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Inequalities in Regional Level Domestic CO_2 Emissions and Energy Use: A Case Study of Iran

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Abstract: An increasing amount of CO_2 emissions from the household sector of Iran led us to analyze the inequality and understand the possible driving force behind the CO_2 emissions. The study of inequality provides information to policy-makers to point policies in the right direction. By considering the differences in the socio-economic factors of provinces, the study aims to analyze the inequality in CO_2 emissions and different kinds of energy consumption, including oil, gas and electricity, for the household sector of Iran's provinces between 2000 and 2017. For this aim, the Theil index and Kaya factor, as a simple and common method, were considered to evaluate the inequality in both CO_2 emissions and energy consumption, and determine the driving factor behind CO_2 emissions. According to the results, inequality in oil and natural gas consumption were increasing, electricity was almost constant; however, CO_2 emissions experienced a decreasing trend for the study period. The Theil index changed from 0.4 to 0.65 for oil, from 0.18 to 0.22 for natural gas, from 0.17 to 0.15 for electricity, and from 0.2 to 0.14 for CO_2 emissions between 2001 and 2017. In addition, the results of the inequality study indicated that most of the inequalities belong to within-group inequalities in energy consumption and CO_2 emissions. The results of the Kaya factor indicate that the second factor, energy efficiency, with a 0.21 value was the main driving factor of inequalities in CO_2 emissions; however, the first factor, energy consumption, can be a potential factor for inequality in the following years, as it increased from 0.00 to 0.11 between 2001 and 2017. It seems that by removing the energy subsidy policy in 2010 and 2013, low-standard and energy-wasting old vehicles were the most effective factors of energy inefficiency in the household sector, which need more accurate policy-making.

Keywords: CO_2; energy; household; inequality; Kaya; Theil

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1. Introduction

The most significant issues of environmental deterioration worldwide are the result of the usage of fossil fuels, CO_2 emissions, and limited accessibility to modern energy sources, such as liquefied petroleum gas (LPG), or renewable and environmentally clean energy sources. Increasing CO_2 levels in the atmosphere, anxiety about global warming, as well as further green and fiscal concerns, such as public health and acidification, are posing a challenge to the use of fossil fuels to provide the world with energy [1–4]. One of the most important concerns for the establishment of a global climate policy is the disparity in the distribution of CO_2 emissions among the nations [5]. The differences in per capita emissions between countries are important for determining distinct mitigation policy targets, and these differences can be related to factors that have evolved differently in each country [5–11].

Energy consumption accounts for the majority of carbon emissions, and it is critical to consider them simultaneously when conducting energy sector assessments [12]. Remarkably, energy consumption is a vital driver of economic growth [13]. The most important reasons for the high intensity of carbon dioxide emissions, which is driven by rapid economic growth, are the great percentage of conventional energy and ongoing burning of energy [14–17]. Energy poverty is exacerbated by low household income, high energy prices, and inefficient structures [13]. Energy poverty is a worldwide issue [18] that may be regarded as a subset of poverty, and it is primarily characterized by a low ratio of yearly income to annual energy consumption, building energy efficiency, and other inhabitant and behavioral attitudes to reaching a certain degree of comfort [19]. Household energy efficiency improvements, such as extensive energy retrofitting of residential structures, provide the greatest potential for energy savings and climate change mitigation [20]. Scholars discovered the so-called energy efficiency conundrum, despite the fact that energy efficiency increases are the most effective win-win strategy for achieving climate change mitigation in families. It means that the actual rate of increase in energy efficiency is lower than the ideal or targeted rate. The energy efficiency increase in the residential sector has been hampered by significant hurdles [21]. A careful inspection of the background of CO_2 emissions in developed countries and the position of developing countries, which are still in the early stages of growth and economic development, leads to developed countries being held responsible for changes and developing countries being criticized for not accepting emission reduction responsibilities. Developed nations have begun to reduce CO_2 emissions (based on legally enforceable targets or voluntary pledges), while some emerging countries, such as China and India, are under increasing international pressure to reduce emissions [22]. In 2021, the European Commission adopted the following building-related elements of the Fit for 55 package: the full proceeds from carbon trading should be used on climate and energy-related programs by Member States. A portion of the new system's income for road transport and buildings should be set aside to address the potential social impact on disadvantaged households, micro-enterprises, and transportation users. By 2030, the Renewable Energy Directive will set a higher goal of producing 40% of our energy from renewable sources. To achieve this aim, all Member States will participate, and specific targets for renewable energy consumption in transportation, heating and cooling, buildings, and industry have been suggested. To fuel the renovation wave, generate employment, and reduce energy usage and costs to taxpayers, the public sector will be compelled to repair 3% of its buildings each year [23].

For two reasons, focusing on heterogeneous attitudes is critical. First, policymakers will be highly interested in policy implications. On the one hand, interventions such as nurturance education begin with children and may be used to develop positive habits of conserving energy and being environmentally conscious [24]. Because of the emergence of the Internet of Things (IoT) and artificial intelligence (AI) technology to manage the household energy demand, the promotion of energy efficiency policies to transition to clean energy and the rise in single-person households, the energy consumption of household sector is changing. Researchers are attempting to minimize home energy use by increasing energy efficiency and anticipating energy usage through new technologies in response to legislative, environmental and technical changes [25]. Understanding the contradictory interaction between socio-economic development and stubborn emergent energy-consumption patterns appears important for policymakers to express effective policy frameworks to optimize energy structure, secure energy supply, and promote environmental protection in the dominant milieu where both the goals of energy use efficiency and a continuous increase in the total energy consumed must be met [26].

Iran is a developing economy with rich and abundant energy resources as the largest holder of total world oil and gas reserves, with 158.4 billion barrels of oil and 33.5 trillion cubic meters of gas reserves [27]. In 2016, 603.9 million tonnes of CO_2 were produced in Iran, where from 2005 to 2015, CO_2 emissions increased by 3.5% [27]. In 2016, the worldwide CO_2 intensity was 0.324 kCO_2/\$ 2005p and in Iran, it was 0.502 kCO_2/\$ 2005p, or 60%

more than global levels. As a result, Iran has the world's tenth highest CO_2 intensity [28]. An evaluation of Iran's GDP trend over the last few decades finds that energy consumption has increased faster than GDP, indicating that energy consumption in diverse sectors of Iran has not been environmentally sustainable [29]. Iran's per capita final energy consumption was 1.5 (agriculture), 3.3 (household), 2.2 (transportation), and 1.5 (industry) times higher than the global average. The share of households in the total energy demand in Iran in 2010 was about 25% and increased to 50% in 2019 [30,31]. On the other hand, households are the second-largest source of CO_2 emissions, accounting for 23.4% of total CO_2 emissions. As a result, households are responsible for around one-fourth of Iran's CO_2 emissions [32].

The trend of Iran's final energy consumption index per household from 2011 to 2017 has decreased due to gradual changes in the patterns of household consumption and optimization because of the modernization of old residential units, as well as the use of new technologies in final uses with a gentle slope, obtaining a decrease of 1.6% in the 6 years. The per capita changes in energy consumption in the household sector in the period 2011–17 decreased by 5.3% compared to the previous years and a decrease of almost 0.4% in these 6 years [33]. At the same time, electricity consumption has increased from 755 kWh to 1029 kWh per capita, and the per capita natural gas consumption has decreased from 586 cubic meters to 585 cubic meters. The per capita oil consumption has decreased from 4.77 barrels per capita in 2011 to 4.66 barrels per capita in 2017. This is while the population growth rate from 2011 to 2017 was an average of 1.27% per year [33]. The maximum per capita oil consumption belonged to West Azerbaijan with 330 litres, while Khuzestan with 33 had the minimum consumption per capita. The gas consumption per capita in Tehran had a maximum consumption of 0.0009 million cubic meters, while Sistan and Baluchestan had the minimum consumption per capita close to zero. For electricity per capita, the maximum belonged to Bushehr with 0.0034 kWh and Ardebil had a minimum consumption per capita of 0.000603 kWh [34].

In this regard, the increasing amount of CO_2 emissions along with growth in population and GDP will increase the concentration of pollutant emissions in the household sector of Iran's provinces. On the other side, there is little known about the factors that influence both CO_2 emissions and energy usage in the household sector on a regional scale. Consumer behaviour has, without a doubt, been widely researched, and different integrated approaches have been offered. Although some of these have been utilized to explain energy consumption behaviour, our understanding of inequalities in household energy usage remains limited [35]. According to the different features of geo-graphical situation, economic, social, climate, natural and human resources that affect energy consumption of the provinces of Iran, regional investigations seem, therefore, necessary to reduce the inequalities in CO_2 emissions, and will help to identify the inequality's principal factor for planning and managing energy consumption in the household sector. From the policy point, national policies have almost been employed to control the emissions and energy consumption already; hence, a disparity analysis in energy consumption and CO_2 emission needs to be conducted from a regional level perspective to achieve a set of effective policy recommendations. Therefore, the study aims to investigate the inequality in both energy consumption and emissions of CO_2 and detect the possible influencing driving factor behind CO_2 emissions in the household sector in the provinces of Iran from 2001 to 2017.

Literature Review

Reviewing the previous related works, it is essential to specify two concepts, inequality computing methods and grouping methodologies. Inequality measure is a scalar numerical depiction of the interpersonal disparities in income within a certain population [36]. The computation of inequality can be possible in different dimensions (economic, social, educational, health, security, consumption), whereas the economic dimension is the most important aspect. For example, inequality in the energy consumption of a household reflects the differences in the energy consumption of a household as a result of differences in characteristics of accessibility, infrastructure, education, income, climate, culture and etc. Equality is contradictory to inequality and refers to the state of being equal, especially in status, rights, or opportunities. The other concept, grouping methodologies, is the grouping of households into the two main within-group and between-group categories based on population or income level. Within-group inequality reflects the inequality in energy consumption of a group. Between-group inequality means that the inequality can be measured between the different groups. The sum of both the between- and within-group inequality is the total inequality.

Several studies have been conducted on the inequality in CO_2 emissions that have mainly highlighted inequality and used decomposition methodology, especially the Theil Index and Kaya factor. Most of the studies have been carried out on a global and regional scale, similar to the EU. The significant results of the researches were inequality in CO_2 emissions because of the changes in the economy or income [5,37–40].

