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CONTENTS

Sr. No.	TITLE & NAME OF THE AUTHOR (S)	Page No.
1.	**SOCIO-ECONOMIC CHALLENGES IN A REBASED ECONOMY: A CASE STUDY OF NCHANGA TOWNSHIP OF CHINGOLA DISTRICT, ZAMBIA** *DR. B. NGWENYA & C. MWANTAKAMA*	1
2.	**DYNAMIC FORECASTING ON ENERGY INTENSITY BY GREY THEORY FOR GREATER CHINA REGION AND IMPLICATION OF SUSTAINABLE ECONOMIC DEVELOPMENT** *PENG JIANG, GHI-FENG YEN, YI-CHUNG HU & HANG JIANG*	5
3.	**ECONOMIC SCALE OF NON-LIFE INSURANCE COMPANIES IN INDIA** *M. MUTHUMEENA & DR. A. MUTHUSAMY*	11
4.	**COINTEGRATION APPROACH TO ESTIMATE INDIA'S TRADE ELASTICITIES** *DR. AMAL SARKAR*	19
5.	**CHALLENGES AND ITS MEASURES IN CORPORATE TAKEOVER AND ACQUISITIONS** *NARESH KUMAR GOEL, ANINDITA CHATTERJEE & KULDEEP KUMAR*	25
6.	**DETERMINING QUALITY OF WOMEN HEALTH CARE SERVICES IN RURAL INDIA** *T. KANNIKA & DR. J. FREDRICK*	30
7.	**INDIA: AGRICULTURE'S CONTRIBUTION TOWARDS CLIMATE CHANGE** *SATRAJIT DUTTA*	35
8.	**AN EVALUATION, COMPARISON AND MANAGEMENT OF NON PERFORMING ASSETS (NPA) IN STATE BANK OF INDIA & ITS ASSOCIATES** *DR. K. JAGADEESAN*	40
9.	**ECONOMIC EMPOWERMENT OF WOMEN IN INDIA** *JASBIR SINGH & SONIA KUMARI*	46
10.	**THE IMPACT OF THE INFORMAL SECTOR ON NATIONAL DEVELOPMENT: STUDY OF THE HUMAN RESOURCE DEVELOPMENT (HRD) ISSUES AND THE CONTRIBUTIONS OF THE ROAD SIDE MECHANICS, ARTISANS/TECHNICIANS ETC. TO THE ECONOMY IN OSUN STATE, NIGERIA** *DR. S. O. ONIMOLE*	49
11.	**GROWTH OF VAT REVENUE** *T. ADILAKSHMI*	55
12.	**EMPOWERMENT OF PEOPLE WITH LEARNING DISABILITIES (DYSLEXIA) TOWARDS SUSTAINABLE DEVELOPMENT: AN INDIAN PERSPECTIVE** *K. JAYASREE*	63
13.	**NON-PERFORMING ASSETS: A STUDY OF SCHEDULED COMMERCIAL BANKS OF INDIA WITH REFERENCE TO GROSS NPAs AND AMOUNT RECOVERED** *VIBHUTI SHIVAM DUBE*	65
14.	**AGRICULTURAL FINANCING SCENARIO IN THE INDIAN STATE OF TRIPURA, A COMPARATIVE STUDY FOR THE PERIOD 2008-09 TO 2012-13** *PURANJAN CHAKRABORTY*	68
15.	**MAJOR POVERTY ALLEVIATION PROGRAMMES IN HIMACHAL PRADESH: AN INTRODUCTION** *KHEM RAJ*	79
16.	**INFRASTRUCTURAL FACILITIES AND AGRICULTURAL DEVELOPMENT IN INDIA: WITH REFERENCE TO AGRICULTURAL CREDIT** *R. KESAVAN*	85
17.	**STATUS OF DALITS IN INDIA: AN EFFECT OF THE ECONOMIC REFORMS** *NAZEEFA BEGUM MAKANDAR*	88
18.	**FINANCIAL INCLUSION: PROGRESS OF PRADHAN MANTRI JAN DHAN YOJANA (PMJDY)** *KAPIL RAHANG*	91
19.	**MAJOR CHANGES IN ADULT EDUCATION OF ANDHRA PRADESH** *BILLA RAJA RUBI KISHORE*	95
20.	**VOLATILITY AND FINANCIAL DERIVATIVES IN NATIONAL STOCK EXCHANGE** *GAURAV GAUTAM & DR. BHUPINDER SINGH*	98
	REQUEST FOR FEEDBACK & DISCLAIMER	102

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DYNAMIC FORECASTING ON ENERGY INTENSITY BY GREY THEORY FOR GREATER CHINA REGION AND IMPLICATION OF SUSTAINABLE ECONOMIC DEVELOPMENT

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ABSTRACT

A prediction model, GM (1, 1), is established based on the panel data of energy intensity during 1998-2012 for Mainland China, Taiwan, Hong Kong, and Macao. Then, based on the prediction results, the heterogeneity of four districts will be discussed. Finally, according to the industrial advantages of four places, the strategies for economic sustainable development are proposed. This paper aims to providing a convenient and feasible method for governmental agencies to predict energy intensity efficiently.

