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Energy Procedia 142 (2017) 3160–3169

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

Analysis of energy consumption in Hunan Province (China) using a LMDI method based LEAP model

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Abstract

In order to analyze the factors that affect energy consumption in Hunan Province comprehensively, firstly, this paper used the Logarithmic Mean Divisia Index (LMDI) and divided the total energy consumption growth of three industries from 2006 to 2015 in Hunan Province into scale effect, structure effect and efficiency effect. Secondly, the long-term energy alternatives planning (LEAP) system was used, and the LEAP-Hunan model with benchmark, scale effect, structure effect, efficiency effect and comprehensive adjustment scenarios was set up to analyze the impacts of the three kinds of effects on the total energy consumption profoundly. LMDI qualitative decomposition results show that the scale effect promotes the rapid growth of energy consumption, and efficiency effect can reduce energy consumption in Hunan Province, while inhibition of the structure effect is not prominent on the growth of energy consumption. The quantitative results of LEAP model are highly consistent with it, whose influence on the structure effect is reasonably extrapolated. This phenomenon shows that the structure effect and efficiency effect will jointly bear the inhibitory effect on the growth of total energy consumption in the future. In addition, the LEAP model has predictions about energy consumption from 2016 to 2040 in Hunan Province.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.

Keywords: energy consumption; LMDI decomposition; LEAP model; qualitative and quantitative analysis

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Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy .
10.1016/j.egypro.2017.12.384

1. Introduction

As one of the six provinces in central China, Hunan has some features that the central provinces all have, such as the faster development of economy, faster transformation of three industries structure, lower energy self-sufficiency and higher degree of external dependence [1,2]. Hunan, as a major energy consumption province, is relatively backward in terms of energy technology and energy management. It is necessary to find out some measures to reduce energy consumption and improve energy utilization.

At present, domestic and foreign scholars pay more attention to the energy consumption decomposition, and most of the methods used are exponential decomposition or LMDI [3-5]. According to the analysis of the four aspects: theoretical foundation, universality, feasibility and result, the author found that the LMDI method presents a better advantage due to its complete decomposition [6]. But at present, the LMDI energy consumption decomposition mainly focuses on the qualitative level, which does not have deeply quantitative study of various decomposition effects on the future energy consumption [7]. As a quantitative analysis model of the energy, economic and environment, the LEAP model has been widely used in the forecast of energy demand during recent years [8,9].

This paper uses LMDI and LEAP to find out the factors that influence energy consumption in Hunan province and figure out their influential capability. The combination of qualitative and quantitative results has importantly referential significance for the functional departments of provincial and municipal governments to formulate energy development planning.

2. Methodology

2.1 LMDI method

According to the LMDI method, the total energy consumption effect of Hunan province is decomposed according to formula (1):

$$\Delta E_{all} = \Delta E_{sca} + \Delta E_{str} + \Delta E_{eff} \tag{1}$$

$$\Delta E_{all} = E_n - E_{n-1} \tag{2}$$

$$\Delta E_{sca} = \sum_k w_{k,n} \ln(Y_n / Y_{n-1}) \tag{3}$$

$$\Delta E_{str} = \sum_k w_{k,n} \ln(S_{k,n} / S_{k,n-1}) \tag{4}$$

$$\Delta E_{eff} = \sum_k w_{k,n} \ln(I_{k,n} / I_{k,n-1}) \tag{5}$$

$$w_{k,n} = L(E_{k,n}, E_{k,n-1}) = \frac{(E_{k,n} - E_{k,n-1})}{\ln(E_{k,n} / E_{k,n-1})} \tag{6}$$

Where, ΔE_{all} is the total effect, which equals the total energy consumption difference of the target year (year n) and the previous year (year n -1). ΔE_{sca} is the scale effect, which refers to the impact of economic increase on the total energy consumption. ΔE_{str} is the structure effect, which means the impact of three industries structure adjustment on the total energy consumption effect. ΔE_{eff} is the efficiency effect, which denotes the impact of technological progress and energy efficiency improvement on the total energy consumption effect.

