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Environmental Impact of Changes in Structure of Household Consumption in Urban and Rural Areas: Environmental Input–Output Approach

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ABSTRACT

The consumption of households and its structure has an important role in the rate of energy consumption and related air pollutant emissions. This study investigates the effect of changes in the structure of consumption in urban and rural areas on the emission of three main energy-related air pollutants (CO2, SO2, and NOX) in Iran during 2001-2011. To this aim, the environmentally extended input-output tables and structural decomposition analysis (SDA) were used. As the contribution of this study, the consumption of households is decomposed into two factors: total consumption and consumption structure. The results revealed that the changes in consumption structure in rural and urban areas increased the emission of all three air pollutants. The effect of changes in total consumption in both urban and rural areas outweighs the effect of changes in consumption structure. The negative environmental impact of urban households is worse than rural ones. The results at sectoral level showed that the changes in urban consumption structure had the main effect on CO2 emission in “water, gas and electricity” (135.68 Mt CO2), “chemical and plastics industry” (30.13 Mt CO2), and “food, clothing and textiles industry” (6.41 Mt CO2) whilst the changes in rural consumption structure had the main effect on CO2 emission in “water, gas and electricity” (25.39 Mt CO2), “chemical and plastics industry” (19.98 Mt CO2), and “food, clothing and textiles industry” (1.74 Mt CO2).

1. Introduction

The growth of economic activity in the world has led to an increase in the consumption of natural resources and fossil fuels. This has raised concerns about sustainable development, climate change, and air pollutant emissions. Accordingly, recent decades have witnessed the growing consideration of the environmental aspects of economic activities. One of the environmental aspects of the economic activities is the emission of air pollutants and greenhouse gases (GHG). The main driver of air pollutants and GHG emissions is fossil fuel combustion in economic activity (Cansino et al., 2016). These pollutants, such as carbon dioxide (CO2), sulfur dioxide (SO2), and nitrogen oxides (NOx) which plays an important role in the global warming and also in creation of diseases, are produced by the combustion of fossil fuels. Global warming is another most environmental concern raised by more GHG emission by humans (Kamalan and Saeedi, 2018).

Household consumption is one of the main factors that affect the GHG and air pollutant emissions directly and/or indirectly. The direct emission of air pollutants by households is caused by direct consumption of fossil fuels by households. The consumption of fossil fuels for cooking, heating rooms and driving cars directly contributes to the emission of air pollutants. Indirect emission of pollutants by households is related to the consumption of goods and services in whose production process fossil fuels are consumed (Su et al., 2017). Households with different lifestyles demand different goods and services, resulting in different amounts and types of environmental impact. Analysis of the environmental impacts of different household types may be useful in assessing more sustainable consumption patterns (Kerkhof et al., 2009).

One of the approaches to estimate direct and indirect emissions by final demand is the environmentally extended input-output (EEIO) model. This method has been widely used in many studies such as Hoekstra (2010), Su and Ang (2012a), Hawkins et al. (2015), Su et al. (2017), and Ma et al. (2019). There are several methods to decompose variables into their components over time. Among these methods, there are two main techniques that are used to decompose emissions and energy changes: index decomposition analysis (IDA) and structural decomposition analysis (SDA). The scope of SDA techniques differs from IDA techniques. I-O SDA methods can gauge the effect of

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more factors by both sector and demand source (Ang et al. 2010; Wang et al., 2017.

I-O SDA approaches have been extensively used to decompose the changes in indirect (embodied) emissions from final demand categories. Peters and Hertwich (2006), Xu and Dietzenbacher (2014), Zhao et al. (2016), and Zhong et al. (2017) have employed this method to identify the role of trade in emissions. Several studies have focused on emissions of households. Kerkhof et al. (2009) analyzed the environmental impact of household expenditures in the Netherlands. Reynolds et al. (2015) evaluated the environmental impacts of the weekly food consumption of Australia's households by income quintile. Steen-Olsen et al. (2016) used the multi-regional I-O model (MRIO) to assess the carbon emission of household consumption in 2012 in Norway. Zhang et al. (2017) analyzed the impacts of different income households on CO2 emissions in China. Zhu et al. (2018) decomposed India's increase in household indirect emissions during 2007-2013. Mach et al. (2018) investigated the role of each expenditure decile of households in emissions in Czech. Few studies have used input-output (I-O) analysis to focus on the effect of final demand and household on emissions in Iran. Banouei and Elham (2014) evaluated the direct and indirect effect of export and import in Iran and showed that "production and distribution of electricity" was responsible for the largest amount of CO2 emission caused by export. Sadeghi et al. (2014) decomposed the changes in CO2 emission into three factors of emission intensity effect, Leontief effect, and final demand effect during 2001-2006 using I-O SDA approach. Bazzazan and Khosrovani (2016) calculated the direct and indirect energy-related CO2 emission by household consumption using I-O table. None of these studies have focused on the effect of household consumption structure in the urban and rural area. This study aimed to fill this gap. This study differs from previous studies in two aspects. First, it is the first study focused on both consumption structure and total consumption of households using I-O SDA in Iran. Second, this is the first study that evaluates the effect of the changes in consumption structure in both rural and urban area.

