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Performance Evaluation Research of Ecological Civilization Policy Based on Data Envelopment Analysis and Artificial Neural Networks Model

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Abstract

Ecological civilization is a new form of human civilization that solves the contradiction between development and environment. Because the ecological civilization policy system has is complex and nonlinear, this paper combines Artificial Neural Network technology with the Data Envelopment Analysis(DEA) method and proposes the hybrid DEA-Artificial Neural Network (DEANN) model to estimate the impact of ecological civilization policy on economic development. The model uses regional eco-efficiency evaluated by DEA as one of the inputs for the neural network; the neural network integrates the total input and output results to provide a quantitative estimate of the ecological civilization policy in different provincial regions from 2003-2016. By training and examining the evaluation results with the DEANN model, this paper tries to predict the impact of 13th Five-Year Total Emission Reduction Policy on economic development. The empirical research results and suggestions can improve the ecological civilization policy performance by negative feedback mechanisms.

Keywords: Eco-efficiency; Ecological Civilization Policy; Performance Evaluation; Data Envelopment Analysis; Artificial Neural Network

1. Introduction

In the age of industrial civilization, the unlimited extraction of natural resources and unrestrained discharge of contaminants led to many serious consequences, such as energy exhaustion, resource shortages, environmental pollution, and ecological imbalance. Thus, natural disasters and ecological crises crop up frequently. Such a phenomenon is especially serious in developing countries such as China. Although China's reform and opening up resulted in the impressive "China Speed", the extensive style of economic growth nevertheless created many environmental problems, including soil desertification, water quality degradation, and air pollution. These environmental problems not only significantly depress people's heath and quality of life but also corrode economic milestones. To balance the contradiction between economic development and environmental quality, the Chinese Government proposed a new form of human civilization based on the theory and practice of sustainable development in developed western countries called ecological civilization and published a series of policies(Ji-Hong, 2007).

Ecological civilization policy is a new form of ecological policy that exists only in China. Based on foreign environmental policy, ecological civilization policy in China is defined as all the normalization, straitjacket, and guidance rules for supporting, promoting, and ensuring the realization of ecological civilization. This policy consists of enforcement measures, such as legislation, and non-enforcement measures, such as public participation(Xiuyu Zhang, Li, Shi, & Yang, 2015). The performance of ecological civilization policy refers to the environmental reception and achievement arising from the implementation of ecological civilization policy. It describes not only the effect of the ecological civilization construction on the local economic environment but also the cost of decreasing resource utilization and environmental contamination. It thus reflects the concept of ecological efficiency(Aibao, 2010). Although the policy in general does not have an immediate effect, the feasibility and effectiveness of one policy can be predicted through the use of scientific evaluation tools and specific mathematical models. Thus, it is possible to regulate the policy by observing the difference between the predicted result and the expected. As a result, policy performance evaluation is the ending as well as the starting point of the policy(Cao & Cao, 2010).

The evaluation index system for foreign sustainable development includes:

1. A causation framework model, such as the Pressures-State-Responses Model proposed by the Organisation for Economic Co-operation and Development (OECD) (OECD, 1998) (Figure 1), the Drivers-Pressures-State-

Impact-Responses Model proposed by the Commission on Sustainable Development (CSD)(WBCSD, 1996), , or the Drivers-Pressures-State-Impact-Responses model proposed by the European Environment Agency (EEA)(Maxim, Spangenberg, & O'Connor, 2009). (Figure 2). These models are intuitive and have a relatively precise description of the casual link between humans and the environment, but it is impossible to simulate a complex nonlinear system such as a policy system.