Iran has also been the subject of some research projects in recent years that have analysed CO_2 emissions and energy consumption in the household sector. First of all, the demographic characteristics and economic studies indicated that income may lead to variations in LPG and electricity consumption. Moreover, household size, household age, and carbon dioxide emissions, except for educational background and income level, are expressively correlated with energy preservation. Furthermore, the results demonstrated that energy consumption and its price, resident rate, non-oil GDP, and FDI have substantial effects on CO_2 emissions. There is a linear relationship between these factors and CO_2 emissions. In addition, when petroleum fuels are replaced by natural gas, CO_2 emissions are reduced. In sum, heterogeneous reactions to energy price and income changes in various income categories, namely urban households, show a larger response to price changes, whereas rural families, particularly mid-income households, show a stronger response to income changes. Moreover, the results show that higher energy prices will decrease energy consumption by Iranian households [30,31,41–44]. Another research, by using multiple linear regression (MLR) and multiple polynomial regression (MPR) analyses, calculated Iran's CO_2 emissions in 2030 under the assumptions of the following two scenarios: business as usual (BAU) and the Sixth Development Plan (SDP). The findings imply that, under the BAU assumption, Iran would most certainly fail to achieve its commitment to the Paris Agreement; nevertheless, complete implementation of the ambitiously structured SDP might have met the objective by the end of 2018 [45]. Studies [30,46,47] have shown that inequality trends have been decreasing for gas and electricity, an unclear and fluctuating trend has been found for petroleum products, and the trend has also been increasing for CO_2 emissions during a specific period. Based on the Kaya decompositions, the type of energy (Alpha) was the main factor behind the CO_2 inequality. Despite recent improvements in energy efficiency across the sectors in Iran, household energy demands have grown dramatically. As Iran rapidly transforms into a consumer society, households have a significant impact on both direct energy usage and corresponding CO_2 emissions, as well as indirect use, as embodied in the products and services; the findings of that research can assist policymakers in focusing on renewable energy projects to minimize energy consumption and CO_2 emissions.

Since the majority of the studies were conducted on a global or regional basis, the suggested policies are provided on a regional and global scale. Individual surveys might have diverse outcomes in policymaking due to differences in energy consumption, GDP, and resources in many sectors of various nations' provinces. As a result, it appears that doing so at the national micro level, regional, provincial, or even sectoral level is preferable. Since households are one of the most polluting sectors, and because of the low percentage of renewable energy in fossil energy-dependent nations such as Iran, this scenario is exacerbated. Our contribution to the literature is in different ways. First of all, the study analyzed the inequality for households, secondly for Iran, and thirdly at the regional level. Finally, both the Theil and Kaya index were used to measure and investigate. From our knowledge, it has not been addressed before in the literature. This matter draws limited attention, and no research has been carried out in this field to recognize the significant source of inequality in energy consumption in the household sector. Therefore, the main novelty of the study is to understand the regional disparities in both energy consumption and CO_2 emissions and regional decomposition of CO_2 emissions in the household sector, which have not been addressed before. This research will serve as a starting point for academic purposes to develop accurate and efficient CO_2 emission reduction policies in the household sector of the economy throughout time.

2. Materials and Methods

The Gini coefficient is limited to measure income inequality in society. In general, the Gini coefficient is a macro economical statistical characteristic that indicates the degree of stratification of society, with respect to the distribution of some goods. On the contrary, the Theil index is scale invariant and does not change during the time of the devaluation. It is able to satisfy the decomposability axiom, meaning that it can decompose inequality into within- and between-group inequality [48]. The Theil index is an inequality metric that has received a lot of attention among researchers. Even though there are other tools to measure inequality, the Theil index (1967) has been a prominent approach. This measure, according to [48], is the only population-weighted inequality index that can be split down into groups of data, is differentiable, symmetric, scale-invariant, and can fulfil the Pigou–Dalton criterion for computing the inequality in CO_2 per capita emissions between territorial units. It may be regarded as a combinatory criterion of inequality according to [9], and its appeal stems from the fact that it can be completely deconstructed into many variables that produce the discrepancy. As a result, it gives extremely useful information. However, it has been created by several scholars to decompose into income and population subgroups. In addition, inequality could be divided into within-group and between-groups, with the following Theil index calculation:

$$I_t = \sum_{i=1}^{S} c_{i,t} \, \text{In} \left(\frac{c_{i,t}}{Q_{i,t}} \right) \quad (1)$$

In Equation (1), S indicates the total number of provinces evaluated, $c_{i,t}$ represents the share of the total of the variables, such as oil consumption, natural gas, carbon emissions, electricity, and $Q_{i,t}$ is a weighting variable, which is illustrated by the percentage of the entire population (or income) of the province I at time t.

A decrease in I_t indicates a similar distribution, whereas a rise indicates a divergence between the provinces. The index calculates the variation in energy consumption that is not explained by income (or population or other weighting variables) [49]. Other variables are responsible for the inexplicable variation (e.g., climate, the economic structure of the province). In the present study, the regional grouping is carried out based on the income of the householders and to this target, 28 provinces of Iran are divided into groups. The first group provinces have the lowest income, while the fourth group includes provinces with the highest income. Another grouping is based on the geographic location of the provinces. The provinces are grouped into $P \leq N$ regions, where $R_g = R_1, \ldots, R_P$ and each province belongs to only one region, R_p, with g taking values between 1 and P [50]. To specify the regional decomposition of the Theil index, it is essential to calculate the total share of each region using the following equation:

$$c_{g,t} = \sum_{i \in g} c_{i,t} \quad (2)$$

$$P_{g,t} = \sum_{i \in g} Q_{i,t} \quad (3)$$

Equations (2) and (3) show the shares of region R_g that concern the total. Based on these, the within-region inequality could be calculated in the following way:

$$T_{g,t} = \sum\nolimits_{i \in R_g} \frac{c_{i,t}}{c_{g,t}} \ln\left(\frac{\frac{c_{i,t}}{c_{g,t}}}{\frac{Q_{i,t}}{P_{g,t}}}\right) \quad (4)$$

A weighted total of the specific within-region values is required to derive the average within-group inequality, which can be calculated using the following equation:

$$T_{W,t} = \sum\nolimits_{g=1}^{G} c_{g,t} \cdot T_{g,t} \quad (5)$$

Inequality between the groups can be calculated as follows:

$$T_{B,t} = \sum\nolimits_{g=1}^{G} c_{g,t} \ln\left(\frac{C_{g,t}}{Q_{g,t}}\right) \quad (6)$$

This section divides the inequality in CO_2 emission distribution into the following two categories: inequality between provinces and inequality within provinces. This allows researchers to investigate whether the decrease in emission inequality is attributable to a drop in disparity between the rich and poor provinces, or whether the change is due to an equalization of provinces with similar income level inequalities [51].

As a result, the entire Theil index could be rewritten as the following equation:

$$T_t = F_{W,t} + F_{B,t} \quad (7)$$

In Equation (7), $F_{w,t}$ signifies a measure of the inequality across provinces in region g, whereas $F_{B,t}$ is a measure of the inequality among the G regions and highlights the differences between the different groups of provinces. For comparison purposes, the Theil index is also calculated based on the intensity, X, for the population and income. To do this, Equation (8) is modified in the following way:

$$T_t = \sum\nolimits_{i=1}^{n} P_{i,t} \ln\left(\frac{\overline{H}_t}{H_{i,t}}\right) \quad (8)$$

where H indicates the average intensity of income or population, of carbon emissions or energy consumption (i.e., electricity, natural gas, and oil).

2.1. Kaya Factors

The "Kaya identity" model produced a simple mathematical equation that integrates economic, demographic, and environmental elements to estimate CO_2 emissions from human activities, as shown in Equation (9). The Kaya identity is a simple and operative approach to assess quantitatively how other important factors impact changes in emissions (or energy consumption). The Kaya identity could be expressed as the following equation:

$$\frac{CO_{2,1}}{POP_i} = \frac{CO_{2,i}}{E_i} * \frac{E_i}{I_i} * \frac{I_i}{PoP_i} = \alpha * \beta * \lambda \quad (9)$$

where $CO_{2,i}$ is the total amount of carbon emissions of the province "i", E_i is the total energy consumption, I_i is the amount of household's income, and Pop_i is the population. The identity of these factors helps to realize the mechanisms specifying the changes in emissions, but it does not indicate causality. In conclusion, an increase in population does not always cause an increase in carbon emissions, just as an increase in income does not always result in an increase in emissions [38].

Carbon emissions ($CO_{2,i}/Pop_i$) are described as by the product of three elements, including the carbon intensity of energy consumption ($CO_{2,i}/E_i$), the energy intensity

(E_i/I_i), and the income per capita (I_i/Pop_i), according to the Kaya identity. As a result, the first factor depicts the fuel mix, the second the energy efficiency and the economy's sectoral structure, and the third the measure of economic productivity. To analyse the inequality of CO_2 emissions, it is possible to employ the Theil index according to Equation (10), which is as follows:

$$T_t = \sum_{i=1}^{n} P_i * \ln\left(\frac{\overline{H}}{H_i}\right) \tag{10}$$

where p_i represents the province's percentage of the total population, H_i represents carbon emissions, and $\overline{H}$ represents Iran's average carbon emissions. The Kaya identity is used to decompose the Theil index obtained with Equation (10) to investigate the sources of carbon emission inequality. In particular, there are three vectors that may be evaluated, one of which has just one value as a variable and the other two of which have average values, which are as follows:

$$\chi_i^{\alpha} = \alpha_i * \overline{\beta} * \overline{\lambda} \tag{11}$$

$$\chi_i^{\beta} = \overline{\alpha} * \beta_i * \overline{\lambda} \tag{12}$$

$$\chi_i^{\gamma} = \overline{\alpha} * \overline{\beta} * \lambda_i \tag{13}$$

where $\overline{\alpha}$, $\overline{\beta}$ and $\overline{\lambda}$ are the provinces averages, which can be calculated using the following equation:

$$\overline{H^{\alpha}} = \sum_{i=1}^{N} P_i * H_i^{\alpha} \tag{14}$$

The same is valid for $\overline{H^{\beta}}$ and $\overline{H^{\lambda}}$. The Theil index may be used to evaluate the amount of inequality for each factor, as shown in Refs. [39,52].

$$T^{\alpha} = \sum_{i=1}^{n} P_i * \ln\left(\frac{\overline{H^{\alpha}}}{H_i^{\alpha}}\right) \tag{15}$$

$$T^{\beta} = \sum_{i=1}^{n} P_i * \ln\left(\frac{\overline{H^{\beta}}}{H_i^{\beta}}\right) \tag{16}$$

$$T^{\gamma} = \sum_{i=1}^{n} P_i * \ln\left(\frac{\overline{H^{\gamma}}}{H_i^{\gamma}}\right) \tag{17}$$