This paper is organized into four sections. The environmental I-O SDA method and data are introduced in Section 2. The analysis of results is discussed in Section 3. Discussion and policy implications are presented in section 4.

2. Methods and Data

2.1. Methods

In the input-output analysis, imports are considered to be competitive or non-competitive. In environmental I-O analysis, non-competitive imports assumption is more suitable (Su and Ang, 2013). In the input-output analysis with non-competitive imports assumption, the total output is obtained as:

$$X = Z^d.1 + Y = A^d.X + Y \quad (1)$$

Where X is the total output vector, Z_d is the domestic intermediate input matrix, Y is the matrix of total final demand, and Ad is the matrix of domestic technical coefficients. According to Eq. (1), the total output matrix can be formulated as:

$$X = (I - A^d)^{-1}.Y = C^d.Y = C^d.(Y_c + +Y_g + Y_i + Y_{ex}) \quad (2)$$

Where $C^d = (I-A^d)^{-1}$ is the domestic Leontief inverse matrix, Y_c is the household consumption, Y_g is the government consumption, Y_i is the gross fixed capital formation and inventory changes, and Y_{ex} is the vector of exports. Pollution emission intensity is estimated by the ratio of total direct pollution emissions to the total output (pollution emissions per unit of output).

$$p_j = \frac{P_j}{X_j} \quad (3)$$

Where p_j is the pollution emission intensity in sector j, P_j is the total direct pollution emissions, and X_j is the total output. Eq. (3) can be rewritten in a matrix form as follows:

$$P = \hat{p}.X = \hat{p}.C^d.Y \quad (4)$$

where P is the vector of pollution emission and $\hat{p}$ is the diagonal matrix of pollution emission intensity. Therefore, total pollution emissions as a result of urban household consumption (Y_{UC}) and rural household consumption (Y_{RC}) can be formulated as:

$$P = \hat{p}.C^d.(Y_{UC} + Y_{RC}) \quad (5)$$

Each of urban and rural household consumption can be disaggregated into two factors: consumption structure and total consumption. Consumption structure shows the share of each sector in total consumption and total consumption is the sum of sectoral consumption by households. The matrix form of these factors is as follows:

$$Y_C = S_C * T_C \quad S = \begin{bmatrix} s_1 = y_{1c} / \sum y_c \\ s_2 = y_{2c} / \sum y_c \\ \vdots \\ s_n = y_{nc} / \sum y_c \end{bmatrix}, \quad T = \sum y_c \quad (6)$$

Substituting Eq. (6) in Eq. (5) yields:

$$P = \hat{p}.C^d.(S_{UC}.T_{UC} + S_{RC}.T_{RC}) \quad (7)$$

Based on Eq. (7), we can decompose the changes in pollution emissions as a result of household consumption changes. Decomposition form and method is not unique. Dietzenbacher and Los (1998) examined many possible forms of decomposition and concluded that the average method is an acceptable approach. Decomposition of pollution emission changes according to Eq. (7) using the average method can be formulated as follows:

$$\Delta P = \bar{\bar{p}}.\bar{C}^{d}.\Delta S_{UC}.\bar{T}_{UC} + \bar{\bar{p}}.\bar{C}^{d}.S_{UC}.\Delta T_{UC} + \bar{\bar{p}}.\bar{C}^{d}.\Delta S_{RC}.\bar{T}_{RC} + \bar{\bar{p}}.\bar{C}^{d}.\bar{S}_{RC}.\Delta T_{RC} \quad (8)$$

The first term in right-hand side is the urban household consumption structure effect, the second term is the urban household total consumption effect, and the third and last terms are the rural household consumption structure effect and rural household total consumption effect, respectively.