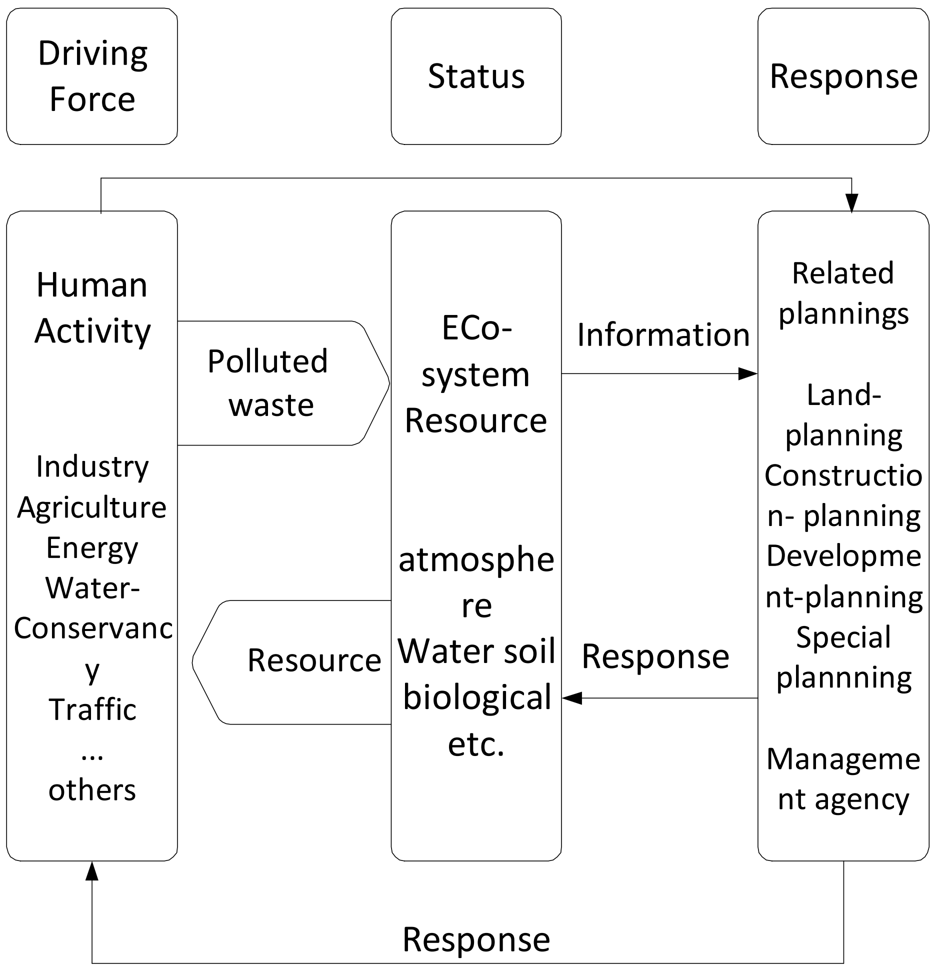


Figure 1. The Pressures-State-Responses model

2. A theme framework model, such as the Environmental Performance Index proposed by Yale University in collaboration with Columbia University (Vörösmarty et al., 2010). The indicators are selected according to the objectives of the environmental policy. Under each environmental theme, there are several subtopics with parallel relationships, and each subtopic is the basis for selecting the indicators at the next level. This model could stress the policy focus and effectively avoid the repeat set problems, but it adopts a simple additive algorithm in describing the coupling relation between subjects of the same level.

3. An Input-Output-Outcome-Impact framework model, such as the Ecological Footprint Indicators proposed by Canadian eco-economists(van den Bergh & Verbruggen, 1999). This model is a kind of economics direction model. It selects indicators from the four aspects of input, output, outcome, and impact according to the regulation of energy and material flow and reflecting the relationship between economic input and output. This model depicts the relation between economics and the environment directly, but it is unable to quantify the evaluation system thoroughly.

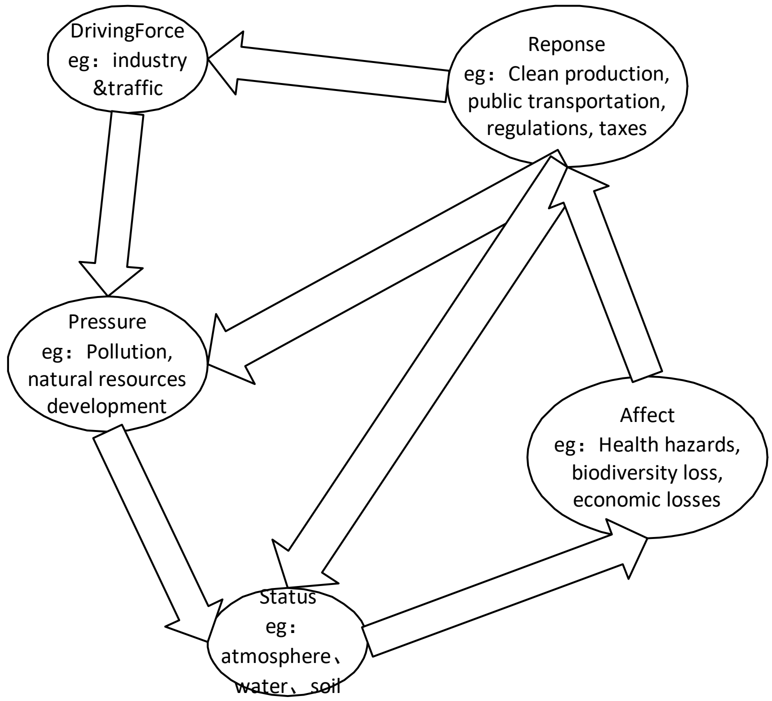


Figure 2. The Drivers-Pressures-State-Impact-Responses model

For the ecological civilization policy proposed by the Chinese government, the evaluation index system is just beginning to develop. The provincial Ecological Civilization Index presented by the Ecological Civilization Research Centre at Beijing Forestry University(Liu, 2010) and the provincial Green Development Index advanced by the Ministry of Ecology and Environment of the People's Republic of China (Li-Yang, Zheng, & Wang, 2013) are both constructed by the theme framework model. Regardless of the evaluation index, the Analytic Hierarchy Process (AHP) algorithm(Gass & Vargas, 2017), a kind of linear evaluation method, is widely used in the performance evaluation of ecological civilization policy at present.

In this paper, we propose a new ecological civilization policy evaluation method by using the Input-Output-Outcome-Impact framework model based on the principle of economics. To our knowledge, such a quantified economic model has never been reported. In addition, when constructing the evaluation algorithm, the artificial neural network model was adopted to enable the algorithm to simulate the characters of the complex nonlinear system. In comparison with the currently used linear evaluation method, our method has significant advantages in predicting the impact of ecological civilization policies on the economy.

2. Methodology

2.1 The impact of ecological civilization policy on the economy

The viability of ecological civilization policy is dominated by the technical and economic feasibility. It is easy to estimate the technical practicability; however, the relation between economics and the environment is complex, and it is very difficult to strike a balance between these two. The Chinese government is undergoing a continuous deepening of understanding regarding the relation between economics and the environment (Figure 3). At the beginning of the period of reform and opening up, economics dominated and environmental protection was ignored. Better invaluable assets than clear water and lush mountains. With the idea of sustainable development gradually taking root, the government has published numerous policies to protect the environment. However, as economic development and environmental protection are simply considered to be independent, the effect of these policies on economic development is studied exclusively when making these policies. Clear water, lush mountains and invaluable assets are all considered as well. The ecological civilization policy was proposed at the 17th conference of the CCP and embedded in the five-pronged approach to modernize socialism for China at the 18th conference of the CCP. Included in the idea of ecological civilization is the idea that economic development and environmental economics affect the protection of the environment, and a beautiful environment promotes economic development. Clear water and lush mountains are invaluable assets (Xiao Zhang & Yue, 2017).

