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Sources of Change in Energy Consumption in Iran: A Structural Decomposition Analysis

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Abstract

Energy consumption has increased significantly in Iran during the recent decades. In this study, an inter-industrial model has been improved to investigate the sources of the changes in the energy consumption of the country. The input-output tables of Iran for the years 1988 and 2001 have been employed as the database of the model. The innovation of this research allows the researchers to study the sources of changes in energy consumption more specifically. It concerns decomposing the effect of changes in economic structure into input substitution, and backward linkage effects. The results show that the level of final demand, input substitution, and backward linkage effects lead to an increase in energy consumption in the country. In contrast, the energy intensity of products, the structural composition of the final demand, and the categorical composition of the final demand have reducing effects on energy consumption.

Keywords: Changes in energy consumption, Inter-industry analysis, Structural decomposition analysis.
JEL Classification*:* C67, Q41, Q43

1. Introduction

Energy consumption has increased in Iran during the previous decades. According to the energy balance sheet of the country, total energy consumption was 325.3 million Barrels of Oil Equivalent (BOE) in 1988, while it shifted to 687 million BOE in 2001. Hence, the total energy consumption has increased, with an annual growth rate of 5.9%, during this period. This consumption with a 5% increment, reached 1229.7 million BOE in 2013 (Energy Balance Sheet of Iran, 2006 and 2013).

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Petroleum products and natural gas are the two major kinds of energy in the country. Petroleum products that comprised 80.5% of the energy consumption in 1988 grew 3.2% annually during the years 1988-2001. In contrast, the volume of the natural gas that comprised 11.5% of the energy consumption in 1988 has grown 15.3% annually during these years. As a result of these growth rates, the share of petroleum products in 2001 reduced to 57.3% of energy consumption, whereas the share of natural gas reached 33.6% of energy consumption in this year. In addition, the consumptions of petroleum products and natural gas have increased with an average annual growth rate of 0.8% and 9.20% during 2001-2013, respectively. So, the share of petroleum products and natural gas reached 35.3% and 53.8% of energy consumption in 2013, respectively (Energy Balance sheet of Iran, 2006 and 2013).

There are a number of reasons for the changes in the energy consumption patterns. Using more energy-efficient technology and structural shifts in the economy can be considered two reasons for this phenomenon. The other possible sources are the level of aggregate final demand and the structural changes involving an increase in the relative weight of the final demand of energy-intensive products. Thus, it seems that introducing the contribution of these factors in an economy would be precious to economic policies (Wood et al., 2009).

This paper employs an input-output Structural Decomposition Analysis (SDA) approach to identify key factors that affected the energy consumption changes in Iran during 1988-2001. The innovation of this study regards decomposing changes in the intermediate consumption effect into input substitution and backward linkage effects. The first factor relies on the input substitution effect, whereas the second factor is related to changes in backward linkage of products. Thus, the results of this method allow the researchers to study the sources of the changes in energy consumption more specifically. Hence, the changes in energy consumption of the economy are attributed to six sources containing energy intensity, input substitution, backward linkage, structural composition of final demand, categorical composition of final demand, and level of aggregate final demand effects.

The paper contains five sections. Section 2 provides a brief review of literature. Section 3 introduces the methodology and data sources of the research. The results of implementation of the model in Iran are presented and discussed in section 4. Finally, the concluding section ends the paper.

2. Literature Review

Many studies have attempted to identify the effects of different factors in

changes in energy consumption through inter-industrial SDA. For instance, this method was used by Rose and Chen (1991) to determine the relative prominence of various sources of change in energy consumption in economic sectors of the U.S. economy in 1972-1982. It was employed by the Chen and Wu's (1994) study in order to analyze the sources of change in the electricity demands of the industrial sectors of Taiwan during 1976-1986. It was also implemented by Chakraborty (2007) to estimate the changes in energy consumption in India during 1994-1999.

The sources of changes in energy consumption and GHG emission during the period 1993-94 to 2003-4 in India were identified using this method by Mukhopadhyay and Chakraborty (2008). And finally, Wood et al. (2009) examined the sources of changes in energy use in the industries and households of Brazil during 1970 to 1996. Zhang and Lahr (2014) investigated the regional disparities in energy consumption in China from 1987 to 2007 using a structural decomposition approach. The results of this study show that China produced more energy-intensive goods for export. Other results of this study show that improving the energy efficiency of energy-intensive sectors leads to significant decline in energy consumption and energy intensity.