Y_n is the GDP of the n year; E_n is three industries energy consumption; $Y_{k,n}$ is industry added value for the k industry in the n year; $E_{k,n}$ is the energy consumption for the k industry in the n year. $S_{k,n} = Y_{k,n} / Y_n$ on behalf of the k industry added value proportion in the n year. $I_{k,n} = E_{k,n} / Y_{k,n}$ stands for energy consumption intensity of the k industry in the n year.

2.2 Grey system model GM (1,1)

This paper is based on grey system model GM (1,1) [10], using GDP time series data from 2011 to 2015 to predict future GDP of key years, which provides enough data support for the establishment of the LEAP-Hunan model. The establishment of GDP time series GM (1,1) model in Hunan province is as follows:

The initial time series: $X^{(0)} = \{X^{(0)}(i), i = 1,2,\cdots,n\}$,

One-accumulate of the time-series: $X^{(1)} = \{X^{(1)}(k), k = 1,2,\cdots,n\}$, where, $X^{(1)}(k) = \sum_{i=1}^{k} X^{(0)}(k)$.

The differential equation of GM (1,1) model can be obtained after $X^{(1)}$ discretization:

$$\frac{dX^{(1)}}{dt} + aX^{(1)} = u \tag{7}$$

The solution of the above differential equation is grey forecasting model:

$$\hat{X}^{(1)}(K+1) = [X^{(0)}(1) - \frac{u}{a}]e^{-ak} + \frac{u}{a},\ k = 1,2,\cdots,n \tag{8}$$

By using the least squares estimation method, a、 u can be obtained:

$$\hat{a} = (a,u)^{\mathrm{T}} = (B^{\mathrm{T}}B)^{-1}B^{\mathrm{T}}Y_n \tag{9}$$

where, $B = \begin{bmatrix} -\frac{1}{2}(X^{(1)}(1) + X^{(1)}(2)) & 1 \\ -\frac{1}{2}(X^{(1)}(2) + X^{(1)}(3)) & 1 \\ \cdots & \cdots \\ -\frac{1}{2}(X^{(1)}(n-1) + X^{(1)}(n)) & 1 \end{bmatrix}$, $Y_n = (X^{(0)}(2), X^{(0)}(3), \cdots, X^{(0)}(n))^{\mathrm{T}}$

By using the model above, the GDP values of 2011-2016 in Hunan Province are as shown in Table 1, and the actual GDP value of 2016 is used to verify.

Table 1. GDP forecast values of GM (1,1) model (billion yuan)

Year	2011	2012	2013	2014	2015	2016
Actual value	19669.56	22154.23	24621.67	27037.32	28902.21	31244.4
Predicted value	19669.56	22391.05	24443.19	26683.41	29128.95	31798.63
Relative error	0.00%	-1.07%	0.72%	1.31%	-0.78%	1.77%

2.3 LEAP-Hunan model

2.3.1 Model structure

The LEAP-Hunan model treats 2015 as the base year, and predicts energy consumption from 2016 to 2040 from the perspectives of the benchmark, scale effect, structure effect, efficiency effect and comprehensive adjustment scenarios. The energy consumption department of this model is divided into four parts, primary industry, secondary industry (industry, construction), tertiary industry and resident life.

2.3.2 Computing process

The total energy demand of the three industries in Hunan province is equal to the product of departmental activity level (industry added value, population, etc.) and energy intensity. For the primary industry, the total number of energy demand means that the added value of primary industry multiplies by the consistent energy intensity, and the secondary industry and tertiary industry are still the same. However, as for energy consumption of the residential sector, this department's activity level is the total population in Hunan Province, and its energy intensity refers to energy consumption per capita. The detailed formulas of the energy requirement in the LEAP-Hunan model are as follows:

$$EnergyDemand = \sum_k E_k \tag{10}$$

$$E_k = ACT_k \times Den_k \tag{11}$$

$EnergyDemand$ is the total energy demand in Hunan; E_k is the energy consumption for each industry and resident life sector; ACT_k is activity level for each sector; and Den_k is the energy intensity for each sector.

