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Original Research

Measurement Method and Empirical Research on Systemic Vulnerability of Environmental Sustainable Development Capability

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Abstract

Systemic vulnerability is an internal and essential factor that influences environmental sustainable development capability. Optimizing adjustments on systemic vulnerability significantly contributes to improved function, decreased disturbance, and guaranteed scientific evolution of environmental sustainable development capability. The connotation of systemic vulnerability of environmental sustainable development capability is defined and demonstrated. Measuring indexes, which reflect three aspects such as economic, ecological, and social subsystems, are established. With the application of the entropy-topsis model, statistical data from 1993 to 2012 in China are collected to carry out empirical research. The measuring values on systemic vulnerability are significantly below the standard values. On the basis of further analysis, adjustment strategy can be constituted for decreasing systemic vulnerability and improving environmentally sustainable development capability.

Keywords: environmental sustainable development, systemic vulnerability, measurement indexes and method, empirical research

Introduction

A regional environmental system that consists of economic, ecological, and social subsystems is an organism with special structure and function. It is formed by human mining and utilization of natural and environmental resources. Economic, ecological, and social function should be concentrated on and balanced to achieve the optimization and cooperation of the integral effectiveness. Essential influencing factors such as economic growth, the utilization efficiency on natural resource, ecological conservation, and scientific progress should be melted into a comprehensive system to strengthen cooperative effect. For a long time, the central and regional governments of China excessively concentrate on rapid economic growth, but ignore environmental conversation and ecological construction. The developmental objectives of economic, ecological, and social subsystems can't be validly integrated so that non-cooperative conflicts exist. Cooperative performance is very low and the environmental sustainable development capability is destroyed. The sensitivity and mutation characteristics of a regional comprehensive system are obvious, and systemic vulnerability of environmental sustainable development capability is significant. On the one hand (Table 1), with rapid economic growth, volume of waste water, industrial emissions, and solid waste increase between 1993 and 2012. Environmental sustainable development capability seriously is threatened. On the other hand (Figs. 1 and 2), consumption of energy and water also displays a gradual incremental tendency

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Table 1. Volume of waste water, industrial emission, and solid waste from 1993 to 2012 in China.

Year	GDP (a hundred million RMB)	Waste water (in 10,000 tons)	Industrial emission (in 10,000 tons)	Solid waste (in 10,000 tons)
2012	519322.30	6748938.75	2306.66	3159.68
2011	473104.05	6591922.44	2217.91	3328.25
2010	401512.80	6172562.00	2185.15	3492.86
2009	340902.81	5890877.25	2214.40	4499.84
2008	314045.43	5716801.00	2321.20	5125.32
2007	265810.31	5568494.16	2468.09	5781.51
2006	216314.43	5144802.00	2588.80	7094.14
2005	184937.37	5245089.00	2549.40	7523.59
2004	159878.34	4824094.00	2254.90	7428.95
2003	135822.76	4671084.34	2421.31	8626.93
2002	120332.69	4661979.62	2422.78	9463.70
2001	109655.17	4755388.56	2548.06	10381.63
2000	99214.55	4831096.94	2660.74	11388.60
1999	89677.05	4903037.20	2775.59	12493.24
1998	84402.28	5443643.18	3265.78	12823.01
1997	78973.03	5363551.16	3221.88	12883.92
1996	71176.59	5246719.76	3072.29	14266.83
1995	60793.73	5181452.68	3014.93	15968.39
1994	48197.86	4599697.99	2833.79	16492.90
1993	35333.92	3753540.73	2392.92	17899.67

that reflects an emergent threat from limited capacity of natural resources. Systemic vulnerability is an internal essential characteristic of a regional comprehensive system. Considering internal and external influencing factors' function, stable and sustainable capability has been destroyed. The negative function of economic growth, which weakens environmentally sustainable development, is accumulating. If the negative tendency is not under control, a regional comprehensive system would inevitably collapse. In this case, quantitative measurement on systemic vulnerability of environmental sustainable development capability should reflect three aspects economic, ecological, and social sub-systems. It is obviously essential to provide some schemes for promoting environmental sustainable development capability of a regional comprehensive system.