KEYWORDS

Greater China region; energy intensity; GM (1, 1); dynamic forecasting; sustainable economic development.

1. INTRODUCTION

Since the latter half of the 20th century, the rapid growth of the economy in the Asia Pacific region won worldwide attention. In the early 1970s, Taiwan and Hong Kong, in the Greater China region, have been among the Asia four little dragons and become an important economic growth pole of the Asia Pacific region; with the tourism industry and the gaming industry as the main pillar industries, Macao's per capita GDP has ranked first in Asia, and second in the world; with the implementation of reform and opening up policy for more than 30 years, China Mainland has achieved magnificent economy and social development, while promoting the economy sustainable development of the Greater China region.

Rapid economic growth has also increased the amount of energy consumption. As is known to all, energy is the guarantee to achieve sustainable economic development, but also the foundation of human survival, which are most fundamental core factors to ensure the national economic health and stable operation (Zhang, 2014). Therefore, how to improve the energy efficiency has gained great attention of all parties. At present, the energy intensity is usually used as one of the indicators to measure the energy utilization.

Energy intensity represents, in a certain period of time, a country (region) create per unit of gross domestic product (GDP) by using the amount of primary energy, namely the ratio of energy consumption to economic output. This indicator mainly reflects the economic structure of the country (region) and the overall level of energy portfolio. The formula can be expressed as: $EI_t = \frac{EC_t}{GDP_t}$, where EI_t represents the energy intensity of the year t, EC_t represents the primary energy consumption of year t, and GDP_t represent the gross domestic product for the year t. when $EI_t > EI_{t+1}$, the energy intensity of the numerical tends to decrease with the time-variation, which indicates the country (region) towards the direction of development of low carbon economy and in line with the requirements of sustainable development for the economic, and vice versa. Hence energy intensity is an essential indicator to measure of economic sustainable development.

Current research on energy intensity is still inadequate. Wang, He, and Wang (2010) analyzed the evolution characteristics of low carbon economy in China from the perspective of energy intensity. Fan (2010) discusses the relationship between energy intensity, energy consumption structure and economic structure of Taiwan. Sun, Li, and Chen (2011) used Zhejiang Province as an example to discuss the factors driving the development of low carbon economy. Zhao et al. (2013) analyzed the impact of energy intensity change on energy structure and industrial structure in China from 1990 to 2010. Fang et al. (2013) applied nonlinear dynamics theory to discuss the development of new energy sources and the influence on energy intensity and economic development. Sun, Guo, and Shi (2013) applied spatial econometric techniques to analyze the spatial spillover effects of energy intensity of 30 provinces in the mainland China.

The above research on energy intensity is very useful for the application and development of this concept in economics. It also emphasizes that energy intensity can be used as an important indicator to measure the sustainable development of economy. As mentioned above, although the Greater China region has become the most noticeable whole in Asia Pacific Economic Circle, but due to the geographical, historical and cultural factors, the economic development of the four places has their own characteristics. In addition, because of the differences in industrial structure, the performance of energy intensity is quite different as well. Therefore, it is highly necessary to predict the dynamic change of the energy intensity and analyze the difference of these four places. Finally, based on the prediction and considering the industrial advantages, strategies for sustainable economic development are proposed.

