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Research Article

Decomposition analysis of Changes in Energy Consumption in Iran: Structural Decomposition Analysis

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Abstract
The aim of this study is decomposition of the changes in energy consumption with emphasizing the structural changes in Iran during 2001-2011 using Input- Output Structural Decomposition Analysis (I_O SDA). Structural changes in this study represent the changes in structure of intermediate input in sectors and also changes in structure of final demand categories. Structural changes in intermediate inputs decomposed into intermediate input substitution in sectors and changes in direct backward linkages. Structural changes in final demand represent the changes of the share of each sector in total final demand categories. The results showed that energy coefficients helped to reduce energy use and final demand changes and technological changes (structural changes in intermediate inputs) caused to increase of energy use. The final demand had the main contribution on increase of energy use (44186.26 BGJ). Among the final demand components, increase in level of investment and household's consumption was the main drivers of energy use increment.

Keywords: Energy Consumption, structural Change, Structural Decomposition Analysis, Iran

Introduction

Production of goods and services in economic sectors needs to consumption of any kind of energies. So, increasing the final demand of sectors and increasing the production of these sectors, will increase the consumption of energies in economy.

Analyzing energy consumption in the economy, especially in the Iranian economy, is important in two respects. The first aspect is that the energy sources used in Iran are fossil fuels and the amount of these fuels also decreases over time. In other words, these energies are not renewable. The second aspect of the importance of energy consumption analysis is the negative environmental impacts of the energy consumption. Unfortunately, the consumption of fossil fuels and consequently the diffusion of air pollutants in the Iranian economy is high. For example, in recent years, Iran has been ranked first in terms of carbon dioxide emissions in the Middle East. It also ranks among the world's top ten carbon dioxide emitters.

On the other hand, factors such as the low price of fossil fuels in Iran compared to other countries, low productivity in fossil fuel consumption in various sectors and the consequent high environmental pollution caused by the consumption of these fuels make doubling the importance of energy consumption analysis in Iran.

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There are two types of energy consumption in economic sectors: direct and indirect (Miller and Blair, 2009; Su and Ang, 2015). Direct energy consumption is the value of energy needs for production of goods and services in one sector. Indirectly energy consumption is the value of energy consumed by sectors through its supply chain, including backward and forward linkages of industries. In other words, indirect energy consumption of particular sector involves energy consumption in other economic sectors due to the production of goods in that sector. For example the backward linkages shows the amount of inputs receives from other sectors and used to produce its own products. If the backward linkages in one sector is high, while the demand for the products of this sector increases, the demand for products in other sectors will also increase, and finally the indirect energy consumption of this sector will increase. The accumulated direct and indirect energy in producing goods and services is called the 'embodied energy. Some sectors and industries may not have a high direct energy consumption, but their indirect use may be very high. This is due to the upstream and downstream linkages of this sector with the high energy-consuming industries. A sector having high indirect energy consumption could increase direct energy consumption in other related industries, resulting in an increase in the overall energy consumption (Supasa et al., 2017). Therefore, both direct and indirect energy consumption must be considered for energy conservation policies. Implementation of these policies requires identifying the factors affecting energy consumption changes.

Different methods have been proposed to determine the share of different factors in energy consumption changes in economic activities. Decomposition analysis is one of these methods. In this method, variable changes are divided into several factors, and the share of each of these factors is determined in these changes. There are two main decomposition methods: Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) (Wang et al. 2017). Structural Decomposition analysis is one of the methods that can determine the contribution of each factor to energy consumption changes. This method also is able to measure the effect of structural changes including changes in structure of intermediate inputs (changes in the inter-linkages between different sectors) and final demand at level of sector and whole economy (Ang et al. 2010, Su and Ang, 2012b, Wang et al., 2017a). Also, this method is able to estimate both direct and indirect energy consumption.

The aim of this study is to determine the drivers of change in energy consumption in Iran during the period of 2001–2011 using Structural Decomposition Analysis highlighting the relative contributions of structural changes.

Literature review

Input- output analysis has been widely used to analyze the energy consumption since 1960s (Miller and Blair, 2009). In recent years, the use of I-O SDA method has greatly increased for decomposition of energy use in different countries around the world.