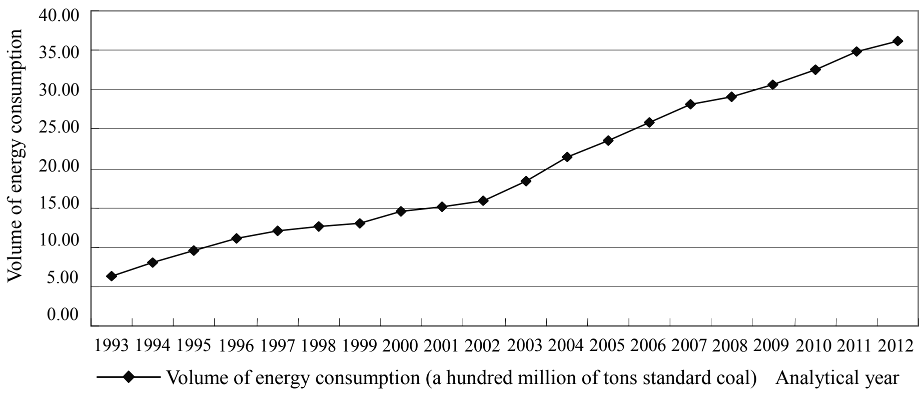

Fig. 1. Volume of energy consumption from 1993 to 2012 in China

Definition and Measurement

Connation Definition

The academic concept about systemic vulnerability which reflects significant research characteristics of natural sciences originates from an ecological area [1-5]. From then on, some scholars apply an analytical method of systemic vulnerability in special research of social science areas such as social welfare, crisis management, disaster losses, political stability, and network security [6-9]. Furthermore, some social science scholars have carried out research on essential characteristics, category, influencing factors, function mechanism, and forming paths of systemic vulnerability of environmental sustainable development capability [10-15]. To sum up, systemic vulnerability is an internal essential characteristic of a regional comprehensive system that is influenced by internal and external factors. Continual damage on stable mechanisms and improving sensitivity reflect uncontrolled negative accumulation. It would obviously stimulate regional comprehensive system collapse. The definition implies three characteristics of systemic vulnerability of environmental sustainable development capability. Firstly, dynamic characteristic are obvious. From the view of time and space, a regional comprehensive system is continually on evolution. Excessive digging and utilizing natural and ecological resources brings out low-level systemic vulnerability in the initial period. The serious unbalance among environment destruction and reservation, extensive economic growth, and unstable development of society bring out high-level systemic vulnerability. The sensitivity and mutation degree of systemic vulnerability factors are gradually increasing and more complicated systemic vulnerability factors are inevitably derived. Secondly, feedback characteristic is significant. Environmental sustainable development capability is seriously affected by sensitivity and mutation degree of systemic vulnerability. Variation of internal and external driving factors certainly brings out corresponding response, and the responding degree is influenced by the sensitive characteristic, the mutation characteristic, and the feedback mechanism of systemic vulnerability factors. Excessive destruction of the environment and extensive economic growth strengthen negative function and tendency. Feedback mechanism is really caused by unfavorable variation of systemic vulnerability factors. Thirdly, time lag is inevitable. When regional systemic vulnerability factors finally form a feedback mechanism, internal destruction mismatch variation of systemic vulnerability factors and time lag is hidden. On the one hand, excessive destruction of the environment has been gradually weakening the ecological circumstance of adjacent regional areas. Negative tendency reflects time lag. On the other hand, performance of corresponding improvement policy to decrease systemic vulnerability is limited by government's administrative efficiency. Negative effects gradually accumulate and the regional system faces the possibility and risk of collapse.

Measurement Aim

The research on systemic vulnerability is an essential basis for environmentally sustainable development capability of a complicated regional system. Key factors that seriously effect systemic stability should be found out. A flexible and suitable adjustment strategy should be constituted to validly improve environmentally sustainable development capability. The regional system consists of economic, ecological, and social subsystems, and measurement aim of systemic vulnerability on environmental sustainable development capability is fundamental to reflect sensitive status. This status responds to the variation of external changes, and negative accumulative degree of systemic vulnerability of environmentally sustainable development capability. Theoretical analysis and quantitative data references can be provided for the constitution of sustainable development strategy. The measurement of regional systemic vulnerability involves many aspects and categories. Measurement on accumulative and longitudinal systemic vulnerability is generally concentrated on. The measurement aim of accumulative and longitudinal systemic vulnerability is to precisely evaluate stability and sensitivity of environmental sustainable development capability. It is mainly caused by extensive industry operation and economic growth mode on the basis of monitoring data and statistical data. Longitudinal evaluation that reflects quantitative description concentrates on own structure and function appraisal. It is fundamental to find out essential influencing factors of regional systemic vulnerability that weaken environmental-

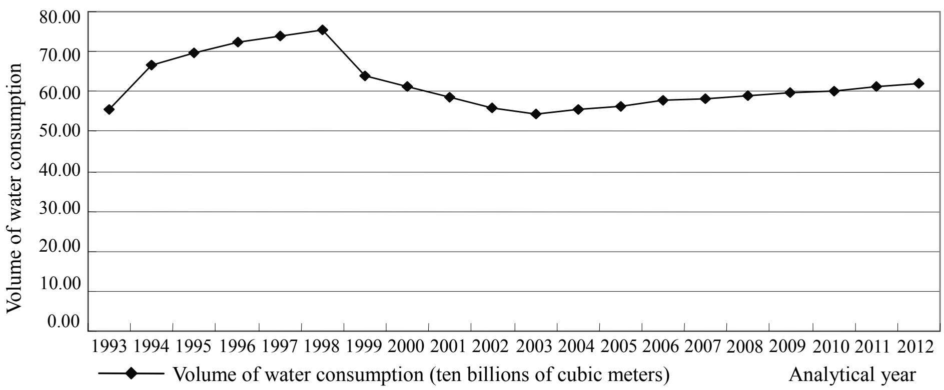

Fig. 2. Volume of water consumption from 1993 to 2012 in China.

Table 2. Amount of investment funds of different kinds of pollution treatment (10,000 RMB).