2. METHODOLOGY

2.1 Grey System

The grey system proposed by Deng in 1982, believed that there is a relationship between any two systems in the real world, but sometimes our understanding of this relationship is not yet mature (Hu, Chen, Hsu, & Tzeng, 2002). There are three types of systems—white, black, and grey. A system is called a white system when its information is totally clear. When a system's information is totally unknown, it is called a black system. If a system's information is partially known, then it is called a grey system (Pi, Liu, & Qin, 2010). Grey system takes the incomplete and small data or the systems with uncertain information as the research objects (Liu, 2014). By generating and developing the known information, it will be transformed into some valuable information (Hu, 2016). After realizing the correct expression of the behavior and evolution law of the system, future changes could be predicted dynamically (Deng, 1982). The grey theory has been successfully applied in many fields such as management, economy, engineering, finance, etc. (Knox & Richardson, 2003; Zorzano, Hochberg, & Morán, 2004; Hu, 2007; Hu, 2008; Bai & Sarkis, 2010; Hu, 2012; Wang, Dong, Wu, Mu, & Jiang, 2011; Lin, 2013; Neupane, Paudyal, & Thapa, 2014; Chithambaranathan, Subramanian, Gunasekaran, & Palaniappan, 2015).

2.2 Establishment of the GM(1,1) Model

By observing certain equal time interval segments of the system, a set of numerical sequences are obtained, named as original numerical sequences $X^{(0)}$:

$$X^{(0)} = \{x^{(0)}(k)\} \quad (1)$$

where $x^{(0)}(k) \gg 0, k = 1, 2, \ldots, n.$

Let $X^{(0)}$ be a primal time sequence, and obtain its First-order Accumulated Generating Operation 1-AGO) data $X^{(1)}$:

$$X^{(1)} = \{x^{(1)}(k)\} \quad (2)$$

where $x^{(1)} = \sum_{i=1}^{k}(k),\ \ k = 1, 2, \ldots, n,$ and

$$x^{(0)}(k) + ax^{(1)}(k) = b \quad (3)$$

is the original form of GM(1,1) model, and essentially, it is a difference equation.

Make quasi-smoothness verification and exponential law verification on $X^{(1)}$, and find out whether it is possible to establish the GM(1,1) model. According to:

$$\rho(k) = \frac{x^{(0)}(k)}{x^{(1)}(k-1)}, k = 2, 3, \ldots, n-1 \quad (4)$$

when $\rho(k) \in [0, \varepsilon], k = 3, 4, \ldots, n$, and $\varepsilon < 0.5$, $X^{(1)}$ was called as quasi-smoothness sequence. Also according to:

$$\sigma^{(1)}(k) = \frac{x^{(0)}(k)}{x^{(1)}(k-1)}, k = 2, 3, \ldots, n-1 \quad (5)$$

when $\sigma^{(1)}(k) \in [a, b], k = 3, 4, \ldots, n$, and $\delta = b - a = 0.5$, $X^{(1)}$follows the quasi-exponential law. When $X^{(1)}$ satisfies the quasi-smoothness sequence and quasi-exponential law at the same time, the GM(1,1) model can then be established.

Make the least-squares estimation on the parameter sequence $\hat{a} = [a, b]^T$, and obtain:

$$\hat{a} = (B^T B)^{-1} B^T Y \quad (6)$$

where

$$B = \begin{bmatrix} -Z^{(1)}(2) & -Z^{(1)}(3) & \cdots & -Z^{(1)}(n) \\ 1 & 1 & \cdots & 1 \end{bmatrix}^T \quad (7)$$

$$Y = [x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n)]^T \quad (8)$$

$$Z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1) \quad (9)$$

$x^{(0)}(k) + az^{(1)}(k) = b$ is called the differential equation of GM(1,1), it is the essential form of the GM(1,1) grey forecasting model.

Determine the whitenization equation and time response formulae of $X^{(1)}$, and build the GM(1,1) forecasting model as follows:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (10)$$

$$\hat{X}^{(1)}(k) = \left(X^{(0)}(1) - \frac{b}{a}\right) e^{-a(k-1)} + \frac{b}{a} \quad (11)$$

$$\hat{X}^{(0)}(k) = \hat{X}^{(1)}(k) - \hat{X}^{(1)}(k-1) \quad (12)$$

Where a is the development coefficient, b is the grey action quantity, $\hat{X}^{(1)}$is the simulative value of $X^{(1)}$, while $\hat{X}^{(0)}$ is the simulative value of $X^{(0)}$. Therein make $x^{(1)}(1) = x^{(0)}(1)$, make inverse accumulated generating operation (I-AGO) on $\hat{X}^{(1)}$, $\hat{X}^{(0)}$ can be obtained. Eqsuations (10), (11) and (12) are the mathematic expression for the GM(1,1) model. The advantage of this model is to reduce the randomness of the original time series, if $X^{(0)}$ is a set of non- negative sequences, then $X^{(1)}$ is a growing sequence (Liu *et al*., 2012).