There have been several studies in Iran that concentrate on decomposition of energy use changes. Most of them used the index decomposition approach (IDA). Studies that have used the SDA method to analyze energy consumption changes in Iran include Jahangard and Rashidizadeh (2011), Sharify and Banihashemi (2013),Sharify and Hosseinzadeh (2015) and Jahangard et al. (2017). Jahangard and Rashidizadeh (2011) studied the change in energy intensity and concluded that of the five factors, the energy consumption coefficient had the greatest effect on the energy intensity change. Sharify and Banihashemi (2013) have investigated the factors affecting energy consumption with an emphasis on the role of household's consumption in Iran using an input- output model in the period 2001-2011. The results of this study showed that the change in final demand was the most important factor in increasing energy consumption during the research period. Sharify and Hosseinzadeh (2015) have investigated the factors affecting energy consumption in Iran by using the Input-Output Structural Decomposition Method during 1986-2001. The results of this study showed that increasing the level of final demand was the most important factor in increasing energy consumption. Jahangard et al. (2017) investigated the energy consumption changes during 2001-2011 using SDA method. The results show that 73% increase in energy consumption was due to the effect of final demand and energy intensity effect of 14% contributed to this increase. Numerous studies have been conducted on energy consumption decomposition in other countries.

Kagawa and Inamura, (2001) assessed the effect of some aspects of technological changes, such as changes in non-energy input structure and non-energy product-mix, on energy consumption in Japan over the period of 1985-1990 based on rectangular input-output framework. Chai et al. (2009) examined the changes in energy consumption intensity in China based on the four input-output tables of 1992, 1997, 2002 and 2004 and found that technological change had the greatest impact on energy consumption changes. Alcantara et al. (2010) used SDA to decomposing the changes in electricity use in Spain. Results of this study showed that the final demand is the main factor affecting the electricity consumption increase. Reddy and Ray (2010) decomposed the energy consumption and energy intensity in Indian manufacturing industries using the SDA method. The results of this study showed that the final demand was the main factor to increasing the energy consumption. Henriques (2011) used the SDA method in Portugal during 1971–2006 and found that structural changes from industry to services contributed to a decline of direct energy intensity. Sheinbaum-Pardo et al. (2012) used the SDA method to explain the changes in energy of the manufacturing industries in Mexico. Xie (2014) proposed a method to evaluate the role of population as another component of energy consumption along with the role of technological change in China. Lan et al. (2016) used Regional Input–Output to decompose energy use changes in 186 countries around the world during 1990 to 2010.

Guevara and Rodrigues (2016) used SDA method to analyze the changes in primary energy consumption in Portugal. Llop (2017) proposed a model for analyzing the changes in the energy sector production in the Catalonia region of Spain during the period of 2001-2011 in two broad categories of technological change in production and final demand changes. In the next step, the technological changes (technical coefficient matrix) were assessed based on three viewpoints: row changes, column changes, and general changes in the multipliers matrix. Su and Ang (2017) used a structural multiplicative decomposition analysis for analyzing the intensity of renewable energy in China. Collado and Colinet (2018) used two decomposition methods including: SDA and Logarithmic Mean Divisia Index (LMDI) to decomposition of energy consumption changes for Spanish economy during. Zhao et al. (2018) decomposed the changes of the energy consumption in 30 provinces of china for the period of 1997–2011.

This study is different from the previous studies in terms of two aspects. Firstly, technological structure changes are decomposed into two different categories, including: changes in input substitution and changes in inter-sectoral linkages. Secondly, the final demand is decomposed into eight factors.

Methodology and Data

Methodology

As mentioned in the previous sections, in this study, structural decomposition in the input-output model is used to investigate changes in energy consumption over the period 2001-2011. In the input-output tables, there are imports of goods and services in the intermediate inputs as well as the final demand. It is therefore necessary to separate the imported items from these two parts and to obtain the matrix of domestic intermediate transactions as well as the domestic final demand. Because it does not consume energy to produce imported goods and services inside the country. These two tables are changed to domestic I-O tables by removing the final and intermediate imports using the presented method in Miller and Blair (2009).