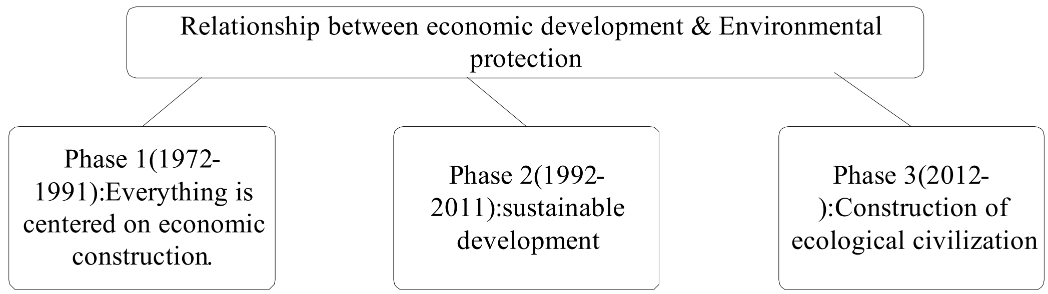


Figure 3. Relationship between economic development & environmental protection

Specifically, ecological civilization policy boosts economic growth from two aspects. One is to improve the ecological efficiency, which is the ratio of the value of economic activity to that of consumed resources and the environmental load. As a result, higher ecological efficiency corresponds to more product output and less unexpected output under the same productive investment and environmental cost. The other result is the control of the total amount of environmental cost and pollution discharge. These two aspects are related. For example, controlling the total amount directly limits the amount of input in the short term; however, in the long run, it also forces the economy to create innovative technology to boost efficiency.

2.2 Application of Artificial Neural Network in Performance Evaluation of Ecological Civilization Policy

The ecological civilization policy system is a complex system the includes economics, society, and the environment. It has characteristics including obvious nonlinearity and uncertainty. Due to the lack of a physical prototype of abstract systems such as the social system, the economic system, and the ecological system, the relevant model is based upon a logical deduction. As the linear model arising from conventional econometrics is inadequate to estimate a complex system, the artificial neural network method is introduced to the new method of evaluating the performance of ecological civilization policy.

The artificial neural network has advantages such as a strong adaptive capability, a self-learning capability, and a fault-tolerant capability (Xiao, Ye, Zhong, & Sun, 2009). Its multi-input multi-output structure is suitable for non-massive parallel calculation. In 2006, Hinto et al. proposed deep learning, which significantly improves the calculation capacity of an artificial neural network by a relatively simple violence calculation (Y. Zhang & Wu, 2009). Today, the process of using a neural network to predict the economy is as follows: network topological structure design, data sample acquisition, input and output data pretreatment, network training, and examination and prediction of network prediction capability(Sc, Cowan, & Grant, 1991).

To precisely predict and evaluate the total effect of the ecological civilization policy on economics, the environment, and society, the model should be able to simulate the multi-effect of the policy. In this paper, we use a combined forecasting method comprising the following four steps.

(1) Choosing the ecological efficiency index and providing the static, quantitative ecological efficiency of the local area.

(2) Using static ecological efficiency as one of the inputs of the neural network, which integrates the total input and output results, constructing a hybrid DEA-Artificial Neural Network model for evaluating the performance of ecological civilization policy.

(3) Training the neural network and examining the result using another sample data.

(4) Using the DEANN model to predict the effect of ecological civilization policy on economics.

3. Evaluation of regional eco-efficiency using the DEA model

3.1 proportional DEA model with the impact of environmental capacity

Ecological civilization policy promotes economic development by boosting ecological efficiency. In this paper, the local ecological efficiency was predicted using the DEA model with environmental capacity.

The DEA model uses an envelope line instead of a production function to keep the inputs or output of decision making units (DMU) constant and determines the economic optimum point by mathematic programming and data statistics. The inputs and outputs of every DMU are mapped to the efficient product frontier side of DEA, and the relative efficiency is evaluated. The difference between the frontier side of ecological efficiency and DMU dominates the performance of ecological civilization policy(Castelli & Pesenti, 2014). Environmental capacity refers to the maximum contaminant capacity which does not significantly harm the ecological system(Luo, 2012).

The inputs of the DEA model are p_{lj}^{b} and δ_j, their definitions are

$$p_{lj}^{b} = y_{lj}^{b}/Co_{lj} \quad (1)$$

$$\delta_j = \sum_{l=1}^{t} \alpha_l p_{lj}^{b} \quad (2)$$

where y_{rj} and y_{lj}^{b} are the rth expected and lth unexpected outputs of jth DMU, Co_{lj} is the environmental capacity of lth unexpected outputs of jth DMU, α_l is the loss coefficient,

$O_{rj} = y_{rj}/\delta_j$ refers to the regulated expected output,$O_{rj} = y_{rj}/\delta_j$， r=1,2,...s is the adjusted total outputs and β_j is the risk attitude representing the efficiency of the decision maker.

The distribution of random variable $\hat{p}_j$ is as follows.