2.3.3 Scenario settings

The decomposition results of the LMDI method show that the influences of scale effect, structure effect and efficiency effect on energy consumption all can be reflected by the growth rate of GDP, the structure of three industries, energy intensity of various industries respectively. Therefore, Combined with these results, the LEAP-Hunan model can be built through scenario analysis which includes the establishment of benchmark scenario, the adjustment scenarios of scale effect, structure effect, efficiency effect and comprehensive. Studying the influences of these effects on the total energy consumption deeply is helpful for mastering the change of future energy demand in Hunan province.

1) Benchmark scenario

The purpose of setting benchmark scenario is to know how other scenarios affect the total effect more obviously. In this scenario, it is assumed that the population growth is equal to the annual average growth rate 5.9‰ of 12th Five-Year in Hunan province and the industries structure remains the same with year of 2016, which is 11.5: 42.2: 46.3. Based on GDP data in 2011-2015, the grey system theory is used to forecast the GDP data of the next 25 years, and results show that the error between 2015 forecasting value and the actual value is only -0.78%. The GDP values of key years are as shown in table 2. The statistical bulletin of national economic and social development of 2016 in Hunan Province present that the actual GDP value is 3124.44 billion yuan and the forecasting value is 3179.863 billion yuan, which shows the error is only 1.77%. Therefore, it is reliable to use grey system theory to predict future GDP data. The change rates of energy intensity for three industries and residential life sectors are extrapolated to -2.2%, -3.5%, -2.5% and 7% respectively according to the developing trend of the 2006-2015 years.

Table 2. GDP forecast values in critical years (billion yuan)

Years	2020	2025	2030	2035	2040
GDP	4515.88	7000.996	10853.69	16826.54	26086.29

2) Scale effect adjustment scenario

The effect of the scale effect on the total energy consumption in Hunan Province mainly is reflected through the GDP growth rate. Because the gray prediction presents that the average annual growth rate of GDP is about 9.1%, then different annual GDP growth rate of 8.5% and 10% are set to make comparisons, where 8.5% is the target value of Hunan Province on national economic and social development in the thirteenth five year plan, and 10% is 12th Five-Year actual value. Taken the GDP forecasting value of 2016 as the base value, and used the growth rate 8.5% and 10% respectively, the GDP value of the key years are calculated as shown in Table 3, and other key parameters are consistent with the benchmark scenario.

Table 3. GDP forecast values in critical years under different scale effects（billion yuan)

Years	2020	2025	2030	2035	2040
Low-speed GDP	4406.841	6626.375	9963.794	14982.125	22527.973
High-speed GDP	4655.637	7497.950	12075.524	19447.752	31320.799

3) Structure effect adjustment scenario

In order to study the structure effect which is the effect of industry structure on the total effect, according to the three industries structure change situation of 2006-2015 in Hunan Province, combined with the national and Hunan province situation, the two scenarios which are low-speed change and high-speed change of industry structure are set up. In the rapidly changing situation, the proportion of the tertiary industry grows rapidly. The detail situation is shown in Table 4, and other key parameters are consistent with the benchmark scenario.

Table 4. Three industries structure under different structure effects

Years	2020	2025	2030	2035	2040
Low-speed	11.5:41.2:47.3	10.5:40.2:49.3	9.6:39.3:51.1	8.7:38.2:53.1	8.1:37.1:54.8
High-speed	11.5:40.5:48	10.5:39.5:50	9.6:38.6:51.8	8.7:37.4:53.9	8.1:36.2:55.7

4) Efficiency effect adjustment scenario

With the improvement of production technology and energy utilization efficiency, the energy consumption intensity of each industry shows a downward trend. Along with economic development and technological progress, people's quality of life has gradually improved, and the demands for various kinds of energy keep going up, and the energy consumption intensity is also increasing. In view of these circumstances, the energy intensity of three industries and residential sector under the efficiency adjustment scenario are shown in Table 5, and other key parameters are consistent with the benchmark scenario.