The Equation of total output in domestic input- output tables is as follows:

$$X = (I - A^{d})^{-1}.Y = C^{d}.Y \quad (1)$$

Where, X denotes the sectoral outputs vector, A^d is to the domestic technical coefficient matrix, C^d is the domestic Leontief inverse matrix and Y is final demand vector. The energy consumption can be shown as:

$$E = e^{\wedge}.X = e^{\wedge}.C^{d}.Y \quad (2)$$

E indicates the energy use vector and e^ is diagonal matrix of direct energy use coefficients. Based on Eq. (2), the total changes in E (energy use) using the decomposition method proposed by Dietzenbacher and Los (1998) can be divided into three factors:

$$\Delta E = \Delta\hat{e}.(\frac{X_0 + X_1}{2}) + (\frac{\hat{e}_0 + \hat{e}_1}{2}).\Delta C.(\frac{Y_0 + Y_1}{2}) + (\frac{\hat{e}_0 + \hat{e}_1}{2}).(\frac{C_0 + C_1}{2})\Delta Y = \Delta\hat{e}.\overline{X} + \bar{\hat{e}}.\Delta C.\overline{Y} + \bar{\hat{e}}.\overline{C}.\Delta Y \quad (3)$$

The bar sign on the variables shows the averages of these variables between two years of study. The first term in right hand side of Eq. (3) indicates the effect of changing the direct energy use coefficients. The second one shows the effect of the changes in structure of intermediate inputs and the last term shows the effect of changes in final demand.

In next step, the structural changes in intermediate inputs can be decomposed into two factors. According to Miller and Blair (2009):

$$\Delta C = C_0 \Delta A C_1 \quad (4)$$

In next step, technical coefficient matrix (A matrix) can be broken down into two sub-matrices, including: the structure of intermediate demand (S) and total intermediate demand (T). Structure of intermediate demand (S matrix) represents the share of each sector in the total intermediate input demands (vertical summation in A matrix) in specific sector. s_{ij} in this matrix is equal to $a_{ij} \big/ \sum_i^n a_{ij}$. T refers to a diagonal matrix, in which its diagonal elements are equal to $\sum_i^n a_{ij}$. The total intermediate demand represents the total domestic intermediate input coefficients that are used by sectors or direct backward linkage of sectors.

Therefore, the changes in the technical coefficient matrix can be decomposed as follows:

$$A = S.T \qquad \Rightarrow \Delta A = \Delta S.\overline{T} + \overline{S}.\Delta T \quad (5)$$

Substituting Eq. (5) in Eq. (4) yields:

$$\Delta C = C_0.\Delta S.\overline{T}.C_1 + C_0.\overline{S}.\Delta T.C_1 \quad (6)$$

Substituting the Eq. (6) in (3) yields:

$$\Delta E = \Delta\hat{e}.\overline{X} + \bar{\hat{e}}.C_0.\Delta S.\overline{T}.C_1.\overline{Y} + \bar{\hat{e}}.C_0.\overline{S}.\Delta T.C_1.\overline{Y} + \bar{\hat{e}}.\overline{C}.\Delta Y \quad (7)$$

As mentioned above, Y is the final demand of various sectors in the economy. This matrix consists of four sections, including household final consumption and investment, Government consumption and exports.

$$Y = Y_C + Y_I + Y_G + Y_X \quad (8)$$

On the other hand, each of final demand components (for example Y_X) can be divided into two sub-matrices including M and Z. The M matrix (with n×1 dimensions) represents the share of each sector in total final demand components (for example the share of each sector in total export). The Scalar Z matrix (1×1) is the sum of the final demand components in the economy and the sum of the final demand components in all sectors (total export). Thus the final demand components (for example Export) matrix and its variations can be rewritten as (8).

$$Y_X = M_{YX}.Z_{YX} \Rightarrow \Delta Y_X = \Delta M_{YX}.\bar{Z}_{YX} + \bar{M}_{YX}.\Delta Z_{YX} \tag{9}$$

By writing Eq. (9) for all components of the final demand and substituting in Eq. (7), we obtain the following equation.