Table 1. Distribution table of $\widehat{p_J}$

Possible Value	a_1 (weight of A_1 scene)	a_2 (weight of A_2 scene)
Probability	1-p	p

Finally,

$$Co_{lj} = L_{lj}^{b} \bullet \hat{p}_j \quad (3)$$

$$\varphi_{lj}^{b} = \frac{\alpha_l}{L_{lj}^{b}} \quad (4)$$

$$\delta_j = \frac{\sum_{l=1}^{t} \varphi_{lj}^{b} y_{lj}^{b}}{\hat{p}_j} \quad (5)$$

Based on Sueyashi(Sueyoshi, 2000) proposed method to introduce random variables in the DEA model, the aforementioned formula becomes

$$\pi_o^s = max \sum_{r=1}^{s} \mu_r O_{ro}$$

$$s.t. \frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} \omega_i \chi_{ij} \bullet \sum_{l=1}^{t} \varphi_{lj} y_{lj}^{b}} \le \frac{1}{a_2} \qquad \text{j=1, …} n$$

$$\text{or} \quad \frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} \omega_i \chi_{ij} \bullet \sum_{l=1}^{t} \varphi_{lj} y_{lj}^{b}} \le \frac{1}{a_1} \qquad \text{j=1, …} n \quad \text{when p} \le \beta_j \quad (6)$$

3.2 Selection of regional ecological efficiency evaluation indicators

From the calculation method of green development index published by the PRC National Bureau of Statistics(China, 2017), , the indexes for evaluating local ecological efficiency are as follows(Table 2):

Input index, including amount of consumed energy, capital, and human resources

Output index, i.e., local GDP.

Table 2. Selection of ecological efficiency evaluation indicators

Index	Name	Detailed description
Input	Amount of capital	Fixed capital(0.1 billion Yuan)
	Amount of human resources	The labor (ten thousands)
	Amount of assumed energy	100M kW·h
Expected output	Economic output	Local GDP(0.1 billion Yuan)
Unexpected output		Amount of waste water(ten hundreds ton)
		Amount of waste gas(0.1 billion cubic meter)

3.3 evaluation result of local ecological efficiency

From the data listed in the China Statistical Yearbook, we calculate the local evaluation index of every province in China. Tibet is excluded due to incomplete data statistics. In some years, there is no total industrial exhaust gas emission data, which is replaced by the total amount of smoke (powder) dust emissions. Since the calculation is a region's annual eco-efficiency, there is no cross-year impact. All data used are from the China Statistical Yearbook 2003-2016(China, 2003-2016).

The calculation results are listed in the table below.

Table 3. The calculation results of local ecological efficiency

	2003	2004	2005	2006	2007	2008	2009
Beijing	0.2008699	0.2454383	0.3686674	0.3637741	0.3775894	0.4632207	0.409755
Tianjin	0.4286898	0.6412324	0.6022596	0.6067788	0.6416896	0.6937706	0.7638702
Hebei	0.1157165	0.1255945	0.1304512	0.0590878	0.10718	0.1295329	0.111373
Shanxi	0.1228236	0.1451614	0.1665215	0.0290798	0.1346397	0.1473433	0.136158
Nei Mongol	0.1999032	0.1883654	0.2822868	0.08051	0.2749662	0.3128316	0.3015428
Liaoning	0.1182832	0.1359638	0.1234572	0.0557346	0.1366979	0.1092387	0.15571
Jilin	0.2565326	0.303809	0.3340747	0.1013447	0.3768519	0.3662675	0.3710508
Heilongjiang	0.2572564	0.3360407	0.3332862	0.0806969	0.2650169	0.2946255	0.2448334
Shanghai	0.1878963	0.243598	0.3003011	0.3633545	0.2898486	0.2843478	0.2885558
Jiansu	0.0961018	0.1126843	0.1173838	0.1032042	0.1348842	0.1417929	0.1467489
Zhejiang	0.1559079	0.1759361	0.1720839	0.1376485	0.1533629	0.1373568	0.1248631
Anhui	0.1901077	0.2362156	0.2446094	0.0829529	0.1996967	0.1984953	0.2058351
Fujian	0.2179067	0.2213297	0.2026818	0.1338251	0.1847733	0.1812396	0.1800004
Jiangxi	0.2382547	0.2921198	0.3145216	0.0936735	0.2747985	0.2855512	0.2813299
Shandong	0.1146963	0.1345744	0.1317575	0.0821727	0.1249994	0.1236795	0.1218732
Henan	0.0977249	0.1155254	0.1223773	0.0433449	0.1223787	0.1235645	0.1167388
Hubei	0.1214364	0.1376144	0.1354836	0.0674745	0.1623337	0.162103	0.1665482
Hunan	0.1324089	0.1611988	0.1765957	0.0501105	0.1791074	0.1872693	0.1795788
Guangdong	0.0693804	0.0840424	0.0977508	0.0914464	0.1004631	0.1030223	0.1001763
Guangxi	0.1218848	0.1288196	0.1390902	0.0583889	0.1320795	0.1304399	0.1440487
Hainan	1	1	1	1	1	1	1
Chongqing	0.2159057	0.2575502	0.2741197	0.113753	0.2461706	0.2769564	0.2353294
Sichuan	0.1138012	0.1400432	0.1433608	0.0561873	0.1157819	0.146999	0.1546342
Guizhou	0.2488748	0.2972991	0.3802027	0.0950709	0.2379985	0.4152228	0.3857295
Yunnan	0.2833152	0.3125812	0.3546784	0.1399183	0.2766617	0.3187405	0.2669739
Shaanxi	0.2117998	0.255784	0.2923738	0.0740306	0.2814902	0.2655245	0.2560979
Gansu	0.3427482	0.468085	0.4623219	0.1374266	0.4046079	0.4286037	0.4659144
Qinghai	1	1	1	0.3326608	1	1	0.9464875
Ningxia	0.4273781	0.4526392	0.4497719	0.2092951	0.5156682	0.6214426	0.6452512
Xinjiang	0.2995548	0.3411693	0.3570836	0.0962927	0.3265216	0.3373594	0.3254086