2.2. Data

In this study, the national input-output tables of 2001 and 2011 were used as the main database. These tables were obtained from the Statistical Center of Iran. They contained data on the imports within the transaction matrix. So, we removed the imports from interindustry transactions and final demands in these tables and calculated I-O tables with non-competitive imports assumption and domestic tables using the technique described in Miller and Blair (2009). In the next step, to eliminate the effect of price changes, 2011 input-output table was deflated to the constant 2001 price using sectoral price index data and double deflation method. These data were obtained from the National Accounts of Statistics Center of Iran. Finally, these two tables were aggregated to 11 sectors. The amount of fossil fuel consumption in physical units in the sectors was calculated by dividing the monetary consumption of these fuels in sectors by sectoral price of these fuels. The monetary consumption of fossil fuels and the price of these fuels in different sectors were obtained from consumption matrix in input-output tables and energy balance sheet, respectively.

In the next step, to calculate CO_2 emissions in each sector, the share of each sector in the physical consumption of fossil fuels in all economic sectors was multiplied by the total amount of CO_2 emissions from each fossil fuel. This has been done for all fossil fuels. The sum of CO_2 emitted from all fossil fuels yields the total CO_2 emissions from all fossil fuels in each sector. This was repeated for SO_2 and NO_x emissions in sectors, too. The amount of air pollutant emissions from each fossil fuels was obtained from the energy balance sheet. Finally, the emissions of three types of air pollutants were aggregated into 11 sectors according to the sectors in the input-output table.

3. Results and Discussion

The effect of changes in consumption structure in urban and rural areas on CO2 emission is shown in Table 1. According to the results, the changes in consumption structure and total consumption of urban households have led to an increase of 134.82 and 858.05 Mt in CO2 emissions in the economy. The changes in structure of consumption in rural areas have increased CO2 emission by 32.5 in the economy. The comparison of the effect of urban and rural consumption shows that the effect of the changes in structure and total consumption on CO2 emission is greater among urban households than among rural households.

Table 1. Results of SDA for CO2 emission changes by households (million ton Mt)

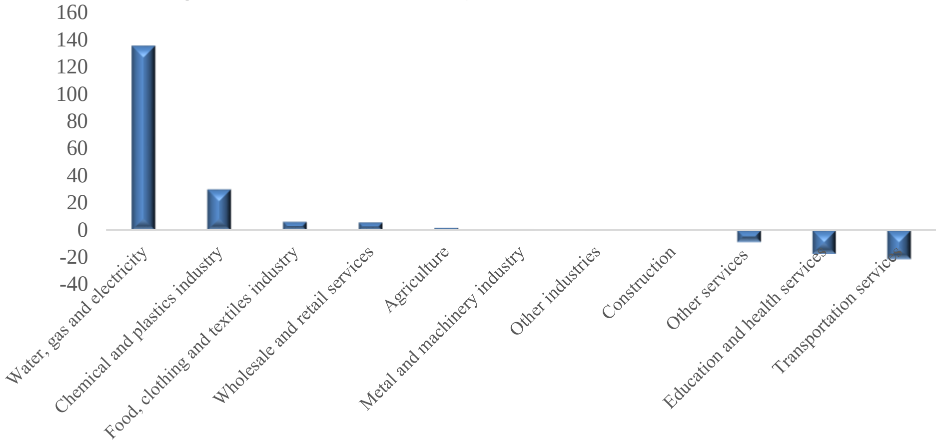
	sectors	Urban		Rural	
		S effect	T effect	S effect	T effect
1	Agriculture	1.89	39.05	-0.25	15.56
2	Food, clothing, and textiles industry	6.41	26.10	1.74	9.73
3	Chemical and plastics industry	30.13	159.55	19.98	55.06
4	Metal and machinery industry	0.95	37.35	1.18	9.40
5	Other industries	0.41	1.30	0.04	0.37
6	Water, gas, and electricity	135.68	339.13	25.39	86.44
7	Construction	-0.06	1.69	0.03	0.30
8	Wholesale and retail services	5.89	28.25	-1.50	8.52
9	Transportation services	-21.03	175.70	-10.97	59.10
10	Education and health services	-17.07	24.24	-2.12	4.83
11	Other services	-8.37	25.69	-1.02	5.24
Total		134.82	858.05	32.50	254.54

Source: Author’s calculations

The results at sectoral level showed that the increase in urban household total consumption entailed an increase in CO2 emission in all sectors. The major contributors were “water, gas and electricity” (339.13 Mt or 39.52% of total), “transportation services” (175.70 Mt or 20.48% of total), “chemical and plastics industry” (159.55 Mt or 18.59% of total), and “agriculture” (39.05 Mt or 5.54% of total).