Year	Waste water of pollution treatment	Industrial emission of pollution treatment	Solid waste of pollution treatment	Noise of pollution treatment
2012	1793555.00	2481727.03	361997.03	29117.11
2011	1577471.00	2116811.00	313875.00	21623.00
2010	1295519.00	1881883.00	142692.00	14193.00
2009	1494606.00	2324616.00	218536.00	14100.00
2008	1945977.00	2656987.00	196851.00	28383.00
2007	1960722.00	2752642.00	182532.00	18279.00
2006	1511165.00	2332697.00	182631.00	30145.00
2005	1337147.00	2129571.00	274181.00	30613.00
2004	1055868.00	1427975.00	226465.00	13416.00
2003	975985.68	1617716.40	275030.66	12973.01
2002	840565.39	1290134.79	300117.81	11372.04
2001	773934.98	994675.09	283849.67	9992.07
2000	623487.32	821154.95	304208.75	8757.18
1999	536977.00	717576.92	258725.51	7683.82
1998	394845.42	626596.01	233681.32	6730.84
1997	304890.24	485106.16	205624.24	5898.88
1996	267114.75	300897.90	167072.27	5163.83
1995	259660.49	395116.84	156028.73	4520.75
1994	188845.12	243180.20	132092.70	3954.38
1993	126055.11	229497.26	110407.56	3458.47

ly sustainable development capability. According to the measurement values on regional systemic vulnerability, the central and regional governments have taken suitable measures to concentrate on investment funds of pollution treatment such as Table 2, and Figs. 3 and 4. It aims to improve environmental sustainable development capability.

Measurement Indexes

Establishment Principles

Firstly, scientific principles concentrate on selecting measuring indexes to reflect connotation and vulnerability of ecological, economic, and social subsystems. Under the guidance of the theory of circular economy, the selected indexes should reflect the reducing, reusing and recycling effect, which can be called the "3R" effect.

Secondly, the operational principle really concentrates on comparative characteristics. Selecting measuring indexes should be easy to acquire statistical data. Considering the lack and availability of present statistical data of regional environmentally sustainable development capability, the selected indexes should be objective and feasible.

Thirdly, significant principle obviously concentrates on selecting indexes to reflect fundamental status of systemic vulnerability of ecological, economic, and social sub-systems. The selected indexes should be direct, specific, and highly relevant. Refining characteristic should be emphasized to avoid selecting excessive indexes.

Lastly, systemic and flexible principle concentrates on selecting indexes to reflect systemic vulnerability of environmental sustainable development capability from many aspects and hierarchies. The selected indexes should reflect tendency and focus on prospective characteristics.

Description of Measurement Indexes

Measurement Indexes on Systemic Vulnerability of Ecological Subsystem

(1) Forest coverage. The index reflects an abundant degree and ecological status of national or regional forest resource. It can be calculated through the proportion of forest area in the regional land area. It is an important index to measure national and regional environmental quality.

Forest coverage %=(*forest area* (km^2) + *shrub area* (km^2) + *forest network area* (km^2) + *surrounding forest area* (km^2))/*regional gross land area* (km^2)×100

(2) Soil and water conservation rate. The index reflects the status of soil and water conservation. Considering the lack of specific statistical data, the sum of non-stocked land area, young afforested land area, shrub land area, sparse wood land area, and woodland area with canopy density under 0.5 values can represent the index.

Soil and water conservation rate % = *area of soil and water loss* (km^2)/*regional gross land area* (km^2) ×100

(3) Water conservation quantity per square kilometer land. Water conservation is an important ecological benefit of a forest ecological system. The essential function is to minimize generation of runoff, increase available water, improve water quality, and regulate runoff. The index is positive.

Water conservation quantity per square kilometer land (m^3/km^2) = (*precipitation* (m^3) × *forest area* (km^2) × *forest coverage* (%) × 0.55)/*gross forest land area* (km^2) ×100

(4) Air index. According to the effect of environmental air quality and every category of pollutant on ecological circumstances and human health, the category of pollution index and limit values of pollutant concentration can be confirmed. Furthermore, the sum of days meeting I and II category standards represents the air index.

Air index % = *the sum of days meeting I and II category standard* (days)/365 ×100

(5) Harmless treatment rate of living garbage. The index reflects the proportion of the harmless treatment quantity of living garbage in the gross quantity. According to measurement standard, harmless treatment rate of living garbage should be above 80%.

Harmless treatment rate of living garbage % = *annual harmless treatment quantity of living garbage* (tons)/*annual gross quantity of living garbage* (tons) ×100

(6) Environmental noise compliance area coverage rate. The index reflects the proportion of the environmental noise compliance area in the regional gross area.

Environmental noise compliance area coverage rate % = *regional environmental noise compliance area* (km^2)/*regional gross area* (km^2) ×100

(7) Nature reserve area coverage rate. Nature reserves can play an important role in many ecological functions, such as purifying air, water and soil conversation, carbon fixation, oxygen release, and biodiversity. The index reflects guaranteeing capability of ecological function.

Nature reserve area coverage rate % = *annual regional nature reserve area* (km^2)/*regional gross area* (km^2) ×100

(8) Wetland area coverage rate. Wetlands have not only abundant resources but also ecological benefits of environmental regulation function. Most wetlands

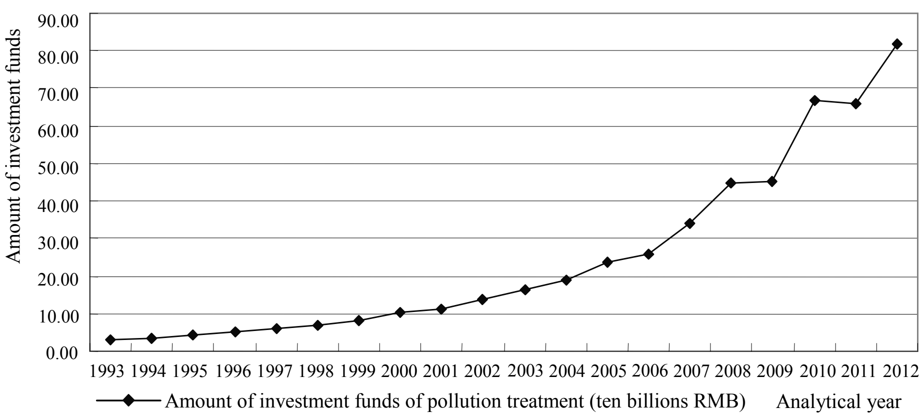

Fig. 3. Amount of investment funds of environmental pollution treatment from 1993 to 2012 in China.