These indices show the partial involvement of each of the three elements of the Kaya identity in the Iranian household sector, such as carbon intensity, energy intensity, and income per capita. To obtain a perfect decomposition, the interaction terms, which can be computed as proposed, must be included in Ref. [52] and are as follows:

$$\text{Inter}_{\alpha,\beta\lambda} = \ln\left(\frac{\overline{H}}{\overline{H^{\alpha}}}\right) = \ln\left(1 + \frac{\sigma_{\alpha,\beta\lambda}}{\overline{H^{\alpha}}}\right) \tag{18}$$

$$\text{Inter}_{\beta\lambda} = \ln\left(\frac{\overline{H}}{\overline{H^{\beta}}}\right) = \ln\left(1 + \frac{\alpha * \sigma_{\beta\lambda}}{\overline{H^{\beta}}}\right) \tag{19}$$

where σ_{α}, $\beta\lambda$ shows the covariance weighted on the population share between carbon and energy intensities, while $\sigma_{\beta\lambda}$ is the weighted covariance on the population share between energy intensity and income per capita. Because of this, the Theil index related to the carbon emissions can be written as the following equation:

$$T_t = T^{\alpha} + T^{\beta} + T^{\lambda} + \text{Inter}_{\alpha,\beta\lambda} + \text{Inter}_{\beta,\lambda} \tag{20}$$

On the contrary, as highlighted in Ref. [38], because the perception of the interaction terms could be challenging or imprecise, the Shorrocks methodology attributes their contribution to the three primary terms [52], Regarding to which interaction terms are divided homogenously into the several components that give origin to them:

$$T_t = \left(T^{\alpha} + \frac{1}{2}\text{Inter}_{\alpha,\beta\lambda}\right) + \left(T^{\beta} + \frac{1}{4}\text{Inter}_{\alpha,\beta\lambda} + \frac{1}{2}\text{Inter}_{\beta,\lambda}\right) + \left(T^{Y} + \frac{1}{4}\text{Inter}_{\alpha,\beta\lambda} + \frac{1}{2}\text{Inter}_{\beta,\lambda}\right) \quad (21)$$

This can be rewritten as the following:

$$I_t = T^A + T^B + T^T \quad (22)$$

2.2. Study Area

Iran's climate is distinct from that of its neighbours'. The variation in temperature between the warmest and coldest places is approximately 40 to 50 °C all year. On a winter night, Shahrekord has a low of 30 °C, whereas Ahwaz has a summer high of 50 °C. The Lut desert in Iran was the world's hottest location in 2004 and 2005. Despite its diverse climate, the majority of the nation, except for the northern coastal parts, receives significant amounts of solar radiation, as measured and recorded at several meteorological stations [53].

As shown in Figure 1, the energy consumption per capita in the household sector and the oil consumption over 17 years were low overall and just four provinces had a high consumption per capita, including Yazd, Kermanshah, Kurdistan, and West Azerbaijan. It seems that these provinces did not have access to gas, making oil consumption per capita high. The map of gas consumption per capita shows that central and big cities had the most per capita usage among the provinces, which shows the better access of these territories to gas infrastructure. However, in this regard, southern and poor provinces, such as Sistan and Hormozgan, had the lowest consumption per capita. Furthermore, even some of the provinces were without a pipeline despite being near the gas sources, which shows that the amount of inequality is higher. Despite the fact that electricity consumption in households showed low and medium per capita usage in the majority of the provinces, inequality was not high in this sector.

The study is based on data gathered from the Annual Energy Balance Sheet and Statistics Centre of Iran for the years 2001 to 2017 [33]. This time, the horizon is intriguing since several changes occurred in the Iranian energy and economic structure as a result of some events, including the subsidy program. Moreover, the most recently published annual energy balance sheet was 2017 in this study.

2.3. Data Analysis

According to income and population, Iran's provinces were divided into four groups based on ad hoc. Appendices C and D represent the range of groups based on the average of the provinces for population and income. The twenty-eight provinces of Iran, based on the averages of the variables (Oil, gas, electricity consumption, CO_2 emissions, Income and population) divided into four groups, respectively very low, below average, above average and very high. Appendix A displays groups of provinces based on income. This division based on mean and standard deviation assists in realizing the possibility of disparities between high- and low-income provinces. Appendix B shows another grouping based on population and the division based on mean and standard deviation. The provinces with the same population that present approximately similar energy structures are in the same group, which suggests that better inequality per capita means better conditions for the provinces. Eight provinces, based on income, had an unstable situation during the study period. Among these provinces, Bushehr, Kohgiloyeh, West Azerbaijan, Mazandaran and Markazi had a more fluctuating situation during the study period. Furthermore, the income groups showed that only Tehran was in the fourth group, while more than 50% of the provinces were in the first group. Most of the big cities were in the third group. Meanwhile, the trend of income showed that most provinces had a stable situation during the period of 17 years, indicating that the economic sector of Iran did not contribute to growth in the income of householders. In this study, oil, gas and electricity are considered as fuels used in the household sector, which includes gas oil, kerosene and fuel oil. In addition, more than ninety percent of electricity generation comes from fossil fuels [33]. Some provinces lack energy sources for agriculture and industry as well and, in return, some provinces have very rich and varied energy sources. These differences in resources cause different incomes for householders in different provinces. In conclusion, inequalities in income will be the cause of an increase in inequality in energy consumption and CO_2 production. Appendix B shows the provinces categorized into four major groups based on population. There were just three provinces with unstable populations, including Sistan, Kerman and Hormozgan. This shows that the majority of provinces showed constant growth and remained in the same group. Tehran was the leader of the provinces in the study period based on income and population, which caused increased inequality among the 28 provinces.

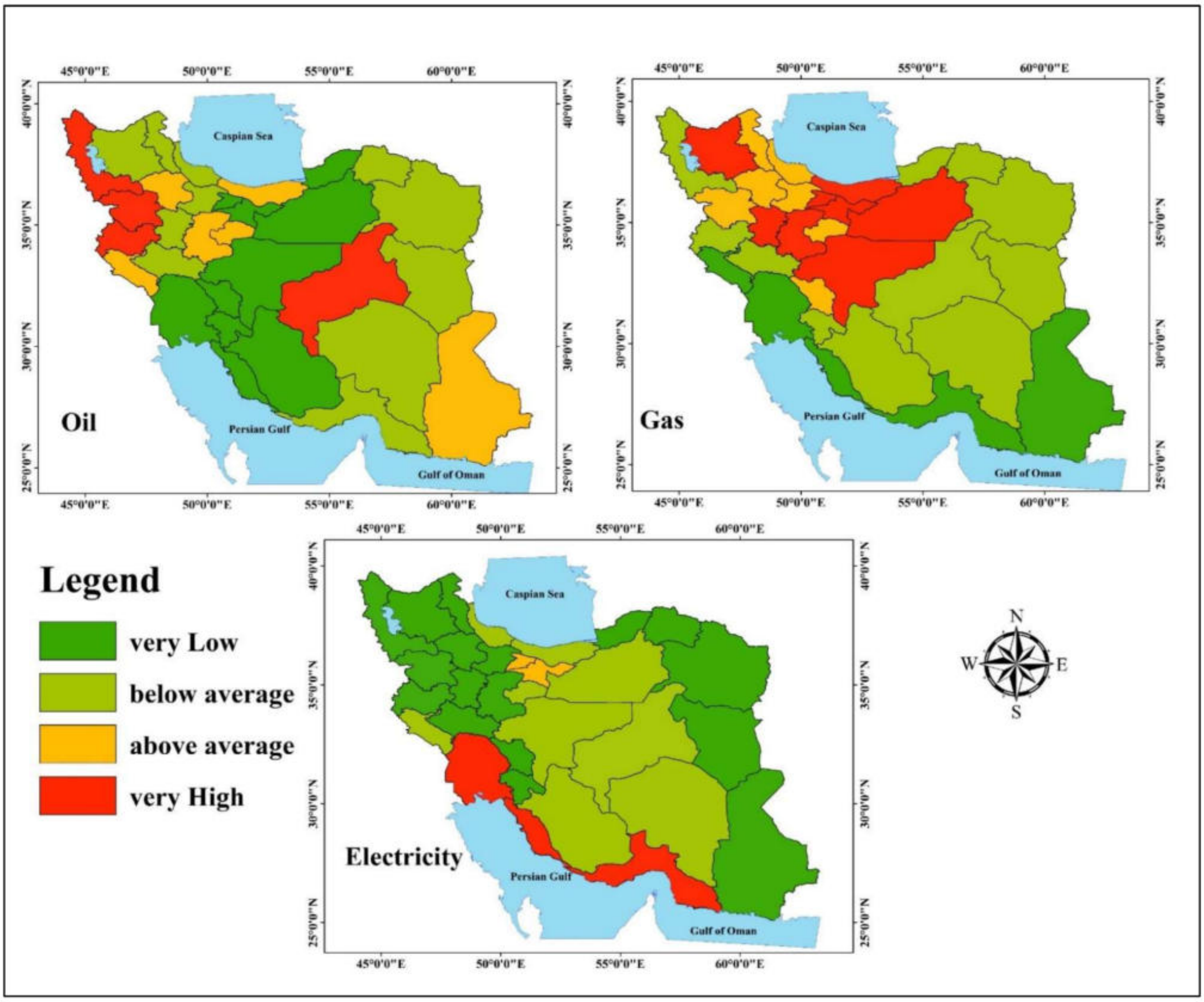

Figure 1. The disparity in all types of energy consumption (oil, gas, electricity) per capita of the provinces of Iran in the household sector from 2000 to 2017 [33].

3. Results

Based on the amount of household consumption in each of the three parts including oil, gas, and electricity during the 17 years of the study period, consumptions were categorized into four groups. Based on the amount of consumption in each province, they were categorized into four groups, with the first group containing provinces with a minimum amount of consumption, and group 4 containing the provinces with maximum energy use. In addition, groups 2 and 3 contained provinces with medium and high consumption.