The effect of changes in structure of urban consumption is shown in Fig. 1. This factor had the main effect on CO2 emission in three sectors including “water, gas and electricity” (135.68 Mt CO2), “chemical and plastics industry” (30.13 Mt CO2), and “food, clothing and textiles industry” (6.41 Mt CO2). This finding can be attributed to the increased share of these sectors in total consumption of households in urban areas over the studied period. The share of “food, clothing and textiles industry” has increased from 10.91% in 2001 to 12.88% in 2011. The share of “water, gas and electricity” and “chemical and plastics industry” has also increased by 2% and 1.5% in total consumption of urban household, respectively. This factor have contributed to the reduction of CO2 emission in four sectors including “transportation sector” (-21.03 Mt), “education and health services” (-17.07 Mt), “other services” (-8.37 Mt) and “construction” (-0.06 Mt). One of the main reasons for the reduction of CO2 emission in these sectors is the reduced share of these sectors in total consumption of urban households. The share of “transportation sector” has decreased by 2% in total consumption of urban households over the studied period. This could be due to the fact that urban households use public transport services to a lesser extent. The share of “education and health services” sector in total consumption of urban households has decreased by 1.2% in total consumption of urban households over the period.

Figure 1. The effect of changes in structure of consum



ption in urban area on CO2 emission

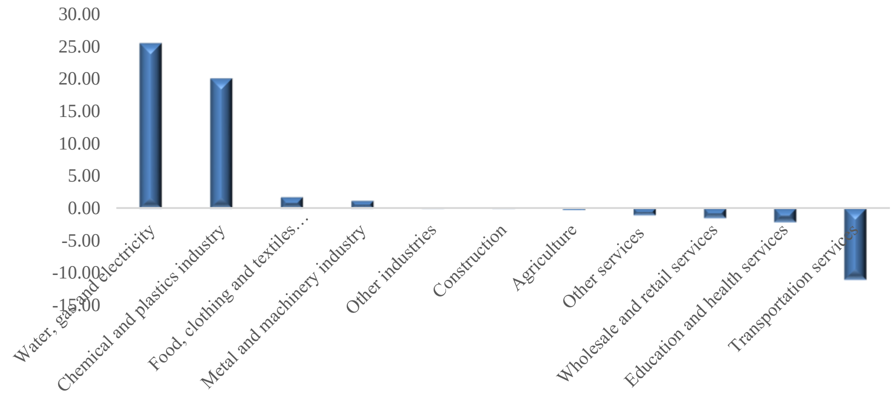


Figure 2. The effect of changes in consumption structure in rural area on CO2 emission

The effect of changes in total rural consumption was positive in all sectors. The top three sectors that contributed to the increasing CO2 emissions included “water, gas and electricity” (86.44 Mt or 33.96% of total), “transportation services” (59.10 Mt or 23.22% of total), and “chemical and plastics industry” (55.06 Mt or 21.63% of total).

The effect of changes in rural consumption structure is shown in Fig. 2. The effect of this factor in six sectors was positive and increased CO2 emission, but it was negative in the other five sectors.

This factor had the main effect on CO2 emission in “water, gas and electricity” (25.39 Mt CO2), “chemical and plastics industry” (19.98 Mt CO2), and “food, clothing and textiles industry” (1.74 Mt CO2). The share of these sectors in total consumption of rural households was increased by 1.53%, 4.46%, and 10% during the study period, respectively.

The effect of changes in consumption in urban and rural areas on SO2 emission is shown in Table 2. According to the results, the increase in total consumption in urban area and rural area led to an increase of 2282.65 Kt and 660.43 Kt in SO2 emission, respectively. The major sectoral contributors to the increasing rate of total consumption in urban and rural areas were found to be “water, gas and electricity”, “transportation services”, ad “agriculture”

Table 2. The results of SDA of SO2 emission changes by households (kilo ton: Kt)

	sectors	Urban		Rural	
		S effect	V effect	S effect	V effect
1	Agriculture	7.77	160.51	-1.01	63.96
2	Food, clothing and textiles industry	20.72	93.47	6.11	34.83
3	Chemical and plastics industry	21.43	116.96	14.09	40.06
4	Metal and machinery industry	9.10	142.28	6.39	35.18
5	Other industries	0.84	2.68	0.09	0.75
6	Water, gas and electricity	379.60	948.80	71.04	241.84
7	Construction	-0.26	7.22	0.13	1.29
8	Wholesale and retail services	17.44	83.70	-4.44	25.25
9	Transportation services	-36.29	682.53	-10.66	208.27
10	Education and health services	-15.48	22.04	-1.96	4.09
11	Other services	-11.41	22.45	-1.60	4.90
	Total	393.44	2282.65	78.18	660.43