2.3 Accuracy Check-up for the GM(1,1) Model

The established GM(1,1) models need to be checked-up to confirm whether they satisfy the accuracy requirements. We usually check their accuracy by methods such as the "posterior error," "residual error," and "degree of grey association." This article took the "posterior error" method as the tool to check the model accuracy (Liu et al., 2012). The steps can be observed as:

Calculate the mean value $\bar{X}$ and mean square deviation S_1^2 of the original sequences:

$$\bar{X} = \frac{1}{n}\sum_{k=1}^{n} X^{(0)}(k) \quad (13)$$

$$S_1^2 = \frac{1}{n}\sum_{k=1}^{n}\left(X^{(0)}(k) - \bar{X}\right) \quad (14)$$

Calculate the mean value $\bar{\varepsilon}$ and mean square deviation S_2^2 of the residual errors:

$$\bar{\varepsilon} = \frac{1}{n}\sum_{k=1}^{n} \varepsilon^{(0)}(k) \quad (15)$$

$$S_2^2 = \frac{1}{n}\sum_{k=1}^{n}\left(\varepsilon^{(0)}(k) - \bar{\varepsilon}\right) \quad (16)$$

Calculate the mean square deviation ratio *C* and small error probability *p*:

$$C = \frac{S_2}{S_1} = \sqrt{\frac{S_2^2}{S_1^2}} \quad (17)$$

$$p = P\{|\varepsilon(k) - \bar{\varepsilon}| < 0.6745S_1\} \quad (18)$$

Check-up the models by C, p values:

A small *C* value usually means the discreteness of the prediction errors is small; while a large *p* value usually means the probability of the smaller errors is big. So, the smaller the *C* value, the bigger the *p* value, and the higher the forecasting precision. Table 1 gives the reference values of the forecasting precision levels. As far as *C* and *p* stay in the allowed scope, the GM(1,1) model can be used to make the prediction (Feng, Ma, Song, & Ying, 2012).

TABLE 1: THE GRADING STANDARDS OF GM(1,1) MODEL PRECISION TEST

Accuracy class	*C*	*p*
First (Good)	< 0.35	> 0.95
Second (Qualified)	0.35 - 0.5	0.95 - 0.8
Third (Scarcely Qualified)	0.5 - 0.65	0.8 - 0.7
Fourth (Unqualified)	> 0.65	< 0.7

3. EMPIRICAL RESEARCH

Energy intensity forecasting can be regarded as grey system problem, because a few factors such as GDP, income, industrial structure and degree of industrialization are known to influence the energy intensity but how exactly they affect the energy demand is not clear (Suganthi and Samuel, 2012). In this study, the data of energy intensity for China mainland, Hong Kong and Macao are selected from the World Bank Open Data, while Taiwan's data is obtained from Bureau of Energy, Ministry of Economic Affairs of Taiwan. To reduce the computational error caused by fluctuation of exchange rates, the selected year data of 1998, 2000, 2002, 2004, 2006, 2008, 2010, and 2012, as shown in Table 2, are converted to purchasing power parity (PPP) based on the PPP of 2005, to ensure that the data from four places are comparable.

TABLE 2: THE ENERGY INTENSITY OF GREATER CHINA REGION (1998 -2012)

Year	China mainland	Hong Kong	Macao	Taiwan
1998	11.51	2.65	1.71	9.30
2000	10.67	2.50	1.63	10.08
2002	9.75	2.41	1.47	9.41
2004	10.53	2.10	1.24	8.96
2006	9.93	1.93	1.00	8.60
2008	8.67	1.85	0.79	7.84
2010	8.57	1.75	0.64	7.67
2012	8.34	1.70	0.48	7.44

Soruce: 1. World Bank Open Data：http://data.worldbank.org/；2. Bureau of Energy, Ministry of Economic Affairs of Taiwan：http://web3.moeaboe.gov.tw/ECW/populace/home/Home.aspx。

Following the previous steps we built the GM(1,1) models for energy intensity of Greater China Region, respectively, and forecasted the energy intensity for the upcoming 8 years (2014, 2016, 2018 & 2020). Now we take the energy intensity of China mainland as an example to explain how to build and calculate these models.