The main differences among the SDA methods as reviewed in some studies. For example, Su and Ang (2012) consider the sources which the changes of energy are attributed to. In the simplest form of structural decomposition, as implemented in Lin and Polenske (1995), Kagawa and Inamura (2001), Hoekstra and van den Bergh (2003), Alcántara and Duarte (2004), Cellura et al. (2012), and Su and Ang (2012), the energy changes are attributed to the energy intensity effect, the Leontief structure effect, and the final demand effect.

By decomposing the final demand effect, changes in energy consumption are decomposed to one or more subdivisions. For instance, the changes in energy consumption in Mukhopadhyay and Chakraborty (1999) and Weber (2009) were attributed to four sources, namely energy intensity, production structure, and final consumption, where the latter was itself decomposed into structure and the size of final demand components.

In subsequent studies, by considering the changes in final demand patterns, the relative weight of the various final users of the economy and the size of the final demand, adding to the previous decomposition, the changes in energy consumption were then attributed to five sources in Nooij et al. (2003) and Xia et al. (2012). Furthermore, Liu et al. (2010) used the SDA method to identify five key factors causing the changes of energy embodied in exports, including changes in the energy consumption attributed to direct

the primary energy efficiency, primary energy consumption structure, structure of intermediate inputs, structure of exports, and scale of exports.

There have been several works in Iran that decomposed the effects of different factors in changes of energy consumption. Mohammadi (2009) decomposed the total energy and also electricity consumption in Iran during 1979-2007. Goudarzy-Rad (2010) decomposed the changes in energy consumption in industry subsectors of Iran through Index Decomposition Analysis (IDA) during 2001-2005. Goli and Ashrafi (2010) have also decomposed the energy intensity in Iran using Ideal Fisher Index during 1981-2006. Babanejad (2010) investigated the changes in energy consumption in the agriculture sector using the input-output table in 2001. Allahyari-Sani (2012) have also used the SDA to decompose the energy consumption in Iran during 1991-2001, and also in Indonesia and Norway during 1995-2005.

In this study, the changes in energy consumption have been decomposed to four factors, namely: production structure effect, consumption structure effect, energy intensity effect, and level of consumption effect.

3. Material and Methods

The supply and consumption table for the year 1988, prepared by the Central Bank of the Islamic Republic of Iran (CBI), was employed as database of the research (Central Bank of Islamic Republic of Iran, 1995). Supply and consumption for the year 2001, prepared by the Statistics Center of Iran was also employed as the other database for the research (Statistics Center of Iran, 2006). These tables were used to prepare two symmetric commodities by commodity input-output tables for the related years.

The second group of data is about energy and price indices of products. The prices of different kinds of energy were obtained from the related center (Power Ministry, 2001). Other data including price indices of products, which were used to calculate fixed price tables, were taken from the CBI site.

Input–output SDA is commonly used to examine the effect of different sources in energy consumption changes over time (Chakraborty, 2007 and Miller and Blair, 2009). This method mainly relies on I-O total output model written as:

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

where *X* denotes the amount of total outputs, *A* refers to the technical coefficient matrix, *C* is the Leontief inverse matrix, and *Y* stands for final goods and services.

To examine the energy consumption in the production process, the energy intensity of products is considered. To this end, the amount of energy that is required for one unit of products is shown by *B*. *B* expresses, in terms of British Thermal Units (BTUs), the energy used to produce one unit of products or energy intensity of each product. Thus, *B* is a row vector in which its element b_j is calculated by dividing the total energy consumption of a specific product to total output of products.

The total energy that is used for producing goods and services during a period can be expressed as:

$$E = B.C.Y \tag{2}$$

E refers to the total energy used for different products.

Based on the contribution of this paper, *C* is decomposed into *M* and *Z*. *M* represents the share of each product in producing specific goods or service in which m_{ij} the element of this matrix is equal to $C_{ij} \Big/ \sum_i^n C_{ij}$. Z refers to a diagonal matrix, in which its diagonal elements are equal to $\sum_i^n C_{ij}$, the backward linkage of products.