Table 5. Annual change rate of energy consumption for each sector

Sectors	Primary industry	secondary industry	Tertiary industry	Resident life
Annual change rate of energy consumption	-2.80%	-4.40%	-3%	5.50%

5) Comprehensive adjustment scenario

Comprehensive adjustment scenario, which includes the scale effect, structure effect, efficiency effect adjustment scenarios. Comprehensive adjustment scenario has two sub-scenarios: low energy demand and high energy demand. Low energy demand scenario (LED) consists of low GDP growth rate, low speed industry structure change and energy intensity values under efficiency effect adjustment scenario. High energy demand (HED) scenario consists of high GDP growth rate, high speed industry structure change and energy intensity values under benchmark scenario, and other key parameters are consistent with the benchmark scenario.

3. Results and discussions

The data used for LMDI decomposition method and LEAP-Hunan model are from *Hunan statistical yearbook in 2006-2016 years*.

3.1 Results analysis of LMDI decomposition method

Through using the LMDI decomposition method above, decomposition results of the total energy consumption effect about three industries during 2006-2015 are shown in table 6. The total effect in the table refers to the increase of energy consumption, which is calculated on the basis of last year.

Table 6. Decomposition results of energy consumption (10^4 tons of coal equivalents)

Years	Total effect	Scale effect	Structure effect	Efficiency effect
2006	812.67	1388.15	265.61	-841.09
2007	945.19	2038.22	101.95	-1194.99
2008	629.28	2168.88	224.26	-1763.86
2009	820.42	1401.55	3.67	-584.80
2010	1186.36	2557.00	390.19	-1760.83
2011	1012.35	2765.72	313.96	-2067.32
2012	291.45	1689.94	-32.07	-1366.42
2013	-1417.14	1438.62	-75.48	-2780.29
2014	302.46	1224.80	-102.24	-820.10
2015	32.70	884.04	-257.90	-593.44
2006-2010	3581.24	8207.86	690.10	-5316.72
2011-2015	-790.53	5240.11	-506.57	-5524.07
2006-2015	3803.06	14858.97	446.45	-11502.36

As what is shown in Table 6 and figure 5, the effect of the three effects on the total effect and the energy consumption of Hunan in 2006-2015 years can be divided into two stages:

During the “11th Five-Year” period (from 2006 to 2010), the total energy consumption continued to increase. The decomposition values of scale effect and structure effect were 8207.86 and 690.10 respectively, and both of them were positive, which means scale effect and structure effect played a role in promoting energy consumption growth. The scale effect decomposition value is about 12 times of the structure effect decomposition value, which denotes the promoting effect of scale effect on energy consumption growth is stronger. In essence, the scale effect is the GDP growth rate, and structure effect is the proportion of tertiary industry. It can be seen that the rapid growth of GDP has greatly promoted the growth of energy consumption during this period, while the influence of tertiary industry structure change on the total energy consumption is not obvious. The decomposition value of efficiency effect is -5316.72, from which it can be seen that the improvement of technology and energy utilization efficiency have greatly restrained the increase of energy consumption.

During the “12th Five-Year” period (from 2011 to 2015), the total energy consumption experienced such a process of increasing-decreasing-increasing. The total effect, structure effect and efficiency effect were negative, which shows that during this period, the structure effect and efficiency effect have a good inhibitory effect on total energy consumption growth. The total effect is negative, which means that during “12th Five-Year”, with the improvement of production technology, energy utilization efficiency and industry structure adjustment, the total energy consumption is greatly reduced. Compared with the “11th Five-Year” period, scale effect decomposition value is 5240.11 in “12th Five-Year”, which is about 35% lower than that in “11th Five-Year” under the same efficiency effect. Although the decomposition value of the total effect and structure effect of the “12th Five-Year” are negative, there is still some year being positive, which indicates that the inhibition effect of structure effect on the total energy consumption of Hunan province is not strong enough, and it needs to continue to enhance its inhibitory effect with the development of economy and society.