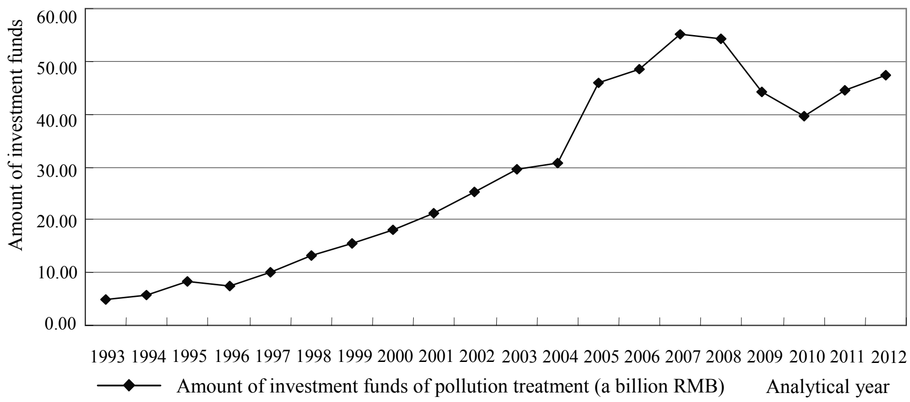

Fig. 4. Amount of investment funds of industrial pollution treatment from 1993 to 2012 in China.

play an important role in protecting biodiversity, preserving fresh water resources, balancing flood, regulating climate, and decreasing pollutants of regional systems.

Wetland area coverage rate %= annual regional wetland area (km^2)/*regional gross area* (km^2) ×100

Measurement Indexes on Systemic Vulnerability of Economic Subsystem

(1) Gross Domestic Product (GDP) per capita reflects individual contributions to economic growth and potential space of individual revenue increment.

GDP per capita (Yuan RMB/person) = *annual gross domestic product* (Yuan RMB)/*annual population* (persons)

(2) Annual productivity of staffs. The index is significantly influenced by technical proficiency, manufacturing technical level, labor enthusiasm, and enterprise operational efficiency of management. The individual average product values in limited time can represent the index.

Annual productivity of staffs (Yuan RMB/person) = *annual industrial value added* (Yuan RMB)/*annual amount of employees* (persons)

(3) Annual growth rate of GDP. The index reflects economic growth speed and potential space. Comparing with national average growth rate (10%), the economic growth level of a regional area can be judged.

Annual growth rate of GDP % = (*regional total GDP of this year* (Yuan RMB) – *regional total GDP of last year* (Yuan RMB))/*regional total GDP of this year* (Yuan RMB) ×100

(4) Industrial emission of waste gas per 10,000 Yuan GDP. Industrial emission of waste gas mainly consists of industrial dust non-removal volume, industrial sulfur dioxide non-removal volume, and industrial soot non-removal volume.

Industrial emission of waste gas per 10,000 Yuan GDP (tons/Yuan RMB) = *annual industrial emission volume of waste gas* (tons)/*annual regional industrial value added* (Yuan RMB)

(5) Water consumption amount per unit output value of 10,000 Yuan GDP. Water consumption volume consists of the water applied in manufacturing, processing, cooling, purifying, etc. The index does not include enterprise's internal reused water.

Water consumption amount per unit output value of 10,000 Yuan GDP (tons/Yuan RMB) = *annual total consumption of industrial water* (tons)/*annual regional industrial value added* (Yuan RMB)

(6) Industrial waste water not meeting standard per 10,000 Yuan GDP. The index is negative. It reflects the burden of water pollution during the process of 10,000 Yuan GDP.

Industrial waste water not meeting standard per 10,000 Yuan GDP (tons/Yuan RMB) = (*total volume of waste water effluent* (tons) – *waste water effluent not meeting standard* (tons))/*regional total GDP* (Yuan RMB)

(7) Unutilized solid waste per ten thousand Yuan GDP. The comprehensive utilization level of solid waste directly reflects reusing and recycling efficiency of solid waste and natural resources in the regional system.

Unutilized solid waste per 10,000 Yuan GDP (tons/Yuan RMB) = (*total volume of solid waste* (tons) – *reused volume of solid waste* (tons))/*total GDP* (Yuan RMB)

(8) Energy consumption per 10,000 Yuan GDP. The lower the index value, the higher the energy utilization efficiency. This reflects the resource-reducing principle of cycling economy theory.

Energy consumption per 10,000 Yuan GDP (tons/Yuan RMB) = *annual total volume of energy consumption* (tons)/*total GDP* (Yuan RMB)

(9) The proportion of non-agricultural output value. The index reflects the quality and potential space of economic growth.