Source: Author calculations

The effect of changes in the structure of urban consumption at sectoral level revealed that four sectors had a negative effect on this factor and SO2 emission reduced in these sectors. These sectors included “transportation” (-36.29 Kt), “education and health services” (-15.48 Kt), “other services” (-8.311.41 Kt), and “construction” (-0.26 Kt). Three sectors that were affected by the changes in the structure of urban households were “water, gas and electricity” (379.6 Kt SO2), “chemical and plastics industry” (21.43 Kt SO2), and “food, clothing and textiles industry” (20.72 Kt CO2). The comparison of the effect of urban and rural household consumption structure shows that this factor had a greater effect on SO2 emission in urban area than in rural area. The changes in the consumption structure of urban households led to an increase of 393.44 Kt in SO2 emissions in the economy while the change in the total consumption led to an increase of 2282.65 Kt.

Table 3 shows the results of SDA of NOx emission changes by households. Based on the results, the changes in the structure of consumption in urban areas resulted in an increase of 303.95 Kt NOx in the whole economy. The changes in total consumption in urban areas led to 2557.16 Kt increase in NOx emission. The changes in consumption structure and total consumption in rural areas resulted in an increase of 42.77 and 775.29 Kt in NOx emission in the whole economy, respectively.

The result at sectoral level showed that the increase in total consumption in rural and urban areas had the greatest impact on NOx emission in “water, gas and electricity” and “transportation services”. The changes in NOx emission in these sectors due to the increase in total consumption in urban area were 864.53 Kt and 820.96 Kt, respectively. The increase in total consumption in rural area resulted in an increase of 220.36 Kt in “water, gas and electricity” sector and 271.03 Kt in “transportation services” sector.

Table 3. The results of SDA of NOx emission changes by households (Kt)

	sectors	Urban		Rural	
		S effect	V effect	S effect	V effect
1	Agriculture	11.24	231.77	-1.43	92.34
2	Food, clothing, and textiles industry	19.99	82.19	5.46	30.62
3	Chemical and plastics industry	42.56	227.94	28.13	78.44
4	Metal and machinery industry	1.32	84.23	2.54	21.08
5	Other industries	1.20	3.80	0.13	1.07
6	Water, gas and electricity	345.88	864.53	64.73	220.36
7	Construction	-0.41	11.21	0.20	2.00
8	Wholesale and retail services	24.67	118.42	-6.29	35.72
9	Transportation services	-87.39	820.96	-43.59	271.03
10	Education and health services	-39.79	56.57	-4.98	10.96
11	Other services	-15.33	55.55	-2.13	11.66
	Total	303.95	2557.16	42.77	775.29

Source: Author’s calculations

One of the main reasons for the increase in emissions in such sectors as "transportation sector" and "water, gas and electricity" is the strong linkage of these sectors with other sectors of the economy. This will increase the intermediate demand for products of these sectors by increasing household consumption from products of other sectors. Following this, energy consumption and pollutant emissions by these sectors will also increase. Another reason for the high share of these sectors in the emission of pollutants is the high energy intensity and also high emission intensity in these sectors. As a result, a small increase in household consumption of the products of these sectors dramatically increases pollutant emissions.

4. Conclusion

This paper used the environmental input-output model to analyze Iran's three energy-related air pollutant emissions including CO2, SO2, and NOx as a result of the changes in the consumption structure and total consumption of households in urban and rural areas. The SDA method in the input-output model was used to decompose the changes into these air pollutants between 2001 and 2011.

The results showed that urban households had greater negative impacts on air pollutant emissions than rural ones. The negative impact of urban households was 3.3 times as great as the negative impacts of rural ones on CO2 emissions, 3.4 times as great as that on SO2 emission and 3.2 times as great as that on NOx emission. These results indicate the importance of controlling the consumption of urban households to reducing total air pollutant emissions. So, appropriate policies should be developed for different households in urban and rural areas to reduce consumption or encourage them to shift their consumption towards sectors with lower energy consumption and lower air pollutant emissions.

Air pollutant emissions from "water, gas and electricity", "transportation services", and "chemical and plastics industry" were most influenced by both urban and rural household consumption. These results can be explained by two reasons. First, the share of these sectors from the total expenditure of rural and urban households has increased over the studied period. In other words, households have spent more money on goods and services provided by these sectors. The second reason is that these sectors have high energy consumption rate and they are highly energy-intensive. So, appropriate policies should be taken to increase energy efficiency and reduce air pollutant emission by these sectors.

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