$$\begin{aligned}\Delta E = {} & \Delta\hat{e}.\bar{X} + \bar{\hat{e}}.C_0.\Delta S.\bar{T}.C_1.\bar{Y} + \bar{\hat{e}}.C_0.\bar{S}.\Delta T.C_1.\bar{Y} + \bar{\hat{e}}.\bar{C}.\Delta M_{YC}.\bar{Z}_{YC} + \bar{\hat{e}}.\bar{C}.\bar{M}_{YC}.\Delta Z_{YC} + \bar{\hat{e}}.\bar{C}.\Delta M_{YI}.\bar{Z}_{YI} \\ & + \bar{\hat{e}}.\bar{C}.\bar{M}_{YI}.\Delta Z_{YI} + \bar{\hat{e}}.\bar{C}.\Delta M_{YG}.\bar{Z}_{YG} + \bar{\hat{e}}.\bar{C}.\bar{M}_{YG}.\Delta Z_{YG} + \bar{\hat{e}}.\bar{C}.\Delta M_{YX}.\bar{Z}_{YX} + \bar{\hat{e}}.\bar{C}.\bar{M}_{YX}.\Delta Z_{YX}\end{aligned} \tag{10}$$

Based on Eq. (10), the total energy consumption change is broken down into 11 factors. These factors include direct energy consumption coefficients, substitution of intermediate inputs, change of backward linkages, and change in structure and level of four components of the final demand.

Data

The main data which is required for this study is the latest two national input- output tables for Iran in 2001 and 2011 that is published by the national statistics center of Iran. Due to the fact that there are imports of goods and services in the transaction matrix and final demand of these tables, it is necessary to remove them from the table. Therefore, these two tables are changed to domestic I-O tables by removing the final and intermediate imports using the presented method in Miller and Blair (2009). In this method, interindustry transactions divided into domestic transactions and imports. In next step, matrix of intermediate output proportions is created and assumed that for each industry the fraction (Mi/Xi) is given by m_i. In final step, this fraction is used to estimate of the domestic transactions matrix.

Other data including the sectoral direct energy consumption in monetary units is provided from Use matrix (Absorption Matrix) in I-O tables. These data is transformed to physical units by dividing these data to price of different types of energies including coal, natural gas, gasoline, white oil, gasoil, black oil, and liquid gas. The energy data in monetary unit is obtained from Use Table (Absorption table) in input- output table of statistical center of Iran. This table shows the use of each fuels in each sector in monetary unit. This monetary unit is based on the market price of fossil fuels (contain subsidy) in country. Also the price of each fuels in the market is contain the subsidy. Therefore dividing these two amount of energy yields the energy use in physical unit.

We calculate the each energy used by each sector in thermal unit. Then calculate the total energy consumption in each sector by summation of each energy type in thermal unit. We did this for both years of study (2001 and 2011). Therefore, for each year of study, a specific amount of energy use was obtained for the whole economy. Changes in this amount of energy consumption have decomposed in the economy.

The consumption of all type of energies is converted to the thermal unit (Giga joule: GJ) and aggregated together to construction of energy input-output tables. In final step, in order to eliminate the effects of price changes, I-O table in 2011 is deflated to constant prices in 2001. The sectoral output in current and constant prices that are used to calculate the sectoral price indices is obtained from Central bank of Islamic Republic of Iran.

The Input-output tables were initially prepared based on the number of sectors for which the price index could be obtained (in 54 sectors). Next, to simplify the calculation, these tables is aggregated into 11 sectors.

Analysis of the results

Table 1 shows the effect of factors on energy consumption changes. According to this table, total changes in energy use during study period was 43740.67 Billion Giga Joules (BGJ).

Table 1. Structural decomposition of energy consumption (Billion Giga Joule: BGJ)

Main Factors	Sub- Factors		Value	Share (%)
Energy coefficient	Energy coefficient	Energy coefficient	-1083.41	-2.48
Structural changes in intermediate input	Structural changes in intermediate input	Input substitution effect	1720.52	3.93
		Backward linkage effect	-1082.70	-2.48
Structural changes in final demand	Households (Y_C)	Structure effect	2849.35	6.51
		Level effect	11979.3	27.39
	Investment (Y_I)	Structure effect	-2582.44	-5.90
		Level effect	16789.28	38.38
	Government (Y_G)	Structure effect	276.80	0.63
		Level effect	1052.33	2.41
	Export (Y_X)	Structure effect	7698.44	17.60
		Level effect	6123.2	14.00
Total changes			43740.67	100

Among the three main factors affecting energy consumption including energy coefficients, structural changes in intermediate inputs and final demand, the effect of energy coefficient was negative and caused to reduction of energy use (-1083.41 BGJ). The final demand had the main contribution on increase of energy use (44186.26 BGJ).