The energy intensity from 1998 to 2012 is:

$$X^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(8)\right) = (11.51, 10.67, 9.75, 10.53, 9.93, 8.67, 8.57, 8.34)$$

Make 1-AGO operation on $X^{(0)}$ and get:

$$X^{(1)} = \left(x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(8)\right) = (11.51, 22.18, 31.93, 42.46, 52.39, 61.06, 69.63, 77.97)$$

According to Eq. (4) and by quasi-smoothness verification on $X^{(1)}$, we know:

$\rho(3) \approx 0.44$；$\rho(4) \approx 0.33$；$\rho(5) \approx 0.23$；$\rho(6) \approx 0.17$；$\rho(7) \approx 0.14$；$\rho(8) \approx 0.12$;

According to Eq. (5) and by exponential law verification on $X^{(1)}$, we know:

$\sigma(3) \approx 1.44$；$\sigma(4) \approx 1.33$；$\sigma(5) \approx 1.23$；$\sigma(6) \approx 1.17$；$\sigma(7) \approx 1.14$；$\sigma(8) \approx 1.12$.

When $k > 3, \rho(k) < 0.5, \sigma(k) \in [1, 1.5]$, $\delta = \mathrm{b} - a = 0.5$, $X^{(1)}$satisfies the two requirements for the quasi-smoothness sequence and quasi-exponential order, so the GM(1,1) can be established.

According to Eq. (9), calculate the generated sequence of the immediate neighboring average value:

$$Z^{(1)}(k) = \left(z^{(1)}(2), z^{(1)}(3), \dots, z^{(1)}(8)\right) = (16.85, 27.06, 37.20, 47.43, 56.73, 65.35, 73.80)$$

Hence we can figure out:

$$\mathrm{B} = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(8) & 1 \end{bmatrix} = \begin{bmatrix} -16.85 & 1 \\ -27.06 & 1 \\ -37.20 & 1 \\ -47.43 & 1 \\ -56.73 & 1 \\ -65.35 & 1 \\ -73.80 & 1 \end{bmatrix} \mathrm{Y} = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(8) \end{bmatrix} = \begin{bmatrix} 10.67 \\ 9.75 \\ 10.53 \\ 9.93 \\ 8.67 \\ 8.57 \\ 8.34 \end{bmatrix}$$

According to Eq. (6), then the parameter sequence can be further determined as

$$\hat{a} = [a, b]^T = (B^T B)^{-1} B^T Y = \begin{bmatrix} 0.041741 \\ 11.428123 \end{bmatrix}$$

because $a > 0$, the original sequence showed a downward trend.

According to Eq. (11), we obtain the GM(1,1) model for China mainland:

$$\hat{X}^{(1)}(k) = \left(X^{(0)}(1) - \frac{b}{a}\right) e^{-a(k-1)} + \frac{b}{a} = -262.27511 e^{-0.041741(k-1)} + 273.78875,$$

By further calculation, we obtain:

$$\hat{X}^{(1)} = \left(\hat{x}^{(1)}(1), \hat{x}^{(1)}(2), \dots, \hat{x}^{(1)}(8)\right) = (11.51, 22.24, 32.52, 42.38, 51.84, 60.92, 69.62, 77.97)$$

According to Eq. (12), make I-AGO on $\hat{X}^{(1)}$, we obtain the simulative value of $\mathrm{X}^{(0)}$:

$$\hat{X}^{(0)} = \left(\hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \dots, \hat{x}^{(0)}(8)\right) = (11.51, 10.72, 10.28, 9.86, 9.46, 9.07, 870, 8.35)$$

According to Eqs. (13) to (18), examining this model by "posterior error" method, we get:

$\bar{X} \approx 9.75$; $S_1^2 \approx 1.31$; $\bar{\varepsilon} \approx -0.0005$; $S_2^2 \approx 0.1874$,

Hence, the mean square deviation ratio is:

$$C = \frac{S_2}{S_1} \approx 0.3789 \in [0.35, 0.50]$$

$p = \mathrm{P}\{|\varepsilon(k) - \bar{\varepsilon}| < 0.6745 S_1\} = \mathrm{P}\{|\varepsilon(k) - \bar{\varepsilon}| < 0.7706\}$,

Because $|\varepsilon_2 - \bar{\varepsilon}| = 0.0533 < 0.7706$, $|\varepsilon_3 - \bar{\varepsilon}| = 0.5338 < 0.7706$, $|\varepsilon_4 - \bar{\varepsilon}| = 0.6648 < 0.7706$, $|\varepsilon_5 - \bar{\varepsilon}| = 0.4651 < 0.7706$, $|\varepsilon_6 - \bar{\varepsilon}| = 0.3997 < 0.7706$, $|\varepsilon_7 - \bar{\varepsilon}| = 0.1364 < 0.7706$, $|\varepsilon_8 - \bar{\varepsilon}| = 0.0067 < 0.7706$, $p = \frac{7}{7} = 1 > 0.95$. According to Table 1, it means the energy intensity of China mainland could be used to make the prediction. The calculation results can be observed in Table 3.