3.1. Descriptive Results

Figure 2 shows the income trend that fluctuated highly during the 17 years, with significant growth between 2010 and 2014. Then, a sharp decrease can be observed until 2017. The income level in group 4, which included only Tehran, demonstrated an unstable situation, with upward and downward trends during the study period. In this regard, the economic sector of Iran has had a very unstable and downward trend in recent years. Group 3, which includes provinces with high incomes, shows a slight growth until 2013. After that, similar to the other group, a declining trend can be observed. Group 1, which includes several provinces with low incomes, had an upward trend from 2001 to 2007 but in 2008 and 2009, a decline can be observed. Then, the trend increased until 2013 and later declined until 2017. Group 2, which includes provinces with medium income levels, shows the same trend as group 1 during the study period. Figure 3 gives information about the growth of population in Iran from 2001 to 2017. The population increased steadily and was similar in all the groups during the study period, in which the majority of the population belonged to group 3. Population group 4 includes just Tehran but the population was higher than or equal with 13 provinces. Group 3 consists of 7 major provinces that include about 50% of Iran's population. Group 1 includes 13 provinces with a total population of about 12.2 million in 2001, reaching 13.3 million in 2017. Group 2, with a population of 13 million in 2001, reached 14.5 million in 2017.

Figures 4–6 demonstrate the trends in the consumption of petroleum, gas and electricity. It seems that after implementing the subsidy-targeting policy in 2010 and 2013, energy consumption (oil, gas, and electricity) might have declined. Figure 4 shows that at the beginning of the first 8 years (2001–2009), oil consumption was high but it declined considerably. In addition, the highest consumption belongs to group 3. The consumption of group 3 in 2001 was between 483 and 1337 million litres and in 2017, it declined to between 123 and 327 million litres. In group 4, the oil consumption was between 1337 and 2192 million litres in 2001, declining to between 327 and 530 in 2017. However, only Tehran and West Azerbaijan were in group 4.

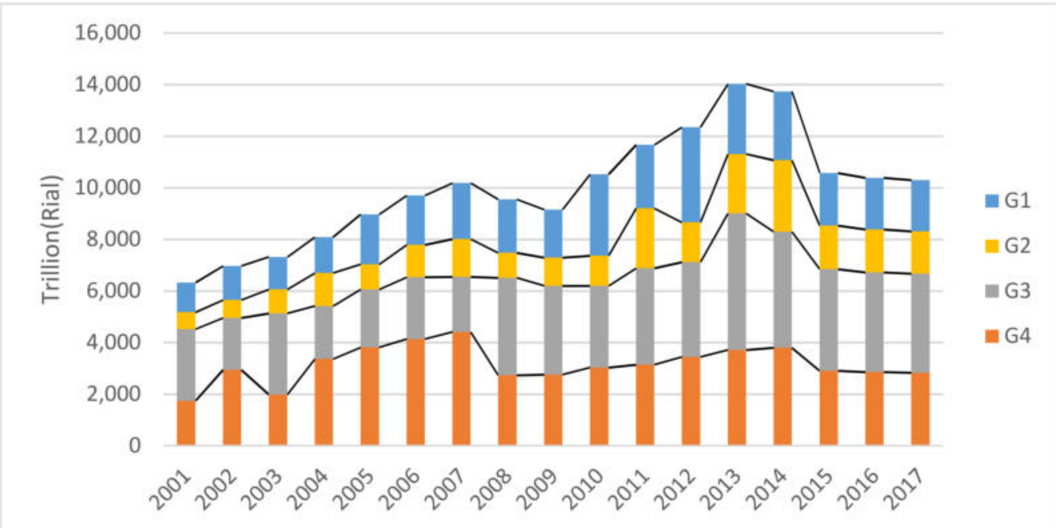

Figure 2. Trend of real income [33].

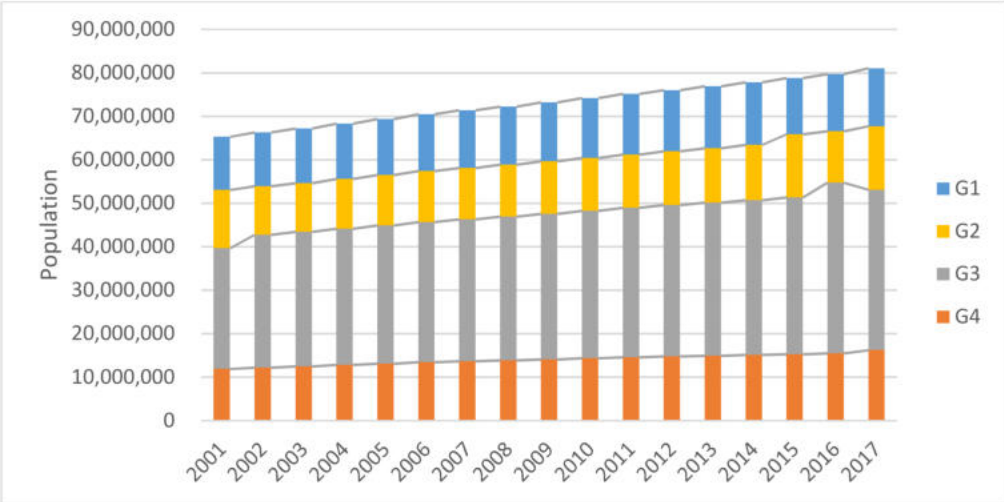

Figure 3. Trend of population [33].

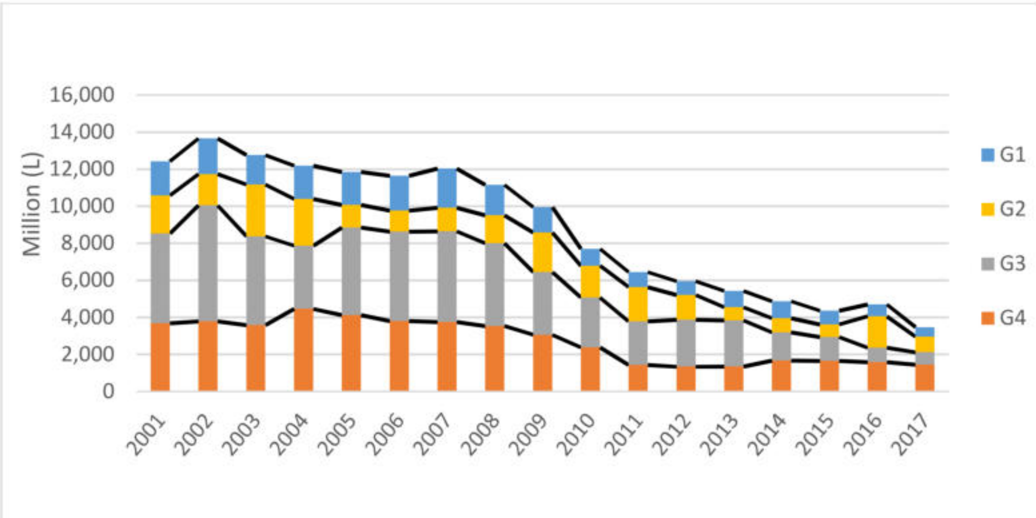

Figure 4. The trend of petroleum product consumption [33].

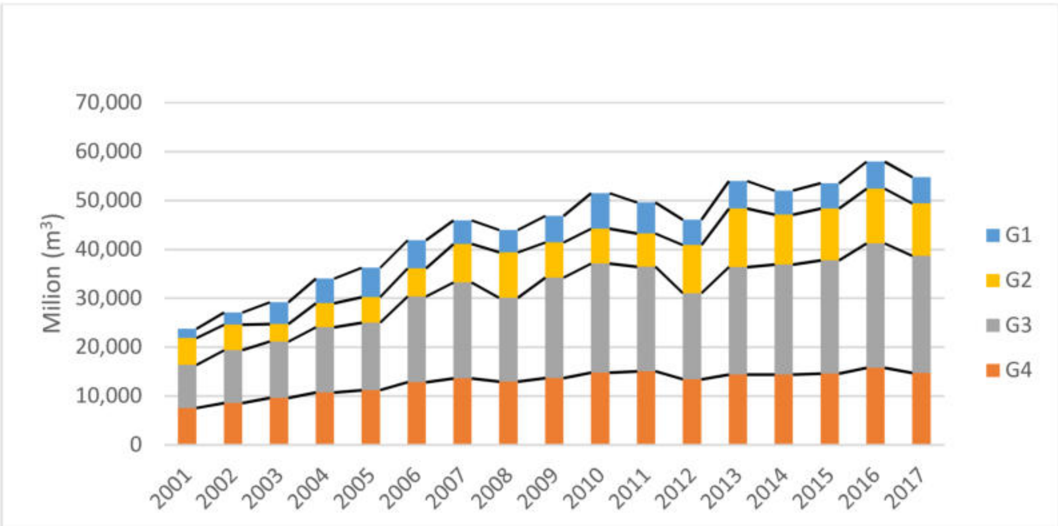

Figure 5. The trend of natural gas consumption [33].

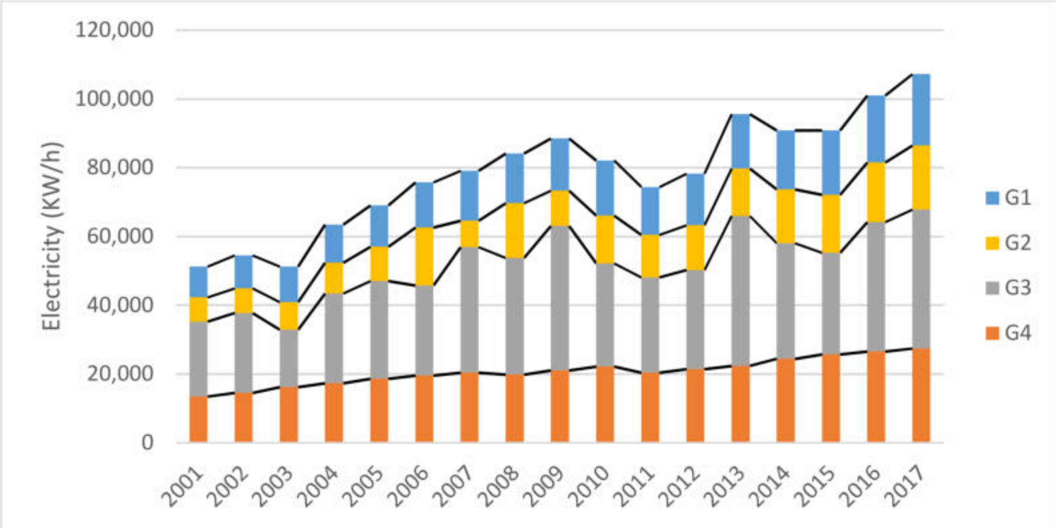

Figure 6. The trend of electricity consumption [33].