The negative effect of the direct energy coefficient on energy use is due to reduction of energy intensity in all economic sectors during study period except the “Agriculture, Forestry and Fishing”, "Clothing and Textile” and Also “Leather Industries”. In other words, the energy intensity of sectors has decreased during study period. The positive effect of final demand on energy use is due to sharp increase of final demand in all sectors.

Based on the energy SDA results, among the 11 sub-factors, eight sub-factors have led to an increase in energy consumption and three sub-factors led to a reduction. As it shown in Fig (1) change in investment level, households’ consumption level and export structure are the main drivers of the energy consumption increases. These three factor caused to increase of 16789.28 BGJ (38.38% of total), 11979.3 BGJ (27.39%) and 7698.44 BGJ (17.6%) in energy use.

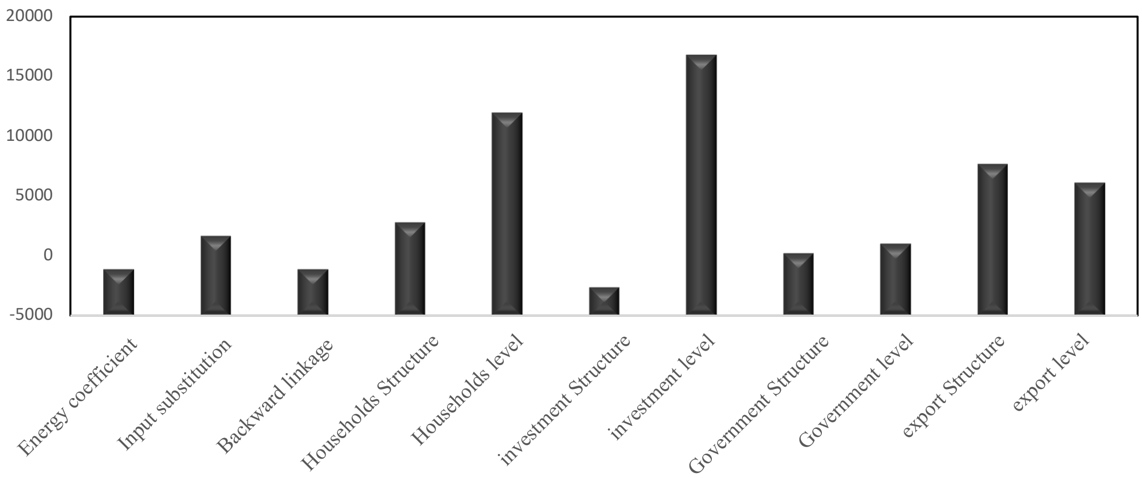

Figure 1. Effect of factors on energy use changes (BGJ)

Given the level of investment (in input-output tables in 2001 and 2011), the amount of investment between two years has greatly increased. So that this amount increased from 193058.86 Billion Rials in 2001 to 616199.38 Billion Rials in 2011 (increase of 219.18%). This sharp increase in investment level has led to a sharp increase in energy consumption. Level of household consumption also increased sharply during the study period (64.87% increase). This has made household consumption levels one of the major drivers of rising energy consumption.

Effect of input substitution on energy consumption is positive. This factor caused to increase of 1720.52 BGJ. One of the reasons for the increase in energy consumption due to the intermediate input substitution in the economy is the increase in the share of highly energy-dependent sectors. For example, the direct coefficients of "chemicals industry" and "rubber and plastics industries" have increased in most economic sectors. These two sectors have high energy intensity in the Iranian economy. Effect of changes in direct backward linkage was negative and contributed to reduction of energy use (-1082.70 BGJ). One of the reason for the decrease in energy consumption due to factor is the reduction of the direct backward linkage coefficients of sectors and the increase of the import of intermediate inputs from abroad during study period. This means that intermediate inputs produced in abroad have replaced the ones produced domestically and the various economic sectors have become more dependent on foreign intermediate inputs. This has reduced energy consumption in various sectors and in all economy as a result of this factor.

The decomposition of energy consumption in sector level is shown in Table 2. According to this table, the effect of changes in energy coefficients in four sectors among the 9 sectors, was negative and reduced energy consumption. Among these four sectors the "Chemical Products "sector have experienced a sharp decline in energy consumption due to changing energy coefficients. This is due to the sharp decline in energy intensity in this sector in 2011 compared to 2001.