Looking at the past years of 2006-2015, the decomposition of the total effect is closely related to the development of Hunan Province. During “11th Five-Year” period, the GDP of Hunan Province grows rapidly with an annual average growth rate 14%, and the industry structure adjustment has been carried out steadily. The new industrialization and industry upgrading have been promoted. The proportion of the secondary industry has increased by 6.4%, and the energy intensity has been decreasing year by year. During “12th Five-Year” period, Hunan Province accelerates the change of economic development mode in response to national policy, taking the new industry and the tertiary industry as the leading industry to promote industry development, further optimization and upgrading. The technological innovation is constantly enhanced and the total energy consumption is also increasing, but the growth rate is slow.

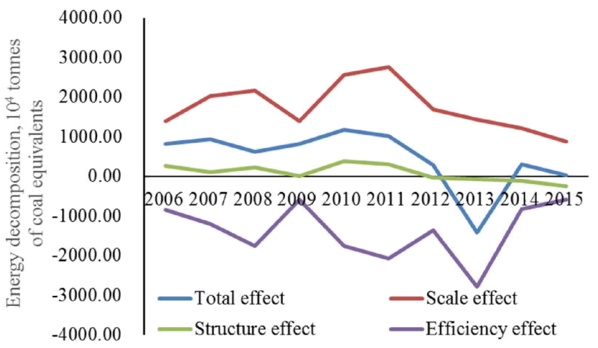

Figure 5. Decomposition results of energy consumption total effect

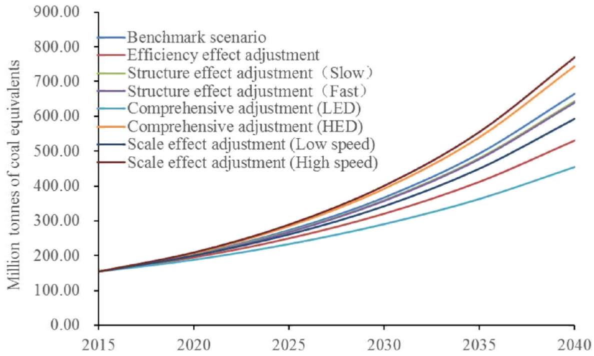

Figure 6. Comparison of total energy consumption in different scenarios

Table 7. Total energy consumption in various scenarios (million tons of coal equivalents)

Years	2015	2020	2025	2030	2035	2040
Benchmark scenario	154.54	204.13	273.49	367.02	493.40	664.46
Scale effect adjustment (Low speed)	154.54	199.96	261.30	342.35	449.78	592.64
Scale effect adjustment (High speed)	154.54	209.46	289.65	400.90	555.38	770.10
Structure effect adjustment (Slow)	154.54	202.34	269.14	359.18	479.86	642.79
Structure effect adjustment (Fast)	154.54	201.08	267.56	357.20	477.02	638.79
Efficiency effect adjustment	154.54	195.15	249.94	320.59	411.83	529.86
Comprehensive adjustment (Low)	154.54	188.35	233.74	291.26	363.43	455.11
Comprehensive adjustment (High)	154.54	207.62	284.99	392.17	539.73	744.08

3.2 Results analysis of LEAP-Hunan model

Figure 6 integrates the trends of energy consumption of various scenarios in a map to facilitate a clearer picture of the impacts of various effects. From the figure it can be seen that only the high scale effect and high demand of comprehensive adjustment scenario of the total energy demand exceed the benchmark scenario, which denotes that the scale effect will continue to play an important role in promoting the growth of energy consumption.

Table 7 shows the total energy consumption of various scenarios, and these data can be used to analyze the impacts of various effects thoroughly.