	2010	2011	2012	2013	2014	2015	2016
Beijing	0.4118613	0.4265486	0.5687318	0.8370982	0.6883851	0.5260181	0.5760404
Tianjin	0.6107351	0.4774129	0.4609095	0.7520016	0.5718977	0.4674586	0.6003267
Hebei	0.0940753	0.0743945	0.0780892	0.101496	0.0823885	0.0396447	0.0525673
Shanxi	0.0985652	0.0902427	0.1185935	0.155748	0.1370926	0.0339427	0.0766256
Nei Mongol	0.2544887	0.2415977	0.273425	0.3281885	0.2374446	0.0975249	0.1423656
Liaoning	0.1458738	0.1236053	0.1330876	0.1931847	0.1348623	0.0703112	0.1115158
Jilin	0.3322617	0.3025622	0.3478431	0.5656479	0.4511531	0.1645279	0.3224404
Heilongjiang	0.2532637	0.2377245	0.2559311	0.4033949	0.3059037	0.0959041	0.1348373
Shanghai	0.2287987	0.2441554	0.3154946	0.4708937	0.4003659	0.3026731	0.3560457
Jiansu	0.1242197	0.0997261	0.1073427	0.1156629	0.0903376	0.0686312	0.0889197
Zhejiang	0.1110913	0.1063394	0.1389517	0.2072152	0.1644428	0.1152267	0.1503167
Anhui	0.1809972	0.1202313	0.139249	0.2104966	0.1648179	0.0896326	0.1419046
Fujian	0.1546623	0.1263893	0.1838311	0.2619452	0.1987299	0.1147575	0.1570908
Jiangxi	0.2466141	0.1728963	0.2275567	0.3451779	0.3001584	0.1152792	0.1491056
Shandong	0.0928538	0.0806611	0.0863621	0.11476	0.0868144	0.0500788	0.0656441
Henan	0.1043023	0.0722264	0.0797415	0.0990923	0.0765953	0.043982	0.0749553
Hubei	0.152114	0.1137194	0.1469901	0.2157067	0.1636068	0.1021659	0.154795
Hunan	0.1532437	0.1414082	0.1543311	0.2225451	0.1899535	0.1137663	0.1730276
Guangdong	0.0854504	0.0211574	0.0903116	0.1283241	0.0966002	0.0479197	0.0803257
Guangxi	0.1318417	0.1165978	0.1248809	0.2109567	0.1834176	0.1161875	0.1624821
Hainan	1	1	1	1	1	1	1
Chongqing	0.2499147	0.2478768	0.3381745	0.4784875	0.3874816	0.2236859	0.2962383
Sichuan	0.1310743	0.1185111	0.1518466	0.235121	0.1835906	0.1033471	0.1344024
Guizhou	0.3293068	0.2957061	0.277819	0.2728376	0.2181215	0.1425582	0.2014858
Yunnan	0.2218788	0.1392379	0.1652571	0.2356167	0.1795435	0.1091123	0.1334055
Shaanxi	0.2195912	0.033249	0.227517	0.2986327	0.2309042	0.0837147	0.1448609
Gansu	0.4875962	0.3018544	0.3461544	0.5301558	0.420889	0.1587495	0.2406194
Qinghai	0.8667771	0.0897164	0.7124711	1	0.7947587	0.2308064	0.3756058
Ningxia	0.2825204	0.4365463	0.4701627	0.6925666	0.4960685	0.2454794	0.3088273
Xinjiang	0.2904417	0.2517678	0.2098984	0.2496855	0.1723454	0.0682027	0.0886056

4. Training and examining of the hybrid DEA-Artificial Neural Network (DEANN) model used to evaluate the performance of ecological civilization policy

4.1 Construction of the model and selection of an evaluating index

Now we have obtained the regional annual eco-efficiency value above, but the evaluation result is static. Since the implementation of the ecological civilization policy has multiple effects on the economy and has a time accumulation effect, we use a multiple neural network with hidden layers in order to evaluate and predict the dynamic and cumulative efficiency of the ecological civilization policy.

The output layer node is the final output value, so the number of output layer nodes is 1 where the regional Gross Domestic Product (GDP) is used. The input layer node (ecological civilization policy) includes two parts: the production input policy and the reduction of major pollutants emissions policy. The production input policy stipulates the fixed capital input (total investment in fixed assets)and total wage bills of employed persons. Reduction of the major pollutants emission policy includes the allowed total amount of COD, ammonia nitrogen and SO2, taking into account the factor of DEA eco-efficiency evaluation and the region serial number; therefore, the number of input layer nodes is 7.

We select a neural network with two hidden layers, and the number of nodes is determined by the following empirical formula:

$$H = \sqrt{N + O} + \alpha, 1 < \alpha < 10 \quad (7)$$

where N is the number of input layer nodes and O is the number of output layer nodes.

We then normalize the input data of the neural network, and the normalization function is as follows:

$$u(z) = \frac{z - z_{min}}{zmin_{max}} \quad (8)$$

where z is the input (output) sample, and zmin and zmax are the minimum and maximum values of the input (output) sample, respectively. That is to say, the data are normalized in the [0,1] interval.