In a similar procedure, *Y*, the column vector of final demand, can be decomposed into *S*, *T* and *F*. *S* is an $n \times m$ matrix that represents the share of products in a specific kind of final demand in which $[\, s_{ij} \,] = [\, Y_{ij} \,] \Big/ [\, \sum_i^n Y_{ij} \,]$. *T* is an $m \times 1$ matrix that shows the share of each kind of final demand in aggregate final demand. Hence, the elements of this matrix are $[\, t_r \,] = [\, \sum_i^n Y_{ir} \,] \Big/ [\, Y \,]$, where *i* refers to the product index and *r* refers to the kind of final user that is ($r = 1, 2, \cdots, m$). Finally *F* is a scalar of aggregate final demand.

Thus, based on the above definition, total energy use can be decomposed as Equation (3):

$$E = B.M.Z.S.T.F \tag{3}$$

Hence, changes in energy consumption during two periods of time can also be decomposed as follows:

Term (4.1) reflects the energy consumption changes due to the variation in the energy intensity. Term (4.2) refers to the changes in the energy consumption as a result of changes in the share of each product in producing a specific commodity or service as the input substitution effect. Changes in energy consumption due to variation in backward linkage have been shown in (4.3). The structural composition of final demand components is measured by term (4.4). The share of different kinds of final demand is examined

through (4.5). The effect of change in the size of aggregate final demand is shown in term (4.6). And finally, term (4.7) refers to the Total Joint Effects (*TJE*) when two or more of the above factors change simultaneously in period *t* compared with period *t-1*.

$$
\begin{aligned}
&\Delta E = E_t - E_{t-1} = B_t.M_t.Z_t.S_t.T_t.F_t - B_{t-1}.M_{t-1}.Z_{t-1}.S_{t-1}.T_{t-1}.F_{t-1} \\
&= \Delta B.M.Z.S.T.F \qquad (4.1) \\
&+ B.\Delta M.Z.S.T.F \qquad (4.2) \\
&+ B.M.\Delta Z.S.T.F \qquad (4.3) \\
&+ B.M.Z.\Delta S.T.F \qquad (4.4) \\
&+ B.M.Z.S.\Delta T.F \qquad (4.5) \\
&+ B.M.Z.S.T.\Delta F \qquad (4.6) \\
&+ TJE \qquad (4.7)
\end{aligned}
\tag{4}
$$

4. Results and Discussion

To reveal the effect of different factors on changes in energy consumption during 1988 to 2001, the proposed model was employed. According to the results, the level of energy consumption in Iran has increased from 2480.99 billion BTUs in 1988 to 2927.06 billion BTUs in 2001.

The increment in energy consumption originates from changes in some sources. As it is shown in Table 1 and Figure 1, the change in the level of aggregate final demand in the economy is the main source of increase in the energy consumption of the country.

Input substitution and backward linkage have had the two most positive

Table 1. Decomposition of the changes in energy consumption during 1988- 2001 period

Factors	Billion BTU unit	Share in total
Energy intensity effect	-110	-24.65
Input substitution effect	306	68.58
Backward Linkage effect	287	64.27
Structural composition of final demand effect	-559	-125.26
Categorical composition of final demand effect	-240	-53.80
Level of aggregate final demand effect	4178	936.57
Joint effect	-3416	-765.7
Total	446	100

Sources: Findings of the research

effects on changes in energy consumption, respectively. On the other hand, the results of the research indicate that the effects of input substitution and backward linkage, the components concerning the production structure of economy, led to an increment in energy use during 1988-2001 in Iran.

In contrast, although the total consumption of energy has been increased, some factors have had negative effects on the changes in energy consumption in the country. The structural composition of final demand has had the major contribution in decreasing energy consumption in Iran. This phenomenon indicates that the share of final demand for energy-intensive products such as transport and metal products in total final demand has decreased.