TABLE 3: SIMULATIVE VALUES AND ERRORS OF GM(1,1) MODEL FOR ENERGY INTENSITY OF CHINA MAINLAND (1998-2012)

No.	Year	Original quantity	Simulated quantity	Absolute error	Relative error
1	1998	11.51	11.51	0	0
2	2000	10.67	10.72	0.05	0.49%
3	2002	9.75	10.28	0.53	5.47%
4	2004	10.53	9.86	0.66	6.32%
5	2006	9.93	9.46	0.47	4.69%
6	2008	8.67	9.07	0.40	4.60%
7	2010	8.57	8.70	0.14	1.59%
8	2012	8.34	8.35	0.01	0.07%
Average error					2.90%
Model accuracy					97.10%

Additionally, according to the forecasting standards of the grey system, when the development coefficient $a = 0.041741 < 0.3$, the GM(1,1) model can be used in the mid-long term forecasting (Liu and Deng, 2000). The calculation result is:

$$\hat{X}^{(0)} = \left(\hat{x}^{(0)}(9), \hat{x}^{(0)}(10), \hat{x}^{(0)}(11), \hat{x}^{(0)}(12)\right) = (8.01, 7.68, 7.36, 7.06)$$

Similarly, we can build the GM(1,1) model for the energy intensity of Hong Kong, Macao and Taiwan from 2014 to 2020. The results are shown in Tables 4–6.

TABLE 4: SIMULATIVE VALUES AND ERRORS OF GM(1,1) MODEL FOR ENERGY INTENSITY OF TAIWAN (1998-2012)

No.	Year	Original quantity	Simulated quantity	Absolute error	Relative error
1	1998	9.30	9.30	0	0
2	2000	10.08	9.98	0.10	0.99%
3	2002	9.41	9.47	0.06	0.62%
4	2004	8.96	8.98	0.02	0.25%
5	2006	8.60	8.52	0.08	0.91%
6	2008	7.84	8.08	0.25	3.12%
7	2010	7.67	7.67	0.00	0.00%
8	2012	7.44	7.28	0.16	2.20%
Average error					1.01%
Model accuracy					98.99%

TABLE 5: SIMULATIVE VALUES AND ERRORS OF GM(1,1) MODEL FOR ENERGY INTENSITY OF HONG KONG (1998-2012)

No.	Year	Original quantity	Simulated quantity	Absolute error	Relative error
1	1998	2.65	2.65	0	0
2	2000	2.50	2.49	0.01	0.34%
3	2002	2.41	2.32	0.09	3.80%
4	2004	2.10	2.16	0.07	3.14%
5	2006	1.93	2.01	0.08	4.06%
6	2008	1.85	1.88	0.03	1.50%
7	2010	1.75	1.75	0.00	0.17%
8	2012	1.70	1.63	0.08	4.55%
Average error					2.20%
Model accuracy					97.80%

TABLE 6: SIMULATIVE VALUES AND ERRORS OF GM(1,1) MODEL FOR ENERGY INTENSITY OF MACAO (1998-2012)

No.	Year	Original quantity	Simulated quantity	Absolute error	Relative error
1	1998	1.71	1.71	0	0
2	2000	1.63	1.70	0.07	4.51%
3	2002	1.47	1.41	0.06	3.85%
4	2004	1.24	1.17	0.07	5.83%
5	2006	1.00	0.97	0.03	2.90%
6	2008	0.79	0.80	0.01	0.91%
7	2010	0.64	0.66	0.02	2.68%
8	2012	0.48	0.55	0.07	15.11%
Average error					4.47%
Model accuracy					95.53%

For the convenience of comparison, Figures 1–4 are given to show the fitting curves for the forecasting values of the four models and the corresponding actual measured values respectively.