The training parameters of the Neural Network are as follows:

Training function: Gradient Descent Optimizer

Activation function: f(x)= max (x, 0) (relu)

Learning rate: 0.03

Maximum number of iterations: 24000

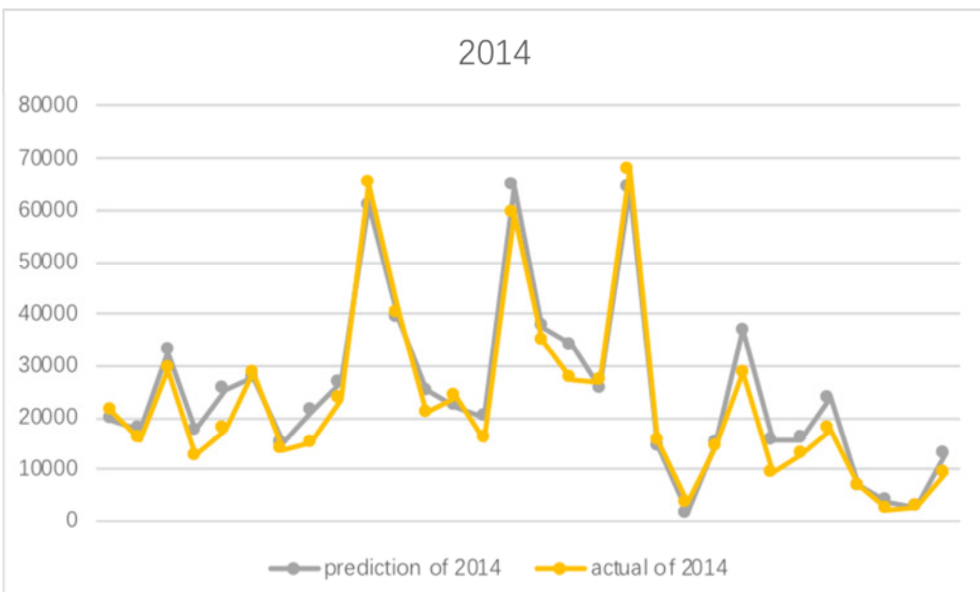
Transfer function: linear transfer function (purelin)

After repeated training and adjustment, the number of nodes of the two hidden layers are: 11,7.

4.2 Training and examination of the hybrid model

Since there is retardation of the impact of policies on the economy, when the model is trained and examined, the data are used in the following way: using the evaluation results of the regional eco-efficiency of the previous year to match the total investment in fixed assets, the total wage bills of employed persons, COD, ammonia nitrogen and SO2 of the year. The data from 2003-2013 are used as the trained set, the data from 2014-2016 are used as the examined set. All the data come from the 2003-2016 China Statistical Yearbook, and normalization processing is applied to the data(China, 2003-2016).

Substituting the data into the model, the prediction and error of the examined set are shown in Table 4.