The proportion of non-agricultural output value % = (1 – *annual regional total quantity of agricultural output value* (Yuan RMB)/*total GDP* (Yuan RMB)) ×100

Measurement Indexes on Systemic Vulnerability of Social Subsystem

(1) Engel coefficient. The index reflects regional individual living level. The lower the index, the higher the consumption level of regional area.

Engel coefficient % = *total amount of individual food consumption* (Yuan RMB)/*total amount of individual consumption* (Yuan RMB) ×100

(2) Purchasing power parity of capita disposable income. The higher the index, the stronger purchasing power of resident.

Purchasing power parity of capita disposable income (Yuan RMB) = *annual capita disposable income* (Yuan RMB)/*retail price index* (%)

(3) Unemployment rate. An excessively high unemployment rate would directly destroy social stability.

Unemployment rate %= annual amount of working age employee (persons)/*annual total amount of working age residents in a regional system* (persons) ×100

(4) Per capita living space of residents reflects living conditions and comfort level. According to the national standard of $30m^2$ per capita, living level of regional areas can be judged.

Per capita living space of resident (m^2/person) = *total amount of residents' living space* (m^2)/*total amount of residents in regional system* (persons)

(5) Per capita paving area of residents. The index reflects traffic flow and coverage of roads in the regional system.

Per capita paving area of residents (km^2/person) = *annual total area of paving road* (km^2)/*total amount of residents* (persons)

(6) Coverage rate of fundamental medical insurance an important stable mechanism to guarantee fundamental living demand of residents.

Table 3. Procedural coefficients and weights of measurement indexes on systemic vulnerability.

Measurement Indexes	Weights (%)	H_j	d_j	$d_j \times w_j$ (10^{-2})	wb_j (%)
Forest coverage (%)	4.50	6.5026	0.0384	0.2500	4.07
Soil and water conservation rate (%)	4.93	6.3628	0.0375	0.2384	3.88
water conservation quantity per km^2 land (million cubic meters per km^2)	4.90	6.2724	0.0368	0.2310	3.76
Air index (%)	4.64	6.1907	0.0363	0.2245	3.65
Harmless treatment rate of living garbage (%)	4.03	5.6091	0.0322	0.1806	2.94
Environmental noise compliance area coverage rate (%)	4.10	6.0700	0.0354	0.2150	3.50
Nature reserve area coverage rate (%)	4.43	5.7838	0.0334	0.1933	3.15
Wetland area coverage rate (%)	4.46	5.3919	0.0307	0.1654	2.69
GDP per capita (Yuan RMB per capita)	2.79	5.7999	0.0335	0.1945	3.17
Annual productivity of staffs (Yuan RMB per capital)	3.16	5.9610	0.0347	0.2066	3.36
Annual growth rate of GDP (%)	3.23	6.3259	0.0372	0.2354	3.83
Industrial emission of waste gas per 10,000 Yuan GDP (tons per 10,000 Yuan RMB)	4.21	5.7771	0.0334	0.1928	3.14
Water consumption amount per unit output value of 10,000 Yuan GDP (tons per 10,000 Yuan RMB)	3.91	6.6851	0.0397	0.2655	4.32
Industrial waste water not meeting standard per 10,000 Yuan GDP (tons per 10,000 Yuan RMB)	4.51	5.0834	0.0285	0.1450	2.36
Unutilized solid waste per 10,000 Yuan GDP (tons per 10,000 Yuan RMB)	4.10	5.9560	0.0346	0.2062	3.36
Energy consumption per 10,000 Yuan GDP (tons of standard coal per 10,000 Yuan RMB)	4.78	6.3823	0.0376	0.2400	3.91
The proportion of non-agricultural output value (%)	3.32	6.5386	0.0387	0.2530	4.12
Engel coefficient (%)	2.61	6.1783	0.0362	0.2235	3.64
Purchasing power parity of capita disposable income (Yuan RMB per capita)	3.33	6.1810	0.0362	0.2237	3.64
Unemployment rate (%)	3.36	5.9182	0.0344	0.2033	3.31
Per capita living space of residents (m^2)	2.52	6.3902	0.0377	0.2406	3.92
Per capita paving area of residents (km^2)	2.43	6.2886	0.0369	0.2323	3.78
Coverage rate of fundamental medical insurance (%)	2.76	6.3477	0.0374	0.2371	3.86
Coverage rate of gas-fired (%)	2.16	6.7163	0.0399	0.2682	4.37
Coverage rate of water for residents' life (%)	2.16	6.7113	0.0399	0.2678	4.36
The amount of students in college per 10,000 residents (persons per 10,000 persons)	2.46	5.6104	0.0322	0.1807	2.94
Per capita cost of social security, welfare, and health care (Yuan RMB per capita)	3.27	5.9231	0.0344	0.2037	3.32
Per capita purchasing power coefficient of education expenditures (Yuan RMB per capita)	2.94	6.1838	0.0362	0.2239	3.65

Coverage rate of fundamental medical insurance %= *total amount of residents with medical insurance* (persons) /*total amount of residents* (persons) ×100

(7) Coverage rate of gas-fired. The index reflects fundamental infrastructure level of regional area.

Coverage rate of gas-fired % = *total amount of residents with gas-fired* (persons)/*total amount of residents* (persons) ×100

(8) Coverage rate of water for residents' life. The index obviously reflects fundamental infrastructure levels.