FIGURE 1: THE ACTIVE TREND OF ENERGY INTENSITY OF CHINA MAINLAND (1998-2020)

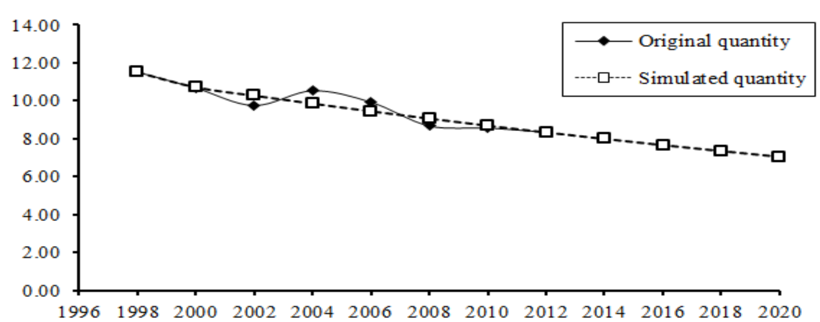


FIGURE 2: THE ACTIVE TREND OF ENERGY INTENSITY OF TAIWAN (1998-2020)

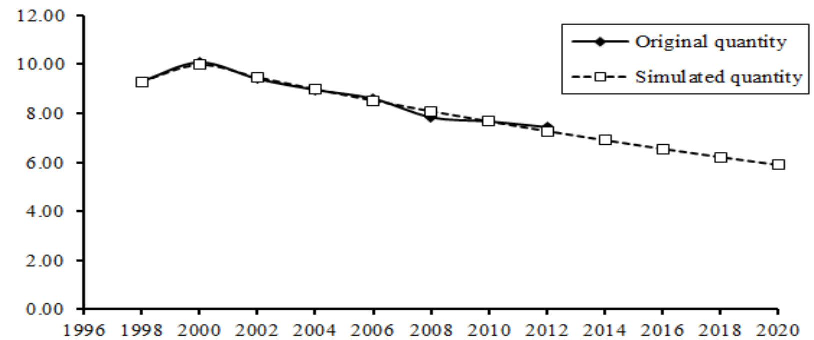


FIGURE 3: THE ACTIVE TREND OF ENERGY INTENSITY OF HONG KONG (1998-2020)

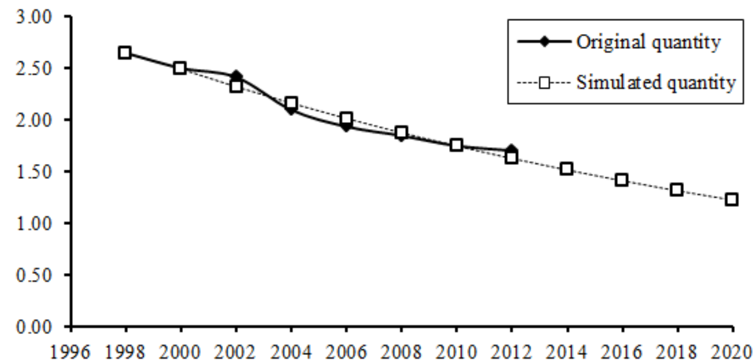
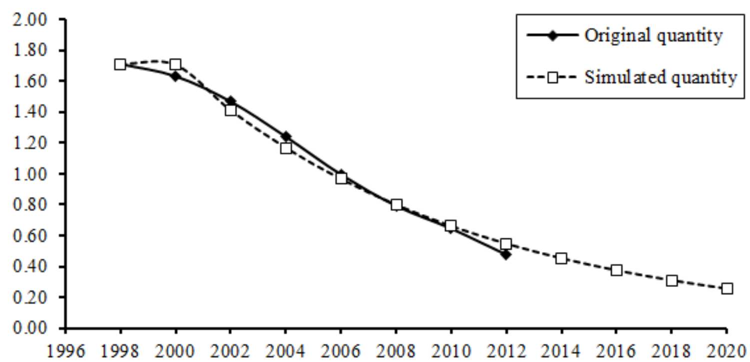


FIGURE 4: THE ACTIVE TREND OF ENERGY INTENSITY OF MACAO (1998-2020)



4. RESULTS

According to the results of empirical research, the GM(1,1) prediction models of four places constructed by the 8 sets of energy intensity using the data from 1998 to 2012 are displayed as follow:

$\hat{X}_{cn}(k) == -262.27511e^{-0.041741(k-1)} + 273.78875$

$\hat{X}_{tw}(k) == -194.53883e^{-0.052666(k-1)} + 203.83883$

$\hat{X}_{hk}(k) == -36.247971e^{-0.071273(k-1)} + 38.8973611$

$\hat{X}_{mo}(k) == -9.8860556e^{-0.189263(k-1)} + 11.5968062$

As shown by the formulas and Figure 1 to Figure 4 above, the development coefficient of four models are all greater than 0, which represents that the energy intensity of these four districts will obviously decline in the future. In other words, per unit of GDP growth will consume less and less amount of energy, and probably low carbon economy will get considerable development.