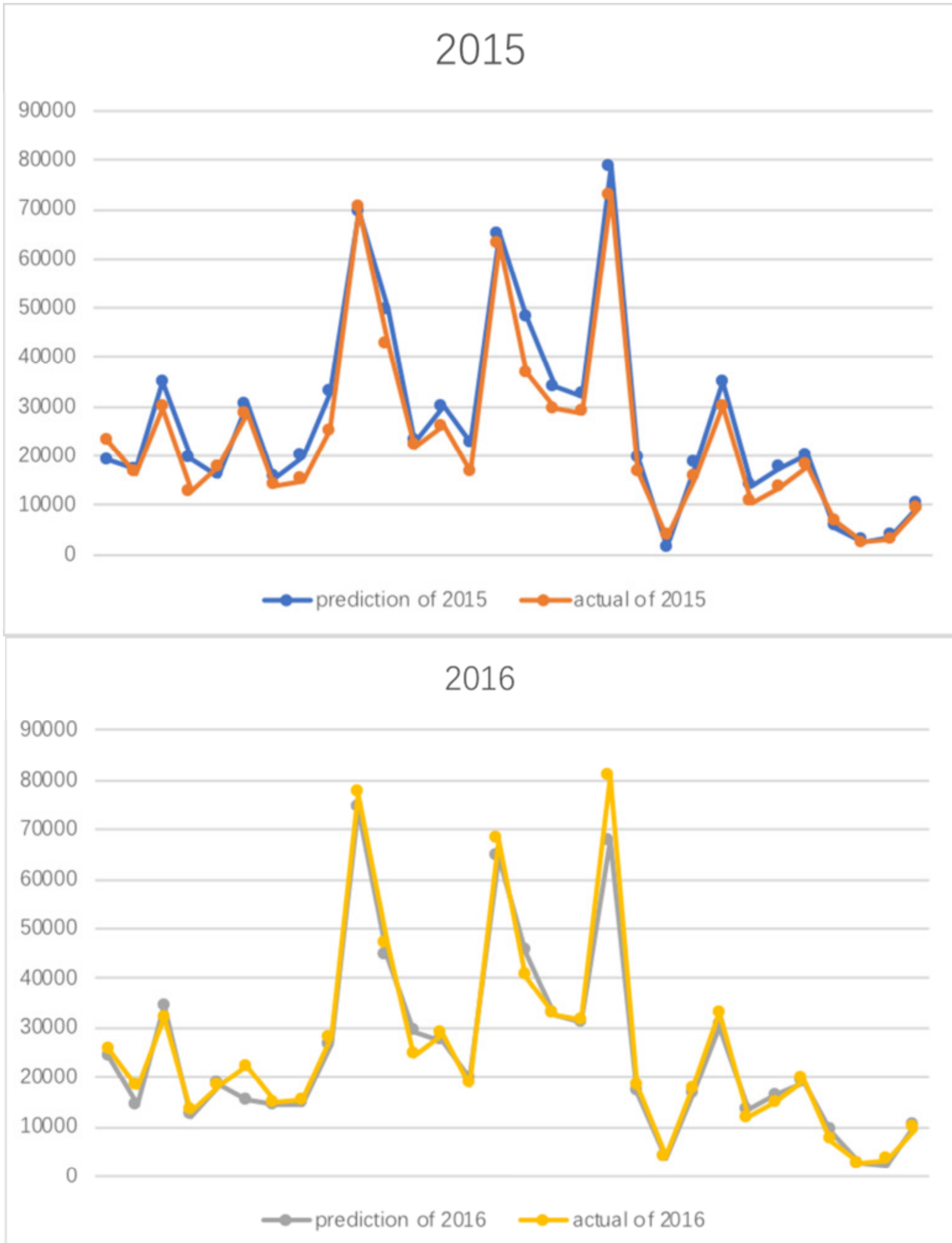


Figure 4. The comparison of prediction and actual value

Table 4. The comparison of prediction and actual value

(Billion Yuan)	prediction of 2014	Actual of 2014	prediction of 2015	Actual of 2015	prediction of 2016	Actual of 2016
Beijing	30012.1	21330.83	19089.38	23014.59	23931.86	25669.13
Tianjin	21752.85	15726.93	16796.43	16538.19	14067.98	17885.39
Hebei	35964.51	29421.15	34732.9	29806.11	34298.99	32070.45
Shanxi	16598.75	12761.49	19664.95	12766.49	11701.28	13050.41
Nei Mongol	24640.53	17770.19	16356.91	17831.51	18844.37	18128.1
Liaoning	27023.38	28626.58	30685.36	28669.02	15064.54	22246.9
Jilin	15103.44	13803.14	15106.48	14063.13	14725.61	14776.8
Heilongjiang	20748.06	15039.38	20115.31	15083.67	14269	15386.09
Shanghai	26690.85	23567.7	33021.33	25123.45	26824.72	28178.65
Jiansu	68390.34	65088.32	69494.62	70116.38	74012.67	77388.28
Zhejiang	40414.07	40173.03	49575.31	42886.49	44315.46	47251.36
Anhui	24415.17	20848.75	23188.36	22005.63	29679.41	24407.62
Fujian	23742.14	24055.76	29735.46	25979.82	27053.71	28810.58
Jiangxi	19508.51	15714.63	22319.78	16723.78	20496.39	18499
Shandong	62273.48	59426.59	65180.14	63002.33	64420.28	68024.49
Henan	45705	34938.24	47979.55	37002.16	45937.5	40471.79
Hubei	28244.72	27379.22	34152.49	29550.19	32748.6	32665.38
Hunan	26602.77	27037.32	32131.22	28902.21	30250.67	31551.37
Guangdong	70681.4	67809.85	78646.28	72812.55	67715.94	80854.91
Guangxi	14291.33	15672.89	19282.38	16803.12	16858.19	18317.64
Hainan	1222.482	3500.72	1771.296	3702.76	3773.515	4053.2
Chongqing	15057.36	14262.6	18852.52	15717.27	16642.2	17740.59
Sichuan	35423.6	28536.66	35698.45	30053.1	30414.92	32934.54
Guizhou	16286.78	9266.39	14863.5	10502.56	14000.49	11776.73
Yunnan	13406	12814.59	16517.8	13619.17	16451.48	14788.42
Shaanxi	21053.82	17689.94	20060.17	18021.86	19314.37	19399.59
Gansu	6576.509	6836.82	5335.104	6790.32	9397.953	7200.37
Qinghai	3830.274	2303.32	3071.652	2417.05	2454.324	2572.49
Ningxia	3097.004	2752.1	4249.496	2911.77	2596.891	3168.59
Xinjiang	12131.7	9273.46	10530.22	9324.8	10646.93	9649.7

It can be seen from the Figure 4 that the DEANN model has good accuracy in predicting policy performance. Some large errors , such as the error for Northern China in 2014, may be due to severe winter smog. Since there are emergency plans in ecological civilization policies, the predicted results are generally higher than the actual value. Most of the predictions are accurate if the policy remains stable and continuous to some degree.

5. Prediction of the economic impact of the Total Emission Reduction Policy by using the DEANN model on a five-year plan (2016-2020)'s data

The trained DEANN model system can help us predict the impact of ecological civilization policies on the economy, help us assess whether policies are feasible and can help in achieving established policy goals.

In the following case, we try to predict the supposed emission and energy consumption data from the set goal of saving energy and cutting emissions, which was issued in the five-year plan (2016-2020) by the State Council of

China on Jan 5, 2017(Council, 2016). Additionally, we assume that the increase in total wages is the same as the rate of GDP growth. The data of Xinjiang Province is the sum of Xinjiang and China Xinjiang Production and Construction Corps in the five-year plan. We adjust different input values, the fixed asset investment, of the trained DEANN model system until the output value, the predicted economic growth rate, is greater than the lowest set economic growth rate. The final fixed asset investment growth is shown in the next table(Table 5).

We can treat this as the basis for measuring whether a policy is feasible. If we cannot afford a high production input, then we have to reduce environmental requirements and allow more emissions. Otherwise, if we want to maintain economic growth and protect the environment, we must increase investment. Additionally, the efficiency improvement caused by technological transformation accumulates growth year by year2.