Figure 5 shows a gradual increase in natural gas consumption during the 17 years. Groups 1 and 2 show the minimum use of energy during the studied period, while the highest shares belong to group 3 and 4. In group 1, the consumption of householders was between 0 and 424 m^3 in 2001, and 12 provinces were in group 1. Furthermore, in 2017, the consumption was between 8 and 981 m^3, and 11 provinces were likewise in group 1. In most of the provinces that were in group 1, householders did not have access to the gas infrastructure that Sistan and Baluchestan, and Hormozgan had. Only Tehran was in group 4 with 7544 m^3 in 2001 and in 2017, Tehran was still alone in group 4 with 14,699 m^3. Group 3 with the highest share of gas consumption with 848 m^3 to 4196 m^3 in 2001, which included the provinces East Azerbaijan, Khorasan, Esfahan, Gilan, and Mazandaran, with the amount of total consumption of 8814 m^3 in 2001. In 2017, consumption was between 1956 and 8327 m^3, including 7 provinces with a total of 23,976 m^3. Generally, the number of gas consumers increased with time; thus, the amount of gas consumption also increased.

Figure 6 illustrates that the electricity consumption increased from 2001 to 2009 but after that, it slightly decreased until 2012, and then it increased moderately to 2017. In addition, group 3 had the majority of the share of electricity consumption among householders. The total amount of electricity consumption in 2001 was 8946 kWh in group 1 including 15 provinces, 7093 kWh in group 2 with 5 provinces, 21,762 kWh in group 3 with 7 provinces, and 13,434 kWh in group 4 including 1 province. However, in 2017, the energy consumption was 20,734 kWh, 18,640 kWh, 40,446 kWh, and 27,384 kWh in groups 1 to 4 with 15, 5, 6 and 2 provinces, respectively. The emergence of developed electrical devices in recent years, such as phones, computers, electrical home appliances and electrical heaters, improved people's welfare but also caused the increased electricity consumption of householders in Iran.

Figure 7 shows the CO_2 emissions that increased slowly during the study period. Between 2007 and 2017, it fluctuated slightly. In addition, among the groups (1, 2, 3, and 4), groups 3 had the highest levels of CO_2 emissions. Large provinces such as West Azerbaijan, Esfahan, Khorasan, and Gilan had 30 million tons in 2001, reaching 54 million tons in 2017. Only Tehran belonged to group 4, where the most CO_2 was produced with 26 million tons in 2001 and increasing to 37 million tons in 2017. Groups 1 and 2 had 8 and 17 million tons, respectively, in 2001, and then they reached 19 and 27 million tons in 2017. The provinces with the lowest CO_2 emissions included Ilam, Bushehr, Charmahal, Sistan and Baluchestan, Kurdistan, Kohgiloyeh and Boyer Ahmad, Hormozgan, and Yazd, provinces that were marginal and undeveloped.

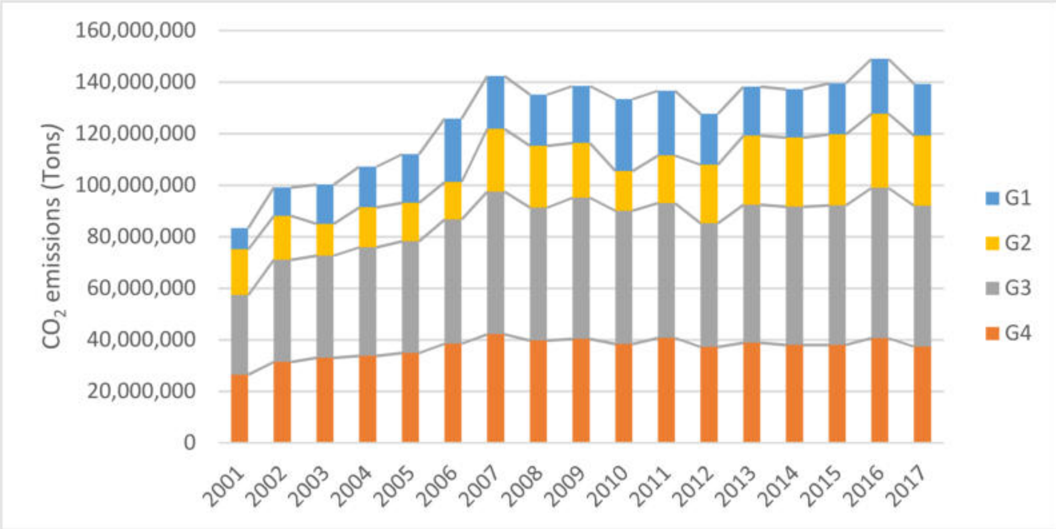

Figure 7. The trend of CO_2 emissions [33].

3.2. Analytic Results

The Theil index for all the energy sources (including petroleum products, natural gas, and electricity) and CO_2 emissions were derived using population and income weights based on GDP grouping methods and regional incomes, taking into account the within- and between-group inequalities. As illustrated in the graphs below, Figure 8 signifies that the Theil trend of petroleum products is increasing, especially after 2010 until 2016. In 2001, the value of the Theil index was 0.40 and reached 0.65 in 2017, showing increased inequality. In addition, the intensity of inequality in petroleum energy was high. Figure 8 also shows that within-group inequality was about 70% and between-group inequality was about 30%. Based on the income weight with the decreasing petroleum consumption in the household sector after 2010, the grade of inequality increases in the within-group type. Furthermore, the first phases of subsidizing in 2010 saw increasing inequality and after that in 2013, inequality increased again. Because of the second phase of subsidizing in 2013 and with the implementation of the subsidy project especially in the fuels sector, the purchasing power of the low-income class significantly decreased. In addition, after 2016 with a reduced the share of subsidies in household fuels, the inequality declined. The majority of provinces had declining trends and preferred the use of gas instead of petroleum. However, some provinces such as Sistan and Baluchestan and Kerman did not show a decline in oil consumption during the study period, which shows they did not have access to gas. This also caused increased inequality in petroleum products.

Figure 9 represents a constant trend in the Theil index interrelated with natural gas until 2010. After that, the Theil index had an increasing trend. The between- and within-group inequalities were determined using the GDP and geographic criteria. This means that the groups created on the basis of the criteria are quite heterogeneous and do not present similarities; in fact, most of the inequality is due to the within group component. According to this, we need to select the criteria that has the maximum amount of heterogeneity intergroup criterion. The best Theil index was chosen based on income group and population weight. The value of the Theil index in 2001 was 0.18 and reached 0.22 in 2017, although in 2016, it reached 0.25. Meanwhile, after 2016, with a reduction in the share of subsidies in household fuels, the inequality declined. In addition, in the first ten years, within-group inequality demonstrated 72% of total inequality, which was higher than between-group inequality. This dominance shows differences in the provinces of unit groups, and the fundamental cause of that was access to gas infrastructure in the provinces. Provinces such as Sistan and Baluchestan, Hormozgan, Ilam, and Bushehr were without gas until 2010, and after that time, they only achieved very low levels of gas infrastructure. After this, between-group shares increased by 60% in 2017. Because of growing gas consumption in groups such as 3 and 4, subsidizing phases in 2010 and 2013 contributed very strongly to increasing inequality in the years after 2010.

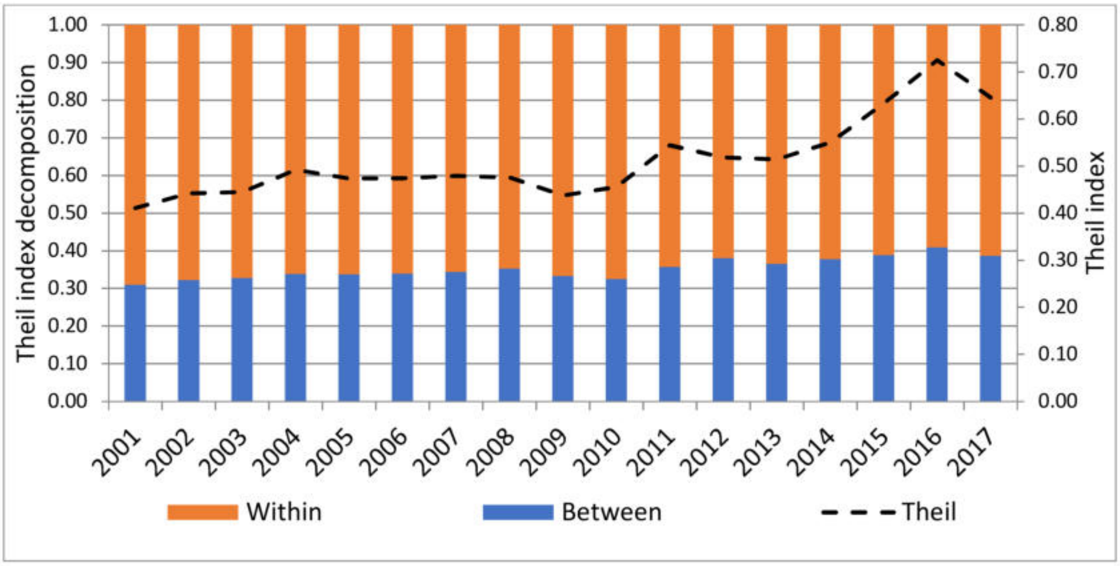

Figure 8. Theil index of petroleum products with income weight.

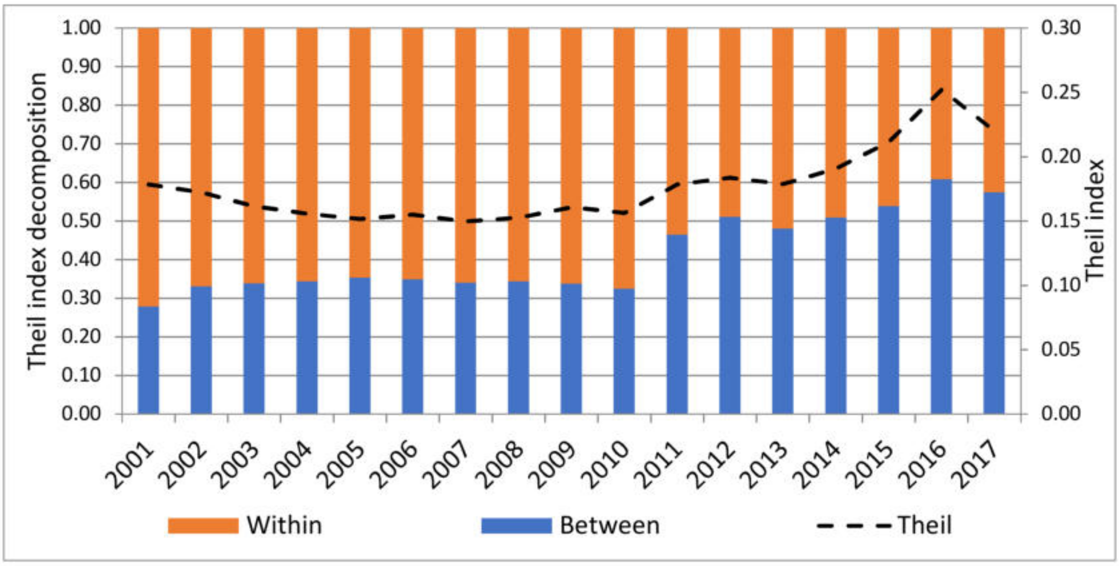

Figure 9. Theil index of natural gas with population weight.