The effect of changing intermediate inputs in all sectors was negative and reduced energy consumption except "Chemical Products" and "Other services". The most negative effect of this factor was in the "Water, Electricity and Gas" sector and has reduced energy consumption by 2286.25 BGJ. One of the reasons for this, could be the increase in the prices of the products in this sector and the reduction of the consumption of these energies in other economic sectors.

Table 2: decomposition of energy consumption in sector level

Sectors	Energy coefficient effect	Intermediate input effect	Household effect	Investment effect	Gov. effect	Export effect
Agriculture	83.26	-21.85	72.17	1.90	76.07	14.81
Chemical products	-2797.53	3543.91	6782.80	249.06	48.66	11763.41
Non-metallic products	752.78	-156.41	235.77	10.37	767.50	229.95
metal and machinery	-945.25	-352.60	548.18	24.32	3450.91	392.57
Other industry	45.54	-32.75	20.45	0.10	19.84	6.75
Water, gas, electricity	1172.81	-2286.25	5863.72	311.73	6791.12	1179.47
Wholesale and retail	-545.15	-28.00	363.46	6.84	568.42	23.65
Transport	1284.98	-91.05	551.35	-62.31	851.02	111.83
Other Services	-134.84	62.80	390.76	787.11	1633.31	99.20
Total	83.26	-21.85	14828.65	1329.12	4206.84	13821.65

As the table data shows, changes in all four components of the final demand has led to an increase in energy consumption throughout the economy. Of these four components, household consumption have the highest impact (14828.65 BGJ) on energy consumption in the economy.

Increasing household consumption during the study period has led to an increase in energy consumption in all economic sectors. Among these sectors, the two sectors including “Chemical products” and “Water, electricity and Gas” have had the highest energy consumption, respectively, as a result of the increase in household consumption.

The increase in investment during the study period, has played a small role in increasing energy consumption (1329.12 BGJ). “Chemical products” and “Other services” had the highest increase in energy consumption due to increased investment. It has also reduced energy consumption in the transport and communications sector (-62.31 BGJ). Increasing government spending during has led to an increase in energy consumption in all economic sectors. The two sectors of “Metal products and machinery” and “Other services” have been most affected by the increase in government spending. Finally, the change in exports has also increased energy consumption in all sectors of the economy. The two sectors of “Chemical products” and “Water, electricity and Gas” have had the highest increase in energy consumption as a result of increased exports.

Conclusions and Recommendations

This paper investigates the effect of structural changes on energy consumption in Iran during the period 2001-2011, using input- output Structural Decomposition Analysis. For this purpose, at first, total changes of energy consumption is decomposed into three main factors including direct energy coefficients, technological changes and final demand. In next step, the technological changes is decomposed into two factors including input substitution and backward linkages. Final demand components is also decomposed into two factors including structure and level. The results of this study showed the final demand had the main contribution on increase of energy use. Among the final demand component, the level of investment and level of household’s consumption had the highest share in energy use increment. Therefore, it is necessary to identify the sectors with the highest share in final demand and in its components and to plan for reducing the energy intensity in those sectors. The other results showed that input substitution caused to increase in energy use. This means that high-energy-intensive inputs (products) have been substituted by low-energy intensive inputs in the sectors during study period. Therefore, it is recommended to identify those sectors that have strong linkages with other sectors and then plan to reduce the energy intensity of those sectors.

Investigating the effect of final demand components on energy consumption at sectoral level has shown that all four components of final demand have increased energy consumption. Of these four components, household consumption has played a major role in increasing energy consumption. Therefore, it is recommended that appropriate policies be implemented by both the government and the households to prevent the unnecessary consumption of goods and services in order to reduce the amount of indirect consumption of energy by the households. On the other hand, the increase in final demand components in the economy has led to a sharp increase in energy consumption in the “Chemical products”, “Metal products and machinery” as well as “Water, electricity and Gas”. Therefore, it is recommended to adopt appropriate policies to increase energy efficiency in these sectors.

This paper suggest a more detailed decomposition to provide more and better information on the factors affecting energy consumption changes. Therefore, the results of this study in Iran, as well as, the use of the proposed method in other countries can help to better planning for optimal energy consumption.

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