicators of the country; then the GEC score as well as the scores of each Module Indicator and Factor Indicator can be obtained. The model can also carry out comprehensive evaluation on each country's environmental competitiveness; all countries can be ranked, compared and analyzed according to respective comprehensive evaluation scores.

4.4 Method of Determining GEC

4.4.1 Definition of GEC Evaluation Period and Area Coverage

Due to various restrictions during GEC evaluation, it is not possible to evaluate the environmental competitiveness of all countries or regions in any time period; therefore, it is necessary to first define the time period and area coverage of the evaluation.

1. **Evaluation Period.** As per the internationally released public statistical data, the latest data year is 2010 and therefore the benchmark year of GEC evaluation is also decided as 2010.
2. **Evaluation Areas.** Based on the collected data, the evaluation and analysis of the environmental competitiveness in this study are done for the 133 countries of the world. And these countries are classified according to the six continents of Asia, Oceania, North America, South America, Europe and Africa; comparative analysis is also done for G20 nations and five BRICK countries.

4.4.2 Indicator Ranking Sections

Base on the tested indicator system, this study adopts radar chart to complete the evaluation and comparative analysis on the each layer of GEC indicators. For the convenience of evaluation result analysis, the rankings are sectionalized. To judge a country's environmental competitiveness level around the globe, the rankings are divided into five sections, 1st–10th, 11th–30th, 31st–60th, 61st–100th and 101st–133rd.

4.4.3 Analysis of Indicator Scores

GEC is composed on five Sub-index and the GEC comprehensive score is obtained from the collective of the five scores; and each countries show varied performance in the five Sub-index. In order to the better demonstrate such variation, the contribution rate of each Sub-index to environmental competitiveness is measured and calculated, so as to show the strengths and/or weaknesses of a country's environmental competitiveness.

$$\mathrm{Y}_i^c = \left(Y_i^1 \times w_i\right) / Y \tag{4.4}$$

Here Y_i^c represents the contribution rate of Sub-index i to comprehensive score, Y_i^1 and Y are defined in Formula 4.1, 4.2, and 4.3, as the evaluation score of Sub-index i and the comprehensive evaluation score of GEC, and W_i represents the weight of Sub-index i in index. The contribution of five Sub-index to the index is given in Fig. 4.5 as pie graph.

At the same time, in order to see the scores of pillars and their performance in the countries, the highest and lowest scores of each pillar is also calculated; the rankings of all pillars can better show their comprehensive performance. As shown in Fig. 4.6, the dark line corresponding to each of the pillar represents the distribution of this indicator in different countries; the hollow triangle in the middle is the country's ranking place.

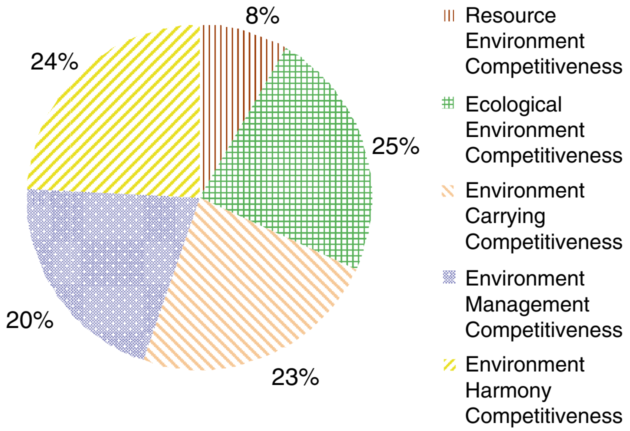

Fig. 4.5 Contribution of sub-index scores

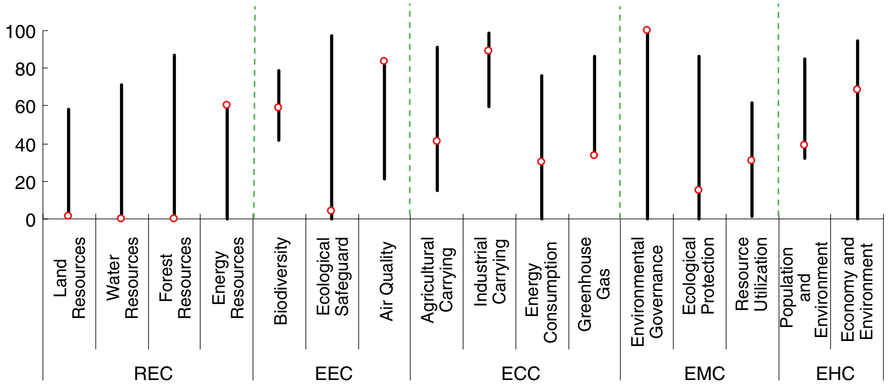

Fig. 4.6 Pillars scores