3.2.1 Scale effect analysis

Figure 7(a) shows the energy consumption changes from 2016 to 2040 of Hunan Province under the benchmark scenario and the two scale effect scenarios. From the figure it can be seen that with the fast GDP growth rate(10%) and high scale scenario energy consumption growth rate, the total energy consumption is far greater than the other two scenarios, and the numbers of total energy consumption in 2020, 2030 and 2040 of Hunan Province are 209.5, 400.9 and 770.1 million tons of equivalent coal respectively. Under the case of low GDP growth rate (8.5%) and low scale effect scenario of energy consumption growth rate, the total energy consumption is less than the other two scenarios, and the numbers of 2020, 2030 and 2040 in Hunan Province are 200, 342.4 and 592.6 million tons of equivalent coal respectively. While for the benchmark scenario, the total energy consumption in 2020, 2030 and 2040 are 204.1, 367 and 664.5 million tons of equivalent coal respectively. Thus, the size of the scale effect can greatly affect the amount of energy consumption in Hunan Province, which is highly consistent with the decomposition results of the LMDI decomposition method.

3.2.2 Structure effect analysis

During the "12th Five-Year" period, the industry structure of Hunan province has been continuously optimized and upgraded, and the proportion of new industries and tertiary industry has increased year by year. Figure 7(b) shows the changes in energy consumption during the 2016-2040 years under the benchmark scenario and two structure effect scenarios. From the figure it can be seen that no matter whether the proportion of the tertiary industry grows faster or grows slower, the total energy consumption caused by the two kinds of structure effect adjustment are always lower than benchmark scenario. This phenomenon shows that with the change of industry structure, the inhibition effect of structure effect on total energy consumption growth is stronger and stronger, which is consistent with the future social and economic development, as well as energy consumption trends. These results are consistent with LMDI decomposition method. A reasonable extrapolation is given which indicates that for Hunan Province and it is necessary to reduce the energy consumption by optimizing and upgrading the industry structure.

3.2.3 Efficiency effect analysis

Figure 7(c) shows the changes of energy consumption in 2016-2040 years under the benchmark scenario and the efficiency effect scenario. As what is shown in the figure, under the situation of the energy consumption intensity drops rapidly, the total energy consumption growth rate and total energy consumption are much lower than the benchmark scenario. Under the benchmark scenario, the total energy consumption in 2020, 2040 and 2030 are 201.1, 367 and 664.5 million tons of equivalent coal, while for the efficiency effect scenario, the total energy consumption are 195.2, 320.6 and 529.9 million tons of equivalent coal, which are 97%, 87.3% and 79.7% of benchmark scenario. Thus, with the improvement of technology and energy utilization efficiency, energy consumption intensity has been reducing year by year, and the efficiency effect has been playing an increasingly important role in inhibiting the growth of energy consumption in Hunan Province. This result also conforms to the efficiency effect decomposition result of LMDI decomposition method.

3.2.4 Comprehensive adjustment analysis

Figure 7(d) shows the changes of energy consumption in 2016-2040 years under the benchmark scenario and two comprehensive adjustment scenarios. In low demand scenario, the total energy consumption in 2020, 2030 and 2040 are 188.4, 291.3 and 455.1 respectively; in high demand scenario, the values are 207.6, 392.2 and 744.1 million tons of equivalent coal respectively. It can be seen that the growth of GDP is low and the increasing speed of tertiary industry is high. When the energy consumption intensity quickly falls down, Hunan province has the least total energy consumption and the slowest growth rate. These results point a clear direction out for the energy consumption, which is seeking and maintaining appropriate GDP growth rate, as well as accelerating the industry structure transformation step, gradually forming a trend dominated by the tertiary industry, and constantly improving the technology and utilization efficiency of energy so that the total energy consumption in Hunan Province can be reduced as much as possible.