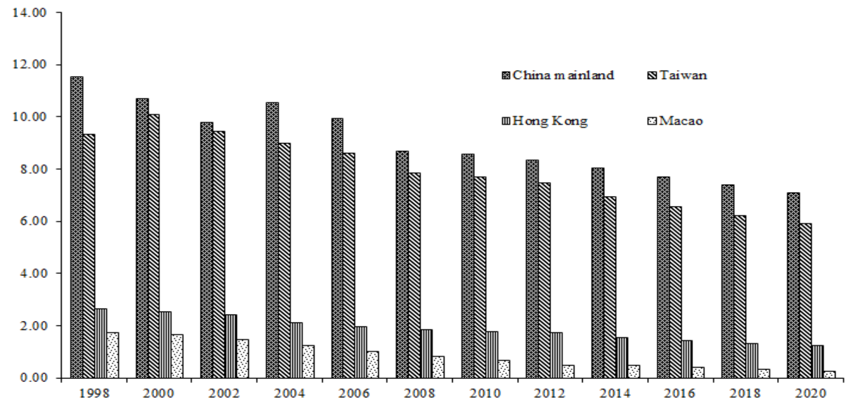
In this paper, the posterior probability method is used to verify the accuracy of model, and the verification results are displayed in table 3-6. The four simulation degrees of simulation value and the actual value for mainland China, Taiwan, Hong Kong and Macau are 97.10%, 98.99%, 97.80% and 95.53% respectively. Due to all models meet the demand of long-term forecast, the results can reasonably reflect the dynamic change tendency of energy intensity in Greater China region.

The predictions result for 2012, 2014, 2016 and 2018 are shown in Table 7. As can be seen, the descent rate of mainland China is the slowest, with an average of 4.08% per year. The descent rates for Taiwan and Hong Kong are 6.01% and 8.65%, and ranked 2 and 3 respectively, while energy intensity of Macao rapid decline with an annual average of 16.56%. Figure 5 displays the downward tendency of energy intensity for four places.

TABLE 7: THE ENERGY INTENSITY PREDICTION OF GREATER CHINA REGION (2014-2020)

Year	China mainland	Taiwan	Hong Kong	Macao
2014	8.01	6.90	1.51	0.45
2016	7.68	6.55	1.41	0.38
2018	7.36	6.21	1.31	0.31
2020	7.06	5.89	1.22	0.26
Average growth rate	-4.08%	-6.01%	-8.65%	-16.56%

FIGURE 5: THE ENERGY INTENSITY DYNAMIC DECLINE TENDENCY OF GREATER CHINA REGION (1998-2020)



According to Figure 5, the absolute values of energy intensity in mainland China and Taiwan are much larger than Hong Kong and Macao, which is mainly caused by the differences of industrial structure.

In the beginning of 1960s, the western developed countries transfer labor-intensive industries to the developing countries gradually. Taiwan used this opportunity to attracting a large number of foreign funds and technology and quickly embarked on the path of development. Today, Taiwan has become one of the world famous high-tech industrial bases. Since the reform and opening up in mainland China, the productivity has increased dramatically so that the first, second and third industries have made considerable progress. And due to super high-speed development of the second industry, China has become a veritable factory of the world. The development of manufacturing industry cannot be separated from the energy consumption, that why mainland China and Taiwan present a greater absolute value in energy intensity. Because of the influence of geographical and political factors over a long period of time, the third industry in Hong Kong and Macao is highly developed and compose a unique industrial structure. With respect to the development of manufacturing industry, energy consumption of third industry is much lower. Thus energy intensity of Hong Kong and Macao shows a lower value.

CONCLUSION

In summary, there is a significant difference in the performance of energy intensity on these four places. In order to provide a steady stream of energy supply for the economic sustainable development, four places should continuing make efforts to reduce energy consumption. Hong Kong and Macao should maintain the existing industrial structure and strive to stable growth in the GDP at the same time to no longer increase energy consumption. China and Taiwan should strive to change the economic growth mode, adjust the industrial structure, and accelerate the transformation and upgrading of the industry to reduce the proportion of manufacturing industry in the GDP. For China, it is imperative for economic growth mode to transform from extensive type to lean type. Taiwan should exert its natural and geographical advantages to vigorously develop the tertiary industry, to strive for innovation in the field of service and content, and to rational allocation of industrial structure to reduce the energy consumption. In addition, developing the scientific energy policy, changing the existing energy structure with coal as the main fuel, improving the usage of clean energy, and developing new energy source are the important channel to reduce energy intensity and achieve economic sustainable development.

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