Coverage rate of water for residents' life % = *total amount of residents with water for residents' life* (persons)/*total amount of residents* (persons) ×100

(9) The amount of students in college per 10,000 residents. Developmental potential space and sustain-

able capability relies on amounts of high intelligent capital.

The amount of students in college per 10,000 residents (person/person) = *total amount of students in college* (persons)/*total amount of residents* (persons)

(10) Per capita cost of social security, welfare, and health care. The costs consist of every kind of security and welfare fund of government investment and residents' individual purchasing.

Per capita cost of social security, welfare and health care (Yuan RMB/person) = *total cost of social security, welfare, and health care* (Yuan RMB)/*total amount of residents in regional area* (persons)

(11) Per capita purchasing power coefficient of education expenditure. The index reflects the education investment of residents. The higher the index, the higher the education expenditure that regional residents can acquire from the governments.

Per capita purchasing power coefficient of education expenditure (Yuan RMB/person) = (*per capita financial education expenditure* (Yuan RMB/person) + *per capita individual education expenditure in regional system* (Yuan RMB /person))/*per capita customer price index of education service* (%)

Methodology

Entropy Model

As for the measurement on systemic vulnerability of environmental sustainable development capability, plenty of relative and complicated influencing factors that are mostly quantitative indexes should be considered. General measurement methods can't avoid the misguidance of subjective factors. To avoid misguidance of specialists, the entropy model is applied in calculating indexes' weight of measurement indexes. As for analytical circumstance of m evaluation objectives and n evaluation indexes, the decision matrix of measurement indexes can be described as matrix A. According to the specific operational procedures [16], the standard decision matrix of measurement can be acquired as matrix R.

$$A = \left(x_{ij}\right)_{m\times n} = \begin{vmatrix} x_{11}, x_{12}, \cdots, x_{1n} \\ x_{21}, x_{22}, \cdots, x_{2n} \\ \cdots, \cdots, \cdots, \cdots \\ x_{m1}, x_{m2}, \cdots, x_{mn} \end{vmatrix}$$

$$R = \left(r_{ij}\right)_{m\times n} = \begin{vmatrix} r_{11}, r_{12}, \cdots, r_{1n} \\ r_{21}, r_{22}, \cdots, r_{2n} \\ \cdots, \cdots, \cdots, \cdots \\ r_{m1}, r_{m2}, \cdots, r_{mn} \end{vmatrix}$$

In matrix R, $r_{ij} \in [0,1]$, $i = 1, 2,\ldots, m$; $j = 1, 2,\ldots, n$. the entropy value of j^{th} measurement index can be calculated as per formula H_j. In the formula, $f_{ij} = r_{ij} / \sum r_{ij} (i = 1, 2,\ldots, m)$, when $f_{ij} = 0$, it can be defined as $f_{ij} \times \ln f_{ij} = 0$, the entropy weight of j^{th} measurement index can be calculated as per formula d_j and standard entropy weight can be calculated as formula w_j.

$$H_j = \quad k \sum_{i=1}^{m} f_{ij} \times \ln f_{ij}, j = 1,2,\cdots,n$$

$$d_j = (1 \quad H_j)/(n \quad \sum_{j=1}^{n} H_j)$$

$$w_j = d_j / \sum_{j=1}^{n} d_j (j = 1,2,\cdots,n), \sum_{j=1}^{n} w_j = 1$$

Topsis Model

Topsis model indicates technique for order preference by similarity to ideal solution, operational procedures can be found in much academic research [17-19]. According to the standard decision matrix of measurement indexes $R = [r_{ij}]_{m\times n}$ $(i = 1, 2,\ldots, m; j = 1, 2,\ldots, n)$ and standard entropy weighs of measurement indexes $W = (w_1, w_2,\ldots,w_n)^T$, the weighed standard decision matrix can be calculated as per formula Z. On the basis of ideal solution S^+ and negative ideal solution S^-, the Euclidean distance between measurement objectives and ideal solution S^+, negative ideal solution S^- can be calculated as per formula d_i^+ and d_i^-, and relative proximity between measurement objectives and ideal solutions can be calculated. According to the comprehensive evaluation values of relative proximity C, systemic vulnerability values order can be acquired. The higher value C, the lower the systemic vulnerability value. In contrast, the lower the value C, the higher the systemic vulnerability value.

$$Z = B \times W = [z_{ij}]_{m\times n} = [x_{ij} \times w_j]_{m\times n}, (i = 1,2,\cdots m, j = 1,2,\cdots n)$$

$$S^+ = \{z_j^+ \big| j = 1,2,\cdots n\} = \max(z_{ij}), (i = 1,2,\cdots,m, j = 1,2,\cdots,n)$$

$$S \quad = \{z_j \big| j = 1,2,\cdots n\} = \min(z_{ij}), (i = 1,2,\cdots,m, j = 1,2,\cdots,n)$$

$$d_i^+ = [\sum_{j=1}^{n} (z_{ij} \quad z_j^+)^2]^{1/2} (i = 1,2,\cdots,m)$$

$$d_i \quad = [\sum_{j=1}^{n} (z_{ij} \quad z_j)^2]^{1/2} (i = 1,2,\cdots,m)$$

$$C = d_i \quad /(d_i^+ + d_i \quad)(i = 1,2,\cdots m)$$

Results and Discussion

With the application of entropy-topsis evaluation model and the programming operation of Matlab engineering calculation software, measurement values on systemic vulnerability of environmental sustainable development capability from 1993 to 2012 in China can be calculated. The specific operational procedure can be described in details according to the above-mentioned contents in this manuscript.