Figure 10 represents the fluctuating trends of the electricity Theil index during the study period. In a similar manner to other energy sources, the within-group was dominant. In addition, the value of the Theil index in 2001 was about 0.17, reaching 0.15 in 2017 because access to electricity in the household sector in the study period was provided for all the provinces. As a result, within-group inequality is higher than between-group inequality. Moreover, there were some reasons for high electricity consumption and constant inequality including, first of all, the fact that energy consumption per capita was six times higher than the world's average; second, the presence of used old devices without energy efficiency standards in most households. Another additional reason was the price of electricity, especially during the summer, based on the regional climatic situation of Iran. Tehran and Khuzestan have the highest electricity consumption among the provinces. However, after the first subsidy program, they showed a declined consumption. However, in the second phase of the subsidy program, their consumption grew. In Iran, electricity is extensively subsidized [54].

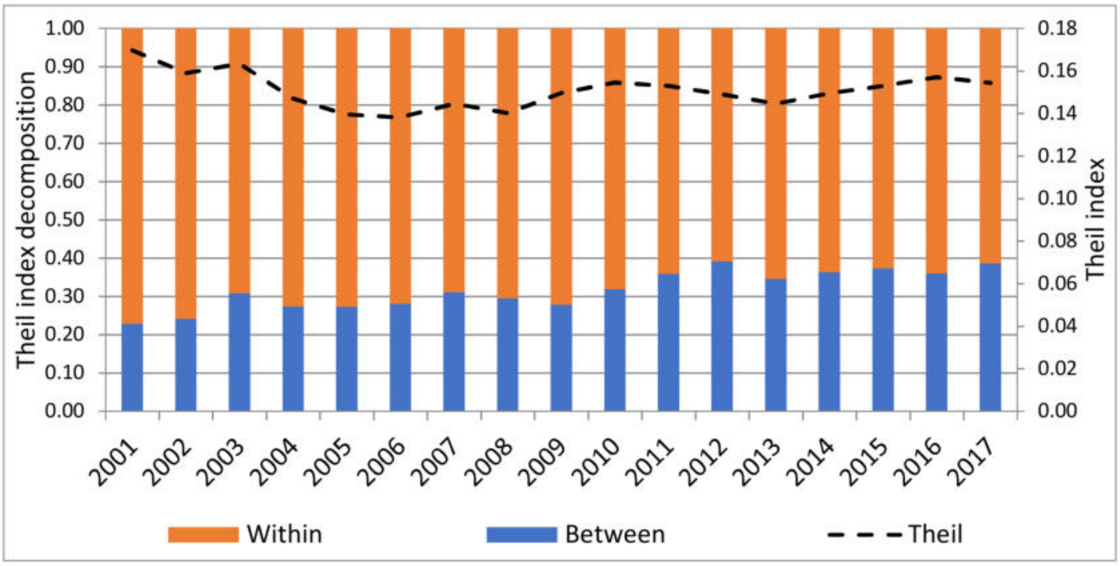

Figure 10. Theil index of electricity with population weight.

Figure 11 demonstrates that the trend of CO_2 emissions with population weight decreased during the study period, indicating that CO_2 production inequality decreased in the household sector. The dominance of inequality belonged to the within-group. The main reason for this goes back to decreasing oil consumption in the household sector. However, the value of CO_2 production was 0.22 in 2001 and reached 0.14 in 2017, which is still high in the household sector. The primary reason for high CO_2 production is the use of fossil fuels, such as gas, and the second reason is that the source of electricity produced for the households was oil power plants. Tehran was the most productive in CO_2 emissions, still showing growth after the first subsidy program in 2010.

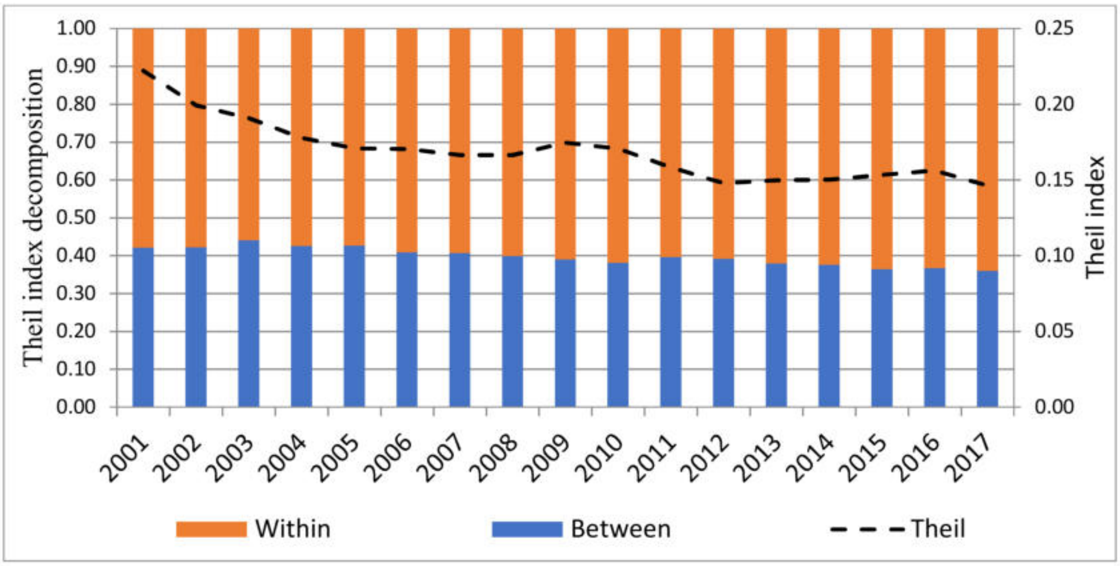

Figure 11. Theil index of CO_2 emissions with population weight.

Appendices E and F show between- and within-group inequalities of the Theil index based on population and income weight for all kinds of energy and CO_2 emission. Appendix E shows the dominance of the within-group type for all sources of energy (oil, gas, and electricity) and CO_2. CO_2 and gas had a slight difference in the between- and within-groups. Appendix F illustrates that oil, gas, and CO_2 dominated the within-group in both cases. Electricity in both cases had substantial differences for the between- and within-group of about 80%. Based on the four indexes for each fuel, the best one selected was based on the maximum amount of heterogeneity intergroup criterion. The trends of the graphs for all the energy sources and CO_2 emissions demonstrate inequality. The Theil index for oil consumption was higher than in other fuels, which presented a high level of inequality (more than 0.5). For the other fuels and CO_2 emissions, the inequality was not much high, however, they have demonstrated an increasing level during the study period. Despite carrying out two phases of subsidizing, one of the development plans in Iran shows that the plans have not been successful and caused increased inequality in consumption among the provinces regarding the household sector. In particular, the families with low-income levels were more vulnerable in subsidizing programs, since with the elimination of the subsidies, many families fell below the poverty line. The government still pay significant subsidies for energy sources (oil, gas, and electricity), i.e., electricity production was around 1300 Rial per kW in 2013, of which just 430 Rial (0.0134 dollars) were paid by the householders.

3.3. Kaya Factor

To analyze the driving factor behind the inequality in CO_2 emissions in the household sector, the Kaya identity has been implemented, and Theil indexes were calculated again according to the Kaya factors. The trend of Kaya identity is presented in Figure 12 and Appendix G. The Theil trend shows a smooth decrease until 2007, and then a little increase as a result of increasing gas consumption instead of oil in the household sector. However, the main factor that influenced more the increase in the inequality in CO_2 emission was T beta (energy efficiency factor), suggesting that energy performance has been the most responsible for the inequality. The principal reason for inequality was the low performance of devices and technology used in the household sector. Most in the household sector are used for heating, cooling, cooking, lighting, water heating and non-substitutable electricity. Energy inefficiency in Iran can be explained by first the increasing number of devices, such as washing machines, flat irons, electrical heaters, gas heaters and gas water heaters. Second, non standard and stale devices increase energy consumption, together with a low proportion of efficient LED lights in the household sector. Moreover, some provinces did not have access to gas, such as Sistan and Baluchestan and Bushehr; therefore, the use of oil heaters was preferred, increasing CO_2 production and energy inefficiency. Nevertheless, energy efficiency is the main source of CO_2 inequality in the household sector and continuing this trend, CO_2 emissions will increase fossil fuel consumption. The materials in buildings and devices used in households are also not suitable or efficient. Moreover, T alpha shows an increasing trend, particularly after 2010 and the first subsidizing program; therefore, Talpha (fossil fuels) is considered the main factor for inequality. As demonstrated in Appendix E, the positive interaction between CO_2 intensity and energy consumption is greater than the interaction between energy intensity and GDP, implying that the growth in CO_2 emissions is related to increased energy inefficiency.

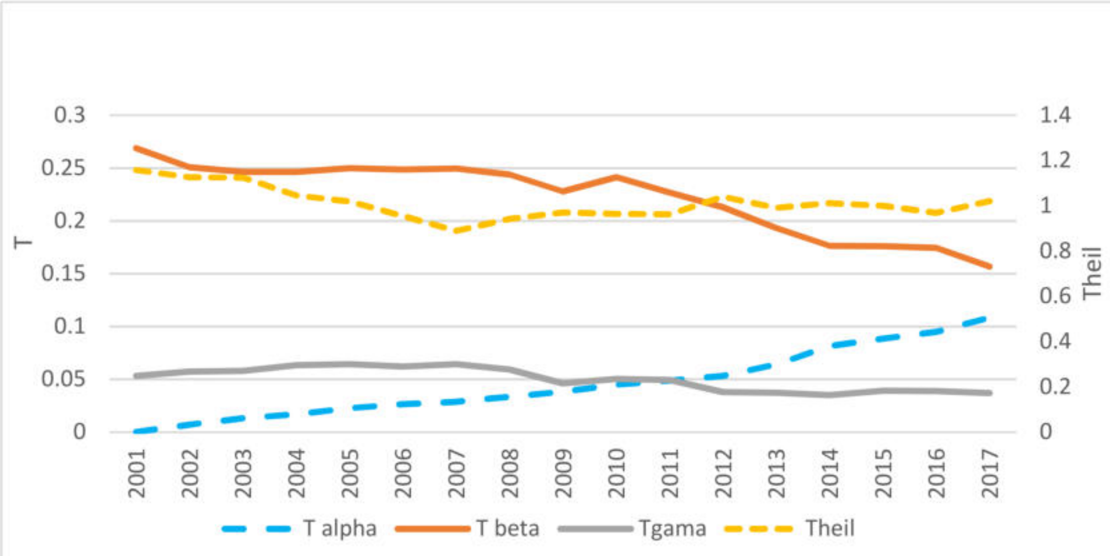

Figure 12. Decomposition of CO_2 emissions based on Kaya factors.