Table 5. The target of economic growth

	Lower limit of GDP(Billion)	Lower limit of Total wage(Billion)	Upper limit of COD(Ten thousand tons)	Upper limit of Ammonia nitrogen (Ten thousand tons)	Upper limit of SO2(Ten thousand tons)
Beijing	31531.98282	10532.68	13.8244	1.38435	4.628
Tianjin	22658.75356	2951.17	17.89896	1.99682	13.9425
Hebei	40836.9538	4062.99	97.8561	7.784	79.8048
Shanxi	17491.19769	3042.83	33.38024	4.1082	89.648
Nei Mongol	24430.71404	2291.2	77.62724	4.3617	109.5501
Liaoning	39279.04196	4494.16	101.1055	8.78256	77.504
Jilin	19267.70686	2178.3	68.94384	4.81104	29.7578
Heilongjiang	20665.9351	2785.52	130.9138	7.5609	40.6107
Shanghai	34421.30378	8975.85	16.9974	3.6805	13.664
Jiansu	96065.51712	13086.52	91.2229	11.92482	66.808
Zhejiang	58758.20799	9134.09	55.20256	8.1164	44.6374
Anhui	30149.62018	3605.52	78.48611	8.29576	40.3284
Fujian	35594.6049	4739.13	58.44146	8.21215	33.79
Jiangxi	22913.02794	2902.25	68.48292	8.13852	46.4728
Shandong	86318.6521	8967.77	155.19608	13.18052	111.3761
Henan	50696.16593	6294.45	105.03552	11.20062	82.3896
Hubei	40486.32122	4755.98	88.84761	10.26414	44.112
Hunan	39598.53246	3836.38	108.57223	13.58389	47.0445
Guangdong	99759.50368	16118.8	143.97824		65.7951
Guangxi	23021.73062	2466.7	70.4088	7.5933	36.6444
Hainan	5073.102094	688.88	18.56452	2.0601	3.23
Chongqing	21534.02201	3094.48	35.16948	4.69437	40.6556
Sichuan	41175.3515	5813.28	103.45408	11.31354	60.2784
Guizhou	14389.41739	2177.89	29.12445	3.23232	79.329
Yunnan	18659.44318	2615.91	43.83477	4.78179	57.7863

Shaanxi	24691.51004	3647.72	44.019	5.004	62.475
Gansu	9303.326872	17089.09	33.57126	3.4224	52.4952
Qinghai	3311.56797	490.9	10.31527	0.986	14.1752
Ningxia	3989.377244	581.33	20.8468	1.60866	31.4688
Xinjiang	12775.78412	2555.35	64.97352	4.43232	74.39467584

From the data in the Table 6 we can see the following trend: In key areas, especially those suffering from heavy pollution, when emissions are heavily cut, those provinces have to input(invest) more than others to achieve the same economic growth rate. The increased investment can be invested in low emission industries, or in transforming the technology of existing production capacity to cut emissions. In contrast, in the 'greener ' areas, the investment growth needs less input. Such a nonlinear relationship is well expressed by the DEANN model.

Table 6. The prediction of fixed asset investment growth rate, which can suit 2020's economic growth target

	Fixed asset investment growth rate in 2020 (%)
Beijing	28.8143
Tianjin	36.7037
Hebei	27.224
Shanxi	15.668
Nei Mongol	23.606
Liaoning	48.2624
Jilin	19.96424
Heilongjiang	20.0744
Shanghai	26.036
Jiansu	7.1306
Zhejiang	39.3524
Anhui	14.41304
Fujian	8.7911
Jiangxi	4.8788
Shandong	55.7792
Henan	25.4798
Hubei	23.06492
Hunan	24.794
Guangdong	62.0108
Guangxi	9.782
Hainan	19.9286
Chongqing	15.0659
Sichuan	17.9387
Guizhou	15.47144
Yunnan	9.7307
Shaanxi	15.425
Gansu	7.3088
Qinghai	7.51616
Ningxia	14.858
Xinjiang	5.68512134

6. Conclusions and Policy Implications

This paper proposes the DEANN model, which is used to evaluate the performance of ecological civilization policy on the basis of regional eco-efficiency evaluation. By training and examining the evaluation results, this paper provides a quantitative evaluation of the ecological civilization policy in different provincial regions from 2003-2016 and tries to predict the performance of emissions reduction policy in environmental planning in the 13th Five-Year Plan.

Based on the study's results, we can draw the following conclusions. (1) Development and the environment can achieve a win-win situation. We cannot obtain economic development at the expense of environmental pollution, and we cannot pursue environmental protection at the risk of economic stagnation. In addition to protecting the environment, the ecological civilization policy has a huge impact on economic development. We can achieve a dynamic balance between economic development and environmental protection by controlling the input of ecological civilization policies. (2) Regional eco-efficiency differs based on not only on the input of ecological civilization policy but also on the local environmental capacity and risk attitude. Therefore, when the ecological civilization policy is evaluated, a different method should be used the main functions and positions of different areas. (3) The performance of ecological civilization policy in the regions of different eco-efficiencies can be regulated through different policies. In developed areas with high ecological efficiency, although current environmental problems are prominent, , it will not be difficult to achieve the goal of environmental quality improvement due to a good foundation. Less-developed areas with low ecological efficiency need to make a great effort to improve the quality of ecological environment. Developing areas with high ecological efficiency require a large number of policies for support, in order to protect their fragile ecological environment and develop their economy at the same time; developed areas with low ecological efficiency need precise control of policies because of their large development base. It is necessary to avoid both over-regulation and a lack of regulation.

Because of the Artificial Neural Network's special negative feedback mechanisms, we suggest eight ways to improve the performance of ecological civilization from the evaluation result: (1) boost the legislation regarding ecological civilization, (2) complete an organizational decision-making mechanism of ecological civilization, (3) establish an economic policy system for ecological civilization, (4) strengthen the adjustment mechanics of interests, (5) set up public participation mechanisms, (6) construct a supervision mechanism for ecological civilization policy, (7) improve the performance evaluation mechanics of ecological civilization policy, and (8) deepen the structural reform of the supply-side for supporting systems.

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