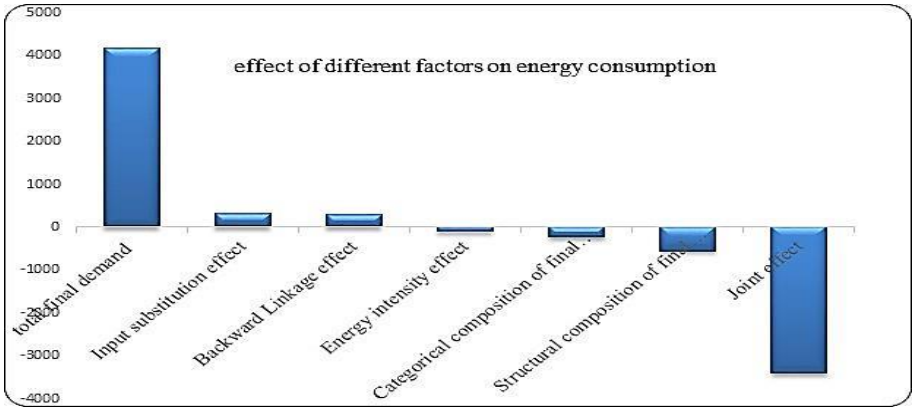

Fig. 1. The effect of different factors on changes of energy use in Iran during 1988- 2001

The categorical composition of final demand is the other factor that led to a negative effect on changes in energy consumption. It reveals that the changes in the share of final demand components in aggregate final demand have oriented to less energy consuming products. The energy intensity effect is another factor that has caused a decrease in energy consumption in the country. However, it had a lower contribution in reducing energy consumption. And finally, the effects of simultaneous changes in different factors led to a considerable decrease in the amount of energy consumption compared with the other sources.

In a more detailed investigation, Table 2 reveals the role of different products on changes in energy consumption through various sources. As a whole, social services and transport services have had the most significant effect on the increment in energy consumption in the country. In contrast, food products and other social and private services have had the greatest influence on the reducing energy consumption. Figure 2 and column B of

Table 2 show the effect of different products on changes in energy consumption through the energy-intensity effect.

Table 2. The effect of products on changes in energy use through various sources in Iran during 1989- 2001 (Unit: Billion BTU)

Products	B	M	Z	S	T	F	TJE	Total
1. Agricultural products	13	-6	14	-31	-10	69	-71	-24
2. Crude Oil & Natural Gas	-4	0	0	1	13	7	-15	2
3. Minerals products	10	11	2	-4	5	14	20	58
4. Food products	-78	-30	49	-99	-50	174	-66	-99
5.Textile and clothes	-26	4	-6	-27	-2	54	-28	-30
6. Wood products	-23	42	6	37	0	52	-110	4
7. Paper products	-8	-1	1	-2	-1	31	-18	2
8. Chemical products	80	-12	2	-16	-16	98	-36	100
9. Petroleum products	-15	-7	-2	-4	-3	80	-52	-3
10. Non-metal products	14	-69	78	-116	61	378	-344	3
11. Metal products	3	-3	2	-3	4	13	-12	4
12. Machinery	-3	-3	0	0	1	7	-5	-4
13. Electricity, Gas, Water	163	46	261	-558	-315	2156	-1742	11
14. Construction	-4	-2	5	-8	8	25	-23	1
15. Transport	-124	374	-113	119	58	597	-685	225
16. Communication	-4	-2	0	7	1	16	-5	14
17. Trade	0	9	0	10	0	0	1	21
18. Restaurants & Hotels	-47	-17	-3	-13	-3	89	-50	-44
19. Banking services	-1	3	0	-2	1	14	-8	6
20. Insurance services	-7	2	-1	3	1	14	-16	-4
21. Professional services	3	0	4	2	-6	16	-6	12
22. Social services	-15	0	3	181	-17	44	79	274
23. Public administration	-43	16	-13	-28	39	116	-114	-27
24. Other services	7	-48	-2	-7	-9	114	-110	-56
Total	-110	306	287	-559	-240	4178	-3416	446