4. Discussion

The analysis of scientific literature on a world scale emphasizes that the most important reasons for inequality are CO_2 emissions, changes in economy and incomes [37–40]. Our research results also show that changes in the economy and the implemented subsidy plan in significantly increased inequality. In addition, another principal source of inequality is represented by the income levels in different provinces of Iran. As a result, the low-level income provinces were more struggling with energy consumption because of the lack of infrastructure.

Inequality amount of oil, gas and electricity consumption and CO_2 emissions investigated during 2001–2017 for the household sector of Iran's provinces. There are some similar researches in Iran that could be helpful for understanding the result of inequality or the increase in equality. According to research by Hafeznia et al. in 2017, it was reported that growing domestic demand, significant energy losses in the residential and commercial sectors, and low energy system efficiency in the industrial and power production sectors are all difficulties facing Iran's natural gas business. Natural gas might act as a bridge for Iran's transition to a low-carbon future if the hurdles are to be overcome and the present study proved that during a time period when the country switched to gas from oil consumption, the household sector amount of CO_2 significantly decreased [42]. However, Barkhordar in 2019 demonstrated that LED lamps distributed by governments could decrease energy consumption and increase energy efficiency among householders and given that the present study reported energy efficiency as one of the reasons for the increase in CO_2 emissions, this research suggestion could increase efficiency and decrease energy consumption and CO_2 emissions [54]. In addition, Hajilary et al. in 2018 concluded that energy consumption and cost, citizen rate, non-oil GDP, and FDI all have a substantial impact on CO_2 emissions, and there is a linear link between these variables and CO_2 emissions. The present research proves some part of that research regarding energy consumption and relationship with CO_2 emissions. [41]. Moreover, Moshiri in 2015 concluded that the withdrawal of energy subsidies in Iran was a key part of the energy pricing reform and essential for limiting the country's rising energy consumption. The cleverly designed cash handout mechanism was also successful in executing the reform and encouraging popular support. However, in order to meet energy efficiency goals, the change needs to go beyond eliminating subsidies. Higher energy costs may, to some extent, inspire energy efficiency, but due to the needed capital and behavioural changes, such energy efficiency measures will take time to materialize. Energy's relative price must also remain high for a long time before its full benefits regarding energy efficiency can be achieved; in other words, real energy prices rather than nominal energy prices must be used and nominal prices should be targeted [43]. The present research indicated that the energy price reformation program was not good enough in control of energy consumption and also CO_2 emissions. According to the Kaya and Theil results, in general, energy as a key factor could play a significant role on inequality in CO_2 emissions. Inequality within/between provinces has changed due to the intervention of the government in energy subsidies. It is evident that an equal subsidy program intensified the consumption of energy, specifically petroleum and natural gas. In the case of electricity and carbon emissions, an unstable trend has been observed, meaning that both electricity and CO_2 emissions were not affected as much as petroleum and natural gas. The most important result of the research was the evaluation of inequality in energy consumption and CO_2 emissions in the household sector between provinces of Iran while considering population and incomes, which has not been done in previous research on that level. In addition, the determining factors behind inequality with the kaya factor, such as the inaccessibility to energy infrastructure and energy inefficiency, can be useful for policymakers to make a decision about energy policy at the regional level in the future.

5. Conclusions

This study attempted to investigate the inequality in oil, natural gas, and electricity consumption, and CO_2 emissions in the household sector of the provinces of Iran from 2001 till 2017. The research also found the criteria of inequality in consumption between the provinces, and also that one of the most important reasons for the inequality increase was the subsidy in 2010 and 2013. Another reason for inequality was the differences within- and between-groups, based on GDP and population. A third reason was the fact that some provinces had no access to gas and oil. Finally, there was inequality in incomes as low-income provinces were characterized by decreased consumption. The Kaya identity result indicated that the main reason for inequality in CO_2 emissions between the provinces of Iran from 2001 to 2017 was energy efficiency. This means that most of the devices and buildings did not use standard materials. Furthermore, the structure of the economic sector was another reason for inequality, as there were no specific programs for using energy in different sectors and subsidizing programs did not continue the trend of the first year of inequality between people and the economy grew. People with low-income levels sank more into poverty after the subsidies and they could not use standard devices and buildings. A successful experience from the European Union [23] first, rebuild the buildings with standard materials, which can be useful for the household sector. Second, it is important to increase renewable energy infrastructure and to use renewable energy sources in transport, heating and cooling, buildings, and industry. Third, the sector will be required to renovate each year parts of buildings to drive the renovation wave that creates jobs and decreases energy consumption. Our research also suggests that at the national level, the subsidy implementation can be done based on each province's situation. Meanwhile, regarding the results, the inequality between provinces increased during the time of implementation of the subsidy. There are many people in each province of Iran who do not yet have supplies and appliances that are taken for granted across most advanced economies, and many people lack even the most basic access to modern energy, which means that more attempts and a precise plan considering each province situation are needed. In addition, the current research suggests some policies for improving equality between provinces. Firstly, transition energy subsidies are needed for renewable sources and to boost clean energy in those provinces such as Sistan, Hormozgan and Bushehr, where there is an adverse lack of energy infrastructure and electricity networks. Secondly, investing in energy efficiency, particularly in big cities such as Tehran, Mashhad and so on, is important. An increase in efficiency can be achieved with transition subsidies for infrastructure and appliances.

One of the main limits of our research was no access to data on a small scale. Secondly, the level of development in each province is significantly different, which could cause an increase in the inequality. Further research should focus on the level of development in the provinces and the relationship with energy consumption. In addition, one of the basic and important issues is the price of energy and energy consumption. Energy transition to renewable sources based on the high potential of solar, wind, water, biomass and geothermal in Iran and due to global warming should be the focus of further studies and governments can boost the private sector with more investment in renewable sources for electricity generation. It is also important to motivate local communities to use renewable energy including solar panels, particularly in the parts that do not have access to electricity.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Iran's provinces groups based on income.

Province	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
AZ1 *	I3	I3	I3	I3	I3	I3	I3	I3	I3	I2	I2	I3	I2	I2	I2	I2	I2
AZ2 *	I2	I2	I2	I1	I1	I1	I1	I1	I2	I1	I2	I2	I2	I2	I2	I2	I2
Ardabil	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Esfahan	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3
Ilam	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Bushehr *	I1	I1	I2	I2	I2	I2	I2	I2	I2	I2	I2	I3	I3	I3	I3	I3	I3
Tehran	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4	I4
Chaharmahal	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Khorasan	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3
Khozestan *	I3	I4	I3	I4	I4	I4	I4	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3
Zanjan	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Semnan	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Sistan	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Fars	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3	I3
Iazvin	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Iom	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1

Table A1. *Cont.*

Province	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Kurdestan	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Kerman	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2
Kermanshah	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Kohgiloyeh *	I3	I3	I3	I3	I3	I3	I2	I2	I2	I2	I2	I1	I1	I1	I1	I1	I1
Golestan	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Gilan	I2	I2	I2	I2	I2	I2	I2	I2	I2	I2	I1	I2	I2	I2	I2	I2	I2
Lorestan	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Mazandaran *	I3	I3	I3	I2	I2	I2	I2	I3	I3	I3	I2	I3	I3	I2	I3	I3	I3
Markazi *	I2	I2	I2	I2	I1	I2	I1	I1	I1	I1	I1	I2	I2	I2	I2	I2	I2
Hormozgan *	I1	I1	I1	I2	I1	I1	I1	I1	I1	I1	I2	I2	I2	I2	I2	I2	I2
Hamedan	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1
Yazd	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1	I1

* Provinces have unstable situation during period.

Appendix B

Table A2. Iran's provinces groups based on population.

Province	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
AZ1	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
AZ2	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
Ardabil	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Esfahan	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
Ilam	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Bushehr	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Tehran	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4	P4
Chaharmahal	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Khorasan	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
Khozestan	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
Zanjan	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Semnan	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Sistan *	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P3	P2
Fars	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
Pazvin	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Pom	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Kurdestan	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Kerman *	P2	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
Kermanshah	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2
Kohgiloyeh	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Golestan	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2
Gilan	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2

Table A2. *Cont.*

Province	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Lorestan	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2
Mazandaran	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3	P3
Markazi	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1
Hormozgan *	P1	P1	P1	P2	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P2	P2	P2
Hamedan	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2
Yazd	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1	P1

* Provinces have unstable situation during period.

Appendix C

Table A3. The range of population groups based on averages.

Year	Group 1 Range	Group 2 Range	Group 3 Range	Group 4 Range
2001	516,951–1,424,571	1,424,571–2,332,190	2,332,190–7,113,070	7,113,070–11,893,950
2002	522,364–1,445,118	1,445,118–2,367,872	2,367,872–7,281,506	7,281,506–12,195,139
2003	527,921–1,466,015	1466,015–2,404,109	2,404,109–7,450,882	7,450,882–12,497,654
2004	533,611–1,487,247	1,487,247–2,440,883	2,440,883–7,621,573	7,621,573–12,802,263
2005	539,459–1,508,844	1,508,844–2,478,229	2,478,229–7,792,760	7,792,760–13,107,290
2006	545,787–1,531,747	1,531,747–2,517,707	2,517,707–7,970,037	7,970,037–13,422,366
2007	547,923–1,548,358	1,548,358–2,548,793	2,548,793–8,097,648	8,097,648–13,646,502
2008	550,171–1,565,554	1,565,554–2,580,936	2,580,936–8,228,368	8,228,368–13,875,800
2009	552,533–1,583,346	1,583,346–2,614,158	2,614,158–8,362,270	8,362,270–14,110,382
2010	555,009–1,601,744	1,601,744–2,648,478	2,648,478–8,499,426	8,499,426–14,350,374
2011	557,599–1,620,758	1,620,758–2,683,917	2,683,917–8,639,911	8,639,911–14,595,904
2012	563,000–1,639,357	1,639,357–2,715,714	2,715,714–8,740,357	8,740,357–14,765,000
2013	569,000–1,658,447	1,658,447–2,747,893	2,747,893–8,841,447	8,841,447–14,935,000
2014	575,000–1,677,804	1,677,804–2,780,607	2,780,607–8,943,804	8,943,804–15,107,000
2015	581,000–1,697,197	1,697,197–2,813,393	2,813,393–9,045,697	9,045,697–15,278,000
2016	587,000–1,716,482	1,716,482–2,845,964	2,845,964–9,147,982	9,147,982–15,450,000
2017	586,000–1,740,661	1,740,661–2,895,321	2,895,321–9,561,161	9,561,161–16,227,000

Appendix D

Table A4. The range of income groups based on averages (Trillion).