Table 4. Procedural coefficients and measurement values on systemic vulnerability in China.

Serial Number	Analytical Year	d^-	d^+	C
1	1993	0.061	0.058	0.513
2	1994	0.055	0.066	0.454
3	1995	0.054	0.067	0.445
4	1996	0.053	0.069	0.433
5	1997	0.049	0.069	0.415
6	1998	0.047	0.083	0.359
7	1999	0.045	0.086	0.341
8	2000	0.045	0.095	0.319
9	2001	0.032	0.078	0.292
10	2002	0.046	0.076	0.375
11	2003	0.049	0.071	0.410
12	2004	0.059	0.048	0.550
13	2005	0.064	0.044	0.594
14	2006	0.063	0.043	0.597
15	2007	0.066	0.041	0.613
16	2008	0.071	0.045	0.614
17	2009	0.069	0.034	0.672
18	2010	0.075	0.031	0.704
19	2011	0.078	0.025	0.760
20	2012	0.081	0.021	0.791

Table 5. Volumes of waste water, industrial emission and solid waste per 10,000 RMB GDP.

Year	Volume of waste water (ton per 10,000 RMB)	Volume of industrial emission (ton per 10,000 RMB)	Volume of solid waste (ton per 10,000 RMB)
2012	12.9957	0.0044	0.0061
2011	13.9333	0.0047	0.0070
2010	15.3733	0.0054	0.0087
2009	17.2802	0.0065	0.0132
2008	18.2037	0.0074	0.0163
2007	20.9491	0.0093	0.0218
2006	23.7839	0.0120	0.0328
2005	28.3614	0.0138	0.0407
2004	30.1735	0.0141	0.0465
2003	34.3910	0.0178	0.0635
2002	38.7424	0.0201	0.0786
2001	43.3668	0.0232	0.0947
2000	48.6934	0.0268	0.1148
1999	54.6744	0.0310	0.1393
1998	64.4964	0.0387	0.1519
1997	67.9162	0.0408	0.1631
1996	73.7141	0.0432	0.2004
1995	85.2301	0.0496	0.2627
1994	95.4337	0.0588	0.3422
1993	106.2305	0.0677	0.5066

After collecting statistical data about systemic vulnerability of environmentally sustainable development capability, the standard decision matrix of measurement indexes can be described, and then procedural coefficients and standard weights of the measurement indexes on systemic vulnerability can be calculated and shown as Table 3 with the application of entropy model.

Based on analytical data in Table 3, the measurement values and procedural coefficients on the systemic vulnerability of environmental sustainable development capability from 1993 to 2012 in China can be precisely calculated and shown as Table 4. According to the measurement values of systemic vulnerability in Table 4 and Fig. 5, two kinds of contrary tendency of systemic vulnerability of the environmentally sustainable development capability can be found. In the first place, accompanied with the rapid economic growth of regional system, excessive industrial emissions, waste water and solid waste have been brought out, these phenomenon significantly inevitably cause uncontrolled environmental pollution and destroy ecological circumstances in most regional systems. The measurement values of systemic vulnerability from 1993 (measurement value on systemic vulnerability is 0.513) to 2001 (measurement value on systemic vulnerability is 0.292 which meets the lowest point) is continually decreasing. This trend indicates that environmentally sustainable development capability is continually weakening. In the second place, under the guidance of cycling economy theory, government policies have been efficiently and rapidly taken to improve the status of environment, the measurement values of systemic vulnerability from 2002 (measurement value on systemic vulnerability is 0.375) to 2012 (measurement value on systemic vulnerability is 0.791, which meets the peak point) is gradually increasing. This trend indicates that environmentally sustainable development capability in China has been significantly restored.

Conclusion

Driven by the internal and external influencing factors, environmentally sustainable development capability of regional systems reflect high sensitivity and systemic vulnerability. This phenomenon inevitably destroys ecological benefits of the environment with the rapid economic growth in China. Considering significant characteristics of a complicated regional system that includes ecological, economic, and social subsystems, the connation of systemic vulnerability of environmental sustainable development capability has been defined, and influencing factors on systemic vulnerability have been found out. Furthermore, the measurement indexes and model on systemic vulnerability of environmental sustainable development capability have been established. On the basis of statistical data about systemic vulnerability of environmental sustainable development capability from 1993 to 2012 in China, the empirical research has been carried out with the application of the entropy-topsis model. The measurement results indicate that systemic vulnerability of environmentally sustainable development capability is affected by three mutual units, including ecological, economic, and social subsystems. As the pacemaker and engine, the future potential space and

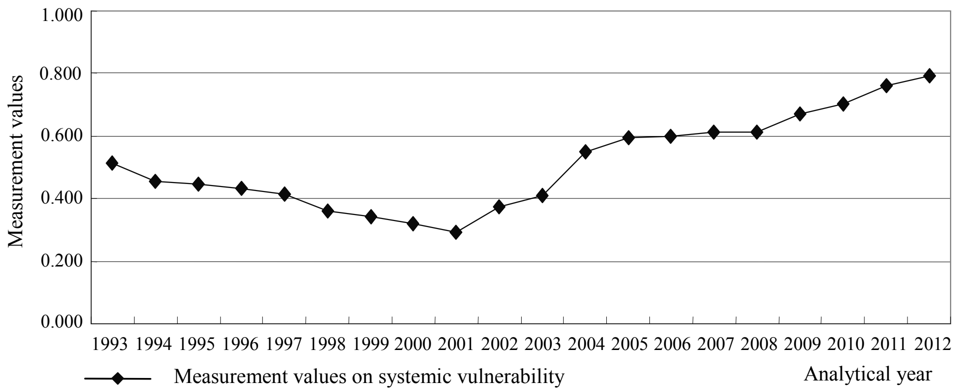

Fig. 5. Measurement values on systemic vulnerability of environmental sustainable development capability.