Source: Findings of the research

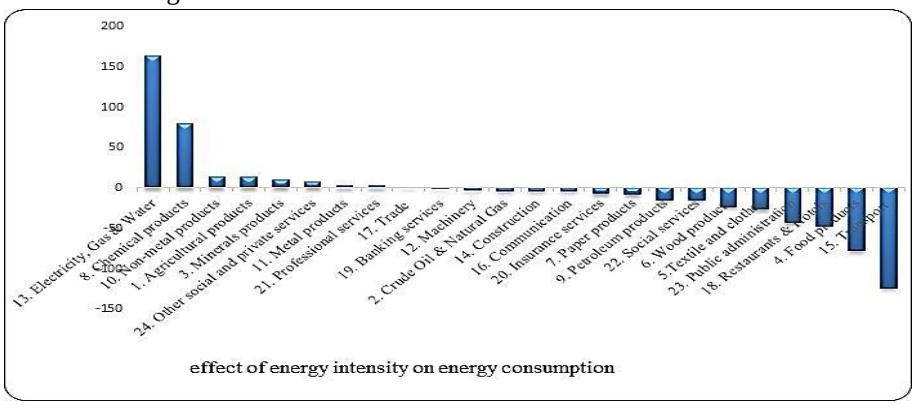

Fig. 2. The effect of products through energy intensity on energy consumption

Nevertheless, as a result of improvement in energy efficiency of products such as transportation, food products, restaurants and hotels, and public administration services, the total effect of this factor led to a reduction in energy consumption in the country, while the energy-intensity of some products like electricity, gas, and water distribution, and chemical products has increased during the same period.

Figure 3 and column M of Table 2 show the effect of different products in view of input substitution on changes in energy consumption. From the viewpoint of input substitution, transportation has had the highest contribution in the increment of energy consumption. On the other hand, the energy pricing policy of the country led the transportation sector to substitute a more energy-consuming technology. In contrast, non-metal products and other social and private services are the main contributors to the reduction of energy use through substitution of their inputs, in order of priority.

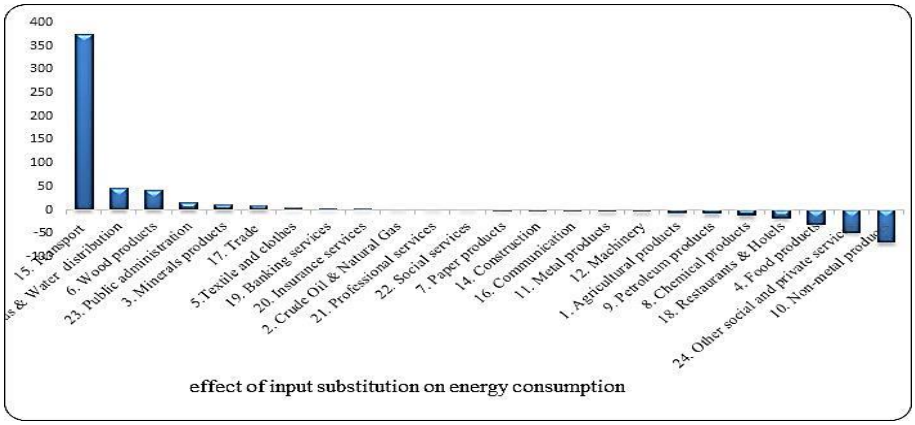

Fig. 3. The effect of products through input substitution on energy consumption

The effect of different products on changes in energy consumption through the backward linkage factor is displayed in Figure 4 and column *Z* of Table 2. According to the results, electricity, gas, and water distribution has had the main effect in the increment of energy consumption through the backward linkage factor. The non-metal and food products can be considered as two other commodities that have increased energy consumption in the country compared to the other products. In contrast, transportation services have had the main reduction in energy use via backward linkage.