Year	Group 1 Range	Group 2 Range	Group 3 Range	Group 4 Range
2001	43–136	136–230	230–984	984–1739
2002	37–143	143–249	249–1055	1055–1861
2003	38–150	150–261	261–1126	1126–1990
2004	48–168	168–289	289–1208	1208–2127

Table A4. *Cont.*

Year	Group 1 Range	Group 2 Range	Group 3 Range	Group 4 Range
2005	57–188	188–320	320–1323	1323–2326
2006	63–205	205–347	347–1451	1451–2555
2007	66–215	215–364	364–1532	1532–2701
2008	65–203	203–341	341–1534	1534–2726
2009	66–197	197–327	327–1542	1542–2757
2010	74–225	225–376	376–1701	1701–3026
2011	84–250	250–416	416–1779	1779–3142
2012	95–268	268–441	441–1942	1942–3443
2013	98–299	299–501	501–2105	2105–3710
2014	96–293	293–490	490–2144	2144–3797
2015	76–226	226–377	377–1643	1643–2909
2016	74–223	223–371	371–1616	1616–2860
2017	74–221	221–368	368–1602	1602–2836

Appendix E

Table A5. Inequality of the Theil index based on population weight for diverse grouping methodologies between (B) and within (W) groups.

Grouping Methodology	Variable	B W	2001	2002	2003	2004	2005	2006	2007	2008	2009
GDP	Oil products	B	26.34	27.05	28.46	30.59	28.18	28.08	28.80	29.86	28.81
		W	73.66	72.95	71.54	69.41	71.82	71.92	71.20	70.14	71.19
	Natural gas	B	27.85	33.04	33.82	34.31	35.29	34.89	33.99	34.37	33.74
		W	72.15	66.96	66.18	65.69	64.71	65.11	66.01	65.63	66.26
	Electricity	B	32.02	32.31	35.33	32.17	32.20	30.15	33.10	27.93	23.82
		W	67.98	67.69	64.67	67.83	67.80	69.85	66.90	72.07	76.18
	CO_2 emissions	B	42.06	42.14	44.01	42.49	42.63	40.80	40.64	39.82	38.98
		W	57.94	57.86	55.99	57.51	57.37	59.20	59.36	60.18	61.02
Population	Oil products	B	25.87	25.95	26.69	28.17	27.68	27.72	29.37	30.10	28.35
		W	74.13	74.05	73.31	71.83	72.32	72.28	70.63	69.90	71.65
	Natural gas	B	41.68	41.10	42.64	41.50	41.84	41.21	40.46	40.18	38.68
		W	58.32	58.90	57.36	58.50	58.16	58.79	59.54	59.82	61.32
	Electricity	B	22.82	24.14	30.77	27.39	27.31	28.09	31.03	29.45	27.80
		W	77.18	75.86	69.23	72.61	72.69	71.91	68.97	70.55	72.20
	CO_2 emissions	B	41.63	41.05	42.60	41.46	41.80	41.16	40.42	40.13	38.64
		W	58.37	58.95	57.40	58.54	58.20	58.84	59.58	59.87	61.36

Table A5. *Cont.*

Grouping Methodology	Variable	B W	2010	2011	2012	2013	2014	2015	2016	2017
GDP	Oil products	B W	29.47 70.53	38.70 61.30	38.66 61.34	36.47 63.53	37.79 62.21	37.49 62.51	38.85 61.15	37.88 62.12
	Natural gas	B W	32.43 67.57	46.40 53.60	51.06 48.94	48.01 51.99	50.84 49.16	53.85 46.15	60.77 39.23	57.42 42.58
	Electricity	B W	24.74 75.26	25.69 74.31	25.75 74.25	24.86 75.14	25.27 74.73	25.27 74.73	25.10 74.90	25.30 74.70
	CO_2 emissions	B W	38.08 61.92	39.56 60.44	39.17 60.83	37.94 62.06	37.58 62.42	36.39 63.61	36.68 63.32	35.93 64.07
Population	Oil products	B W	29.97 70.03	39.12 60.88	38.29 61.71	36.39 63.61	36.10 63.90	34.70 65.30	36.38 63.62	35.48 64.52
	Natural gas	B W	38.18 61.82	39.00 61.00	39.00 61.00	37.53 62.47	37.24 62.76	36.79 63.21	36.31 63.69	35.69 64.31
	Electricity	B W	31.85 68.15	35.91 64.09	39.13 60.87	34.53 65.47	36.26 63.74	37.24 62.76	35.95 64.05	38.57 61.43
	CO_2 emissions	B W	38.14 61.86	38.96 61.04	38.96 61.04	37.49 62.51	37.21 62.79	36.76 63.24	36.28 63.72	35.65 64.35

Appendix F

Table A6. Inequality of the Theil index based on income weight for diverse grouping methodologies between (B) and within (W) groups.

Grouping Methodology	Variable	B W	2001	2002	2003	2004	2005	2006	2007	2008	2009
GDP	Oil products	B W	30.94 69.06	32.14 67.86	32.72 67.28	33.78 66.22	33.73 66.27	33.88 66.12	34.37 65.63	35.26 64.74	33.27 66.73
	Natural gas	B W	28.87 71.13	28.32 71.68	28.51 71.49	28.36 71.64	29.22 70.78	28.25 71.75	28.52 71.48	26.25 73.75	23.10 76.90
	Electricity	B W	13.84 14.04	14.04 85.96	12.06 87.94	11.87 88.13	14.40 85.60	15.24 84.76	16.45 83.55	14.14 85.86	10.17 89.83
	CO_2 emissions	B W	28.84 71.16	28.30 71.70	28.48 71.52	28.33 71.67	29.19 70.81	28.23 71.77	28.50 71.50	26.22 73.78	23.08 76.92
Population	Oil products	B W	28.71 71.29	30.06 69.94	31.00 69.00	32.09 67.91	32.22 67.78	32.24 67.76	32.05 67.95	32.31 67.69	30.74 69.26
	Natural gas	B W	27.30 72.70	26.96 73.04	27.74 72.26	27.58 72.42	28.59 71.41	27.49 72.51	27.85 72.15	25.42 74.58	22.62 77.38
	Electricity	B W	6.05 93.95	6.47 93.53	5.78 94.22	5.85 94.15	7.68 92.32	7.97 92.03	8.95 91.05	6.58 93.42	6.55 93.45
	CO_2 emissions	B W	47.46 52.54	45.25 54.75	44.39 55.61	44.20 55.80	45.39 54.61	43.88 56.12	43.05 56.95	43.19 56.81	30.02 69.98

Table A6. *Cont.*

Grouping Methodology	Variable	B W	2010	2011	2012	2013	2014	2015	2016	2017
GDP	Oil products	B W	32.42 67.58	35.67 64.33	38.01 61.99	36.49 63.51	37.70 62.30	38.78 61.22	40.88 59.12	38.64 61.36
	Natural gas	B W	25.50 74.50	26.48 73.52	22.63 77.37	24.05 75.95	23.17 76.83	23.68 76.32	24.36 75.64	23.55 76.45
	Electricity	B W	9.76 90.24	10.43 89.57	8.76 91.24	6.18 93.82	7.94 92.06	8.96 91.04	9.05 90.95	10.05 89.95
	CO_2 emissions	B W	25.47 74.53	26.46 73.54	22.60 77.40	24.03 75.97	23.14 76.86	23.66 76.34	24.34 75.66	23.53 76.47
Population	Oil products	B W	29.88 70.12	33.18 66.82	34.68 65.32	33.66 66.34	33.24 66.76	33.95 66.05	35.93 64.07	34.72 65.28
	Natural gas	B W	24.93 75.07	25.67 74.33	21.56 78.44	22.72 77.28	21.81 78.19	22.51 77.49	23.21 76.79	22.30 77.70
	Electricity	B W	5.70 94.30	5.91 94.09	5.70 94.30	3.83 96.17	5.59 94.41	6.22 93.78	6.22 93.78	7.22 92.78
	CO_2 emissions	B W	36.38 63.62	37.79 62.21	29.03 70.97	29.36 70.64	26.81 73.19	28.21 71.79	28.84 71.16	27.42 72.58

Appendix G

Table A7. Decomposition of CO_2 emissions of Iran's household sector by kaya factor and interactions.

Year	T Alpha	T Beta	T Gamma	Interaction (Alpha, Beta and Gamma)	Interaction (Beta and Gamma)	Theil
2001	0.00	0.27	0.05	0.83731	−0.00169	1.15808
2002	0.01	0.25	0.06	0.81280	−0.00156	1.12649
2003	0.01	0.25	0.06	0.80891	−0.00140	1.12494
2004	0.02	0.25	0.06	0.72089	−0.00107	1.04674
2005	0.02	0.25	0.06	0.68401	−0.00098	1.01992
2006	0.03	0.25	0.06	0.61896	−0.00079	0.95554
2007	0.03	0.25	0.06	0.54738	−0.00067	0.88948
2008	0.03	0.24	0.06	0.60659	−0.00083	0.94220
2009	0.04	0.23	0.05	0.65882	−0.00092	0.97065
2010	0.05	0.24	0.05	0.62863	−0.00075	0.96446
2011	0.05	0.23	0.05	0.63826	−0.00076	0.96243
2012	0.05	0.21	0.04	0.73598	−0.00105	1.03937
2013	0.06	0.19	0.04	0.69662	−0.00087	0.99061
2014	0.08	0.18	0.04	0.71980	−0.00094	1.01192
2015	0.09	0.18	0.04	0.69728	−0.00090	1.00013
2016	0.09	0.17	0.04	0.66221	−0.00079	0.96952
2017	0.11	0.16	0.04	0.71914	−0.00093	1.02058

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