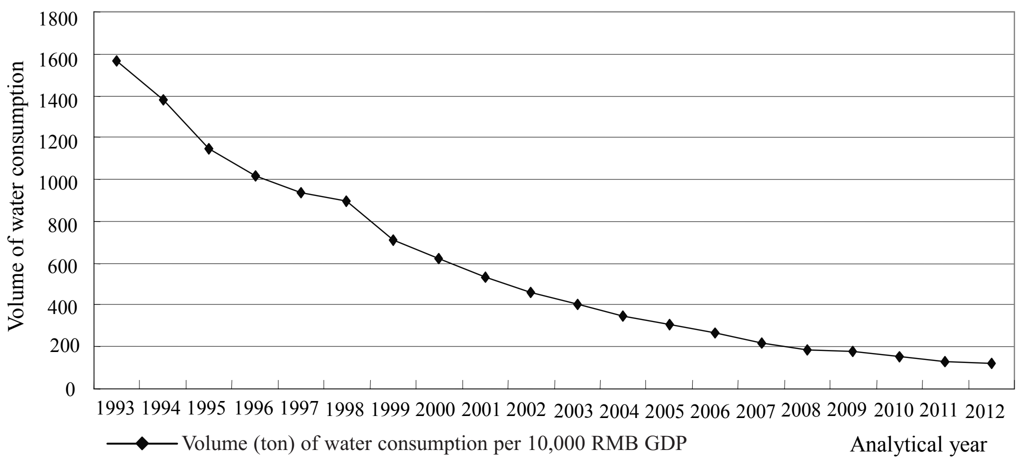

Fig. 6. Volume of water consumption per ten thousands RMB GDP from 1993 to 2012 in China.

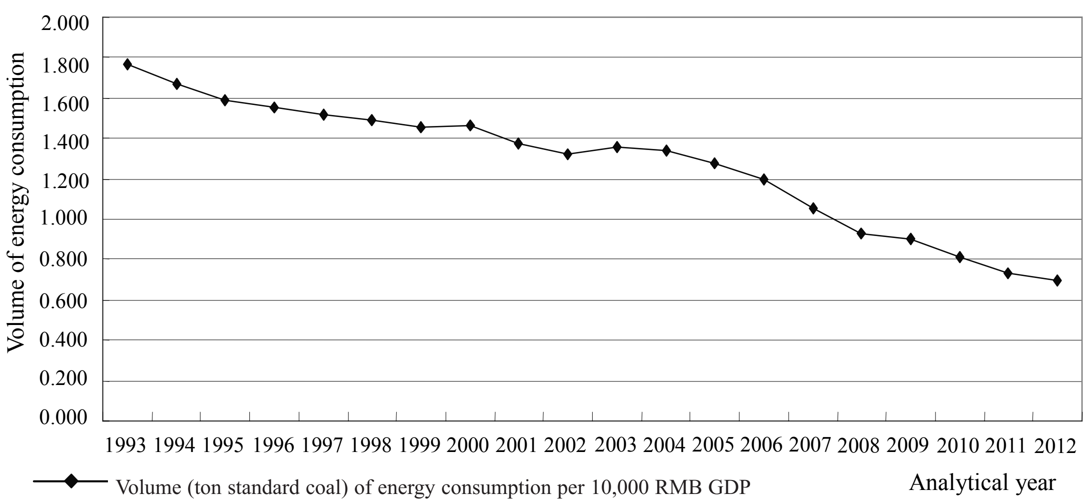

Fig. 7. Volume of energy consumption per 10,000 RMB GDP from 1993 to 2012 in China.

environmental cost caused by economic growth really brings out excessive systemic vulnerability to environmental sustainable development capability. The central and regional government should take measures to optimize the growth mode and improve operational efficiency of leading industrial clusters, manufacturing technical specification and supporting processes system. These administrative measures, which highly focus on environmental protection, energy-saving, and intensive production, should be applied in leading regional industries for promoting contributions to gross domestic product of resource and energy consumption per unit.

According to Figs. 6 and 7 ,and Table 5, the volumes of waste water, industrial emission and solid waste per 10,000 RMB GDP have significantly decreased as utilization efficiency of energy and water has gradually increased from 1993 to 2012 in China. The low-end industries that really reflect high consumption and cause intensive pollution must be transformed to improve industry layout. The new leading industries, which are suitable for the capacity of the environment, should be introduced and supported to form new economic growth points. In this case, systemic vulnerability would be gradually decreased and the environmentally sustainable development capability would significantly and substantially be improved. Accordingly, ecological function of most regional systems would be rapidly restored and the essential balance of ecological subsystems, economic subsystems, and social subsystems would be strengthened in China.

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