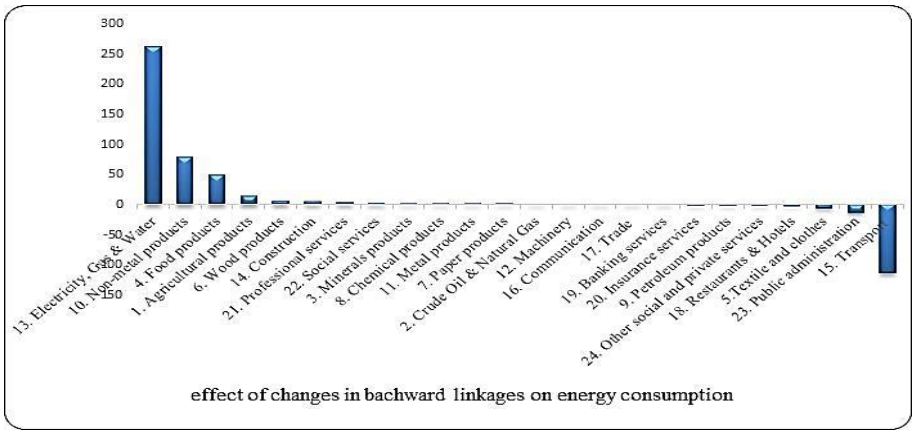

Fig. 4. The effect of products through backward linkage on energy consumption

The effect of products in the structural composition of final demand on changes in energy consumption is shown in column *S* of Table 2 and Figure 5. According to the finding of the research, changes in the share of electricity, gas, and water distribution, non-metal products, and food products in different components of final demand have had the most significant effects on the reduction in energy consumption of the country. However, the changes in the share of social services, transportation; and wood products caused an increment in the energy consumption through structural composition changes in final demand.

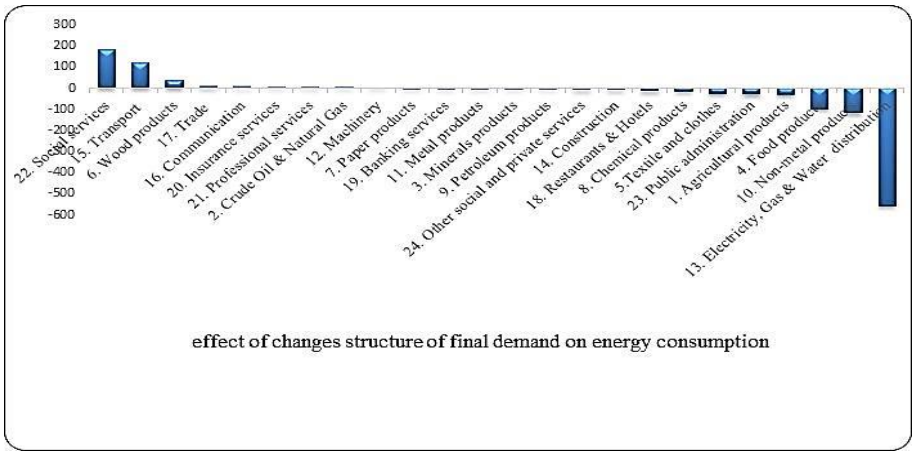

Fig. 5. The effect of products through structure of final demand on energy use

The contribution of products through the category of final demand is displayed in column *T* of Table 2 and Figure 6. Electricity, gas, and water distribution and food products have had the main effect on decreasing energy

consumption through the categorical effect of final demand, respectively. In contrast, public administration, transportation; and non-metal products led to the highest degree of increment in energy consumption, respectively.

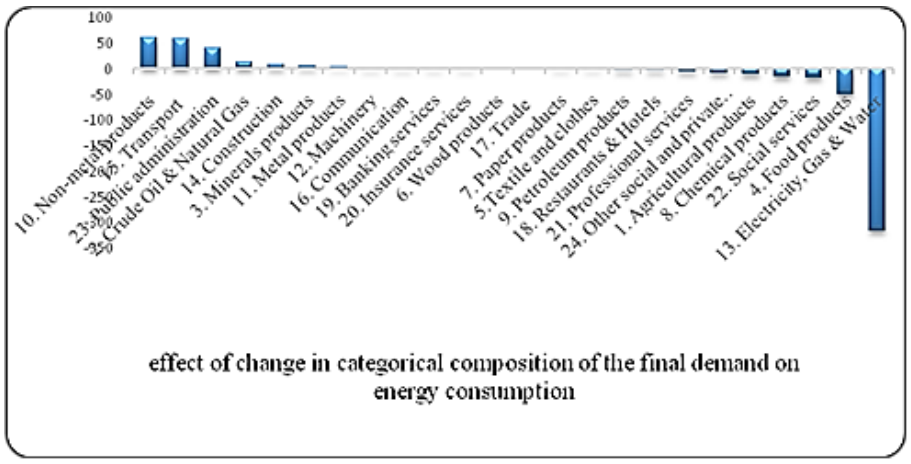

Fig. 6. The effect of products through category composition on energy consumption

The level of aggregate final demand for products has had different effects in comparison with other sources. Since the level of final demand for all products has been increased in 2001 compared to 1988, the final demand for all products has had positive effects on changes in energy consumption. However, the increment in electricity, gas, and water distribution and transportation services have had the strongest effects on changes in energy consumption (Fig. 7).