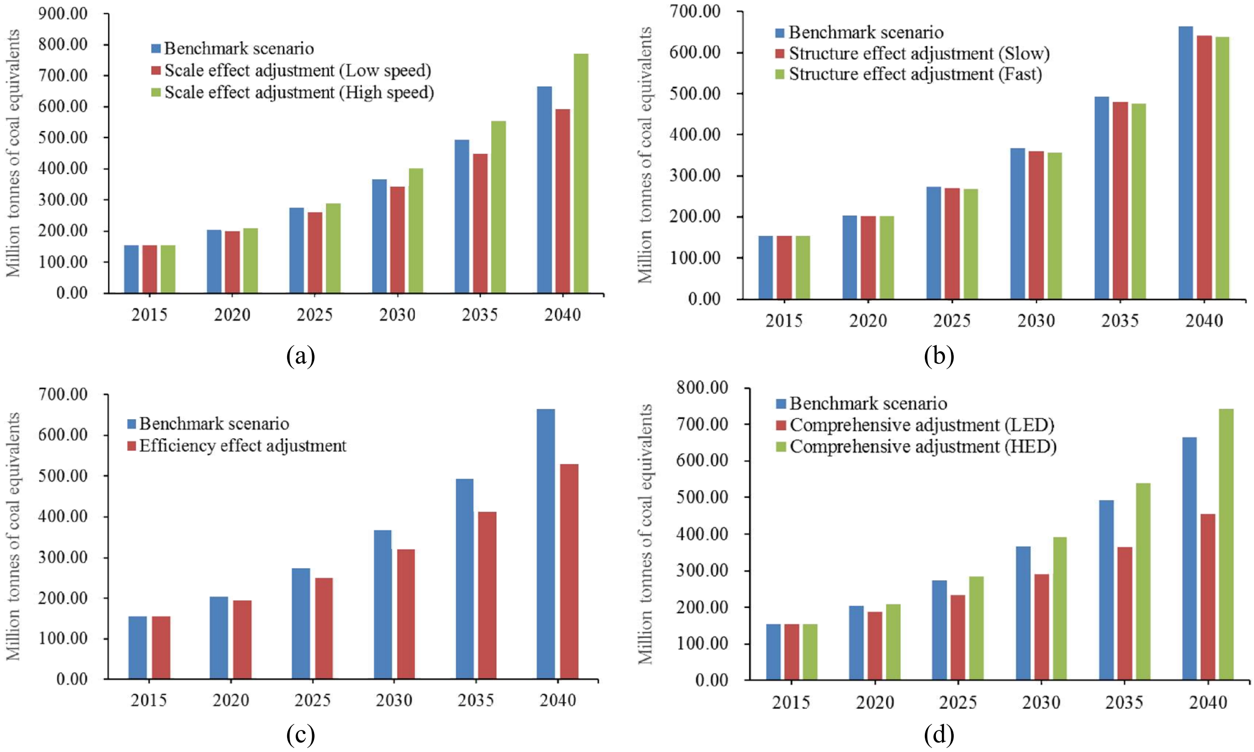

Figure 7. Comparison of total energy consumption between benchmark scenario and other scenarios

4. Conclusions

1) LMDI results show that the efficiency effect has effectively restrained the growth of energy consumption, and the inhibitory effect is strong. The scale effect has played a continuous role in promoting the growth of energy consumption. The impact of the structure effect on the growth of energy consumption gradually changes from promotion to inhibition. Overall, the scale effect's role in promoting the growth of energy consumption is becoming weak gradually, and the adverse function of the structure effect and efficiency effect on the growth of energy consumption is increasing.

2) The results of LEAP-Hunan model are highly consistent with decomposition values of LMDI method, and the decomposition result of LMDI structure effect is reasonably extrapolated by LEAP-Hunan model. The structure effect and efficiency effect will jointly undertake inhibition effect on total energy consumption growth, and inhibition impact of structure effect will increase year by year.

3) During the period of 2016 to 2040, there are only the high scale effect and high demand comprehensive adjustment scenarios in which the energy demands exceed the benchmark scenario. Energy consumption forecasts for all other scenarios are lower than benchmark scenario. Among all these scenarios, the high speed scale adjustment scenario has the maximum energy demand, which indicates that GDP growth rate will be the most critical factor in determining the total energy consumption in the future.

Acknowledgements

This paper is supported by National Natural Science Foundation of China (61573381).

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