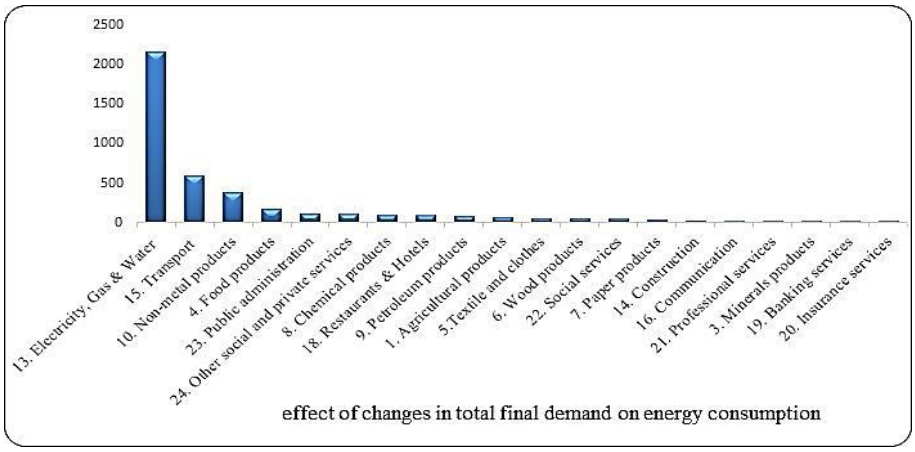

Fig. 7. The effect of products through the level of final demand on energy consumption

And finally, as shown in Table 2, electricity, gas, and water distribution, transportation, and non-metal products caused most of the reduction through the joint effect of different factors. However, a few products such as social services and mineral products have had the highest rate of increment in energy consumption through the joint effect of different factors.

5. Concluding remarks

The SDA of energy consumption prepares a useful tool for exploring the overall and partial changes in energy consumption for policy makers. To this end, an inter-industrial model was developed to study the sources of changes in energy consumption in a country. The innovation of the research concerns decomposing the effects of structural changes into input substitution and backward linkage effects. Compared with the current models, the proposed model allows the researchers to trace the sources of changes in energy consumption in more detail and more specifically. The model was employed to investigate the sources of changes in energy consumption in Iran during 1988 to 2001.

The changes in energy consumption of Iran have been under two contrary forces. However, the amount of energy consumption has increased during this period. The growth in the level of final demand was the main source of increment in energy consumption in the country. In addition, the changes in input substitution and backward linkage factors have led to an increase in the energy consumption.

In contrast, other factors have had a tendency to decrease the energy consumption. Among these factors, the joint effect of different factors has had the largest effect on energy consumption decrement. Changes in other factors, including structural and categorical composition of final demand and energy intensity of products, resulted in a decline in energy consumption in this period. Thus, although energy consumption has increased in Iran, the energy intensity of products has declined. This phenomenon reveals an improvement in the energy efficiency as a result of using an energy saving technology during the period.

A more detailed investigation has been carried out on the effects of products through different sources on changes in energy consumption. It was concluded that although the increment in the level of final demand for all products has led to an increase in energy consumption, the products can be divided into three groups:

I) Products that have had an ignorable effect in the growth of energy consumption.

II) Products that lead to a decrease in energy consumption during this period.

III) Products which are the cause of increment in the energy consumption in the country.

Thus, although a part of the increment in final demand for final consumption during 1988-2001 is acceptable, it can still be concluded that the most effective policy to reduce energy consumption in the country would be focused on final consumption of electricity, gas, and water distribution and transportation services, in order of priority. In addition, based on the results, the next effective policy for energy consumption reduction in the country would be focused on the input substitution effect of transportation services. And then, improvements in energy intensities of electricity, gas, and water distribution and chemical products are suggested to be considered as the following effective policies for decreasing the energy consumption of the country, in